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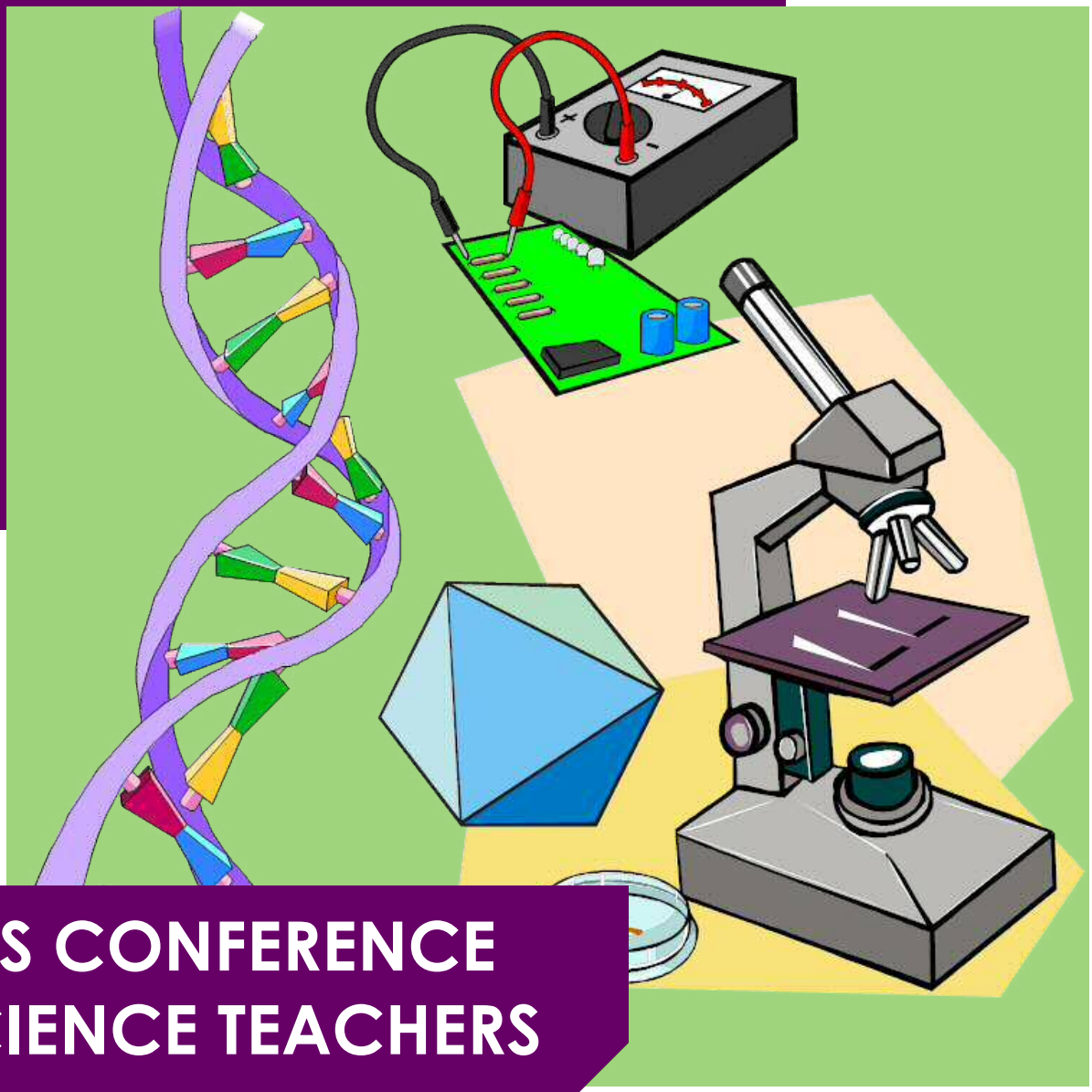

ASLA'S CONFERENCE FOR SCIENCE TEACHERS 2018

Program and Lab Manual

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SCIENTISTS and INNOVATORS in the SCHOOLS

Acknowledgements

ASLA would like to thank our sponsors:

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We would also like to thank Dalhousie's Biology and Earth Sciences Departments for helping to make this project a success.

SCIENTISTS and INNOVATORS in the SCHOOLS

Schedule

8:30-9:00: Registration in the Biology lounge (5th floor of the LSC)

9:00-9:10: Opening words from ASLA's President
Welcome speech from the Dean of the Faculty of Science

9:15-10:30: Session 1: Group A: 'Cell & Molecular Biology' in lab 2097
Group B: 'Ecology Leads to Evolution' in lab 2098

10:30-11:00: Tea and coffee break in the Biology lounge

11:00-12:15: Session 2: Group A: 'Ecology Leads to Evolution' in lab 2098
Group B: 'Cell & Molecular Biology' in lab 2097

12:15-1:00: Lunch in the Biology lounge

1:00-1:30: Information session: 'Science Fair' by Dr. Adam Sarty

1:30-2:45: Session 3: Group A: 'Earth Science's in lab 2055
Group B: 'Plants & Oceans' in lab 2097
Information session on 'Ocean School'/ Greenhouse visit

2:45-3:15: Tea and coffee break in the Biology lounge

3:15-4:30: Session 4: Group A: 'Plants & Oceans' in lab 2097
Information session on 'Ocean School'/ Greenhouse visit
Group B: 'Earth Sciences' in lab 2055

4:30– 4:45: Closing remarks from the Chair of the Biology Department in the Biology lounge

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Additional conference activities include:

Science Fair information session: *Adam Sarty*

Information session on Ocean School: *Ocean School Team*

Greenhouse tour: *Rajesh Rajaselvam*

LAB 1: Cellular and Molecular Biology

Microscopy and DNA extraction

Developed by: Georgia Denbigh, Cailyn Zamora and Arunika Gunawardena, Biology Department, Dalhousie University

Contact: arunika.gunawardena@dal.ca
Website: http://pcdlab.biology.dal.ca/

Introduction:

What are living things made of?

Individuals: Every living thing in existence is an individual. From the animals that roam the earth, to sessile plants, even microscopic bacteria! All these unique individuals are made up of complex systems that allow them to eat, breathe, and survive (Figure 1A).

Organs: An organ is a structural unit of an individual that is designed to perform a specific function. Organs are composed of different tissues that work together towards a common goal. In humans, the heart, liver and kidneys play essential roles for everyday living. Plants also make use of organs, such as roots for taking up nutrients and water from the environment, shoots for transporting water and sugars to the plant body, leaves that are vital for photosynthesis and generating sugars for food and finally, flowers used for reproduction (Figure 1B).

Tissues: A tissue is a group of similar cells that work together to carry out a specific function. A group of one or more tissues make up an organ. There are three main tissue systems in plants: epidermis, vascular tissue and ground tissue. Epidermal tissue forms the outer surface of leaves and plant body. Vascular tissue transports water and nutrients throughout the plant. Ground tissue has several functions, including storage, support and wound response (Figure 1C).

Cells: Each living thing is made up of one or more cells. The cell is the basic building block of all life. Plants and animals are made up of various cells that perform different specialized functions. For example, xylem cells specialize in the transport of water and minerals, whereas phloem cells transport sugars. Cells undergo

numerous functions and processes each day to ensure normal development and survival of an individual. These processes can include cellular division, energy production, homeostasis and even cell death (Figure 1D).

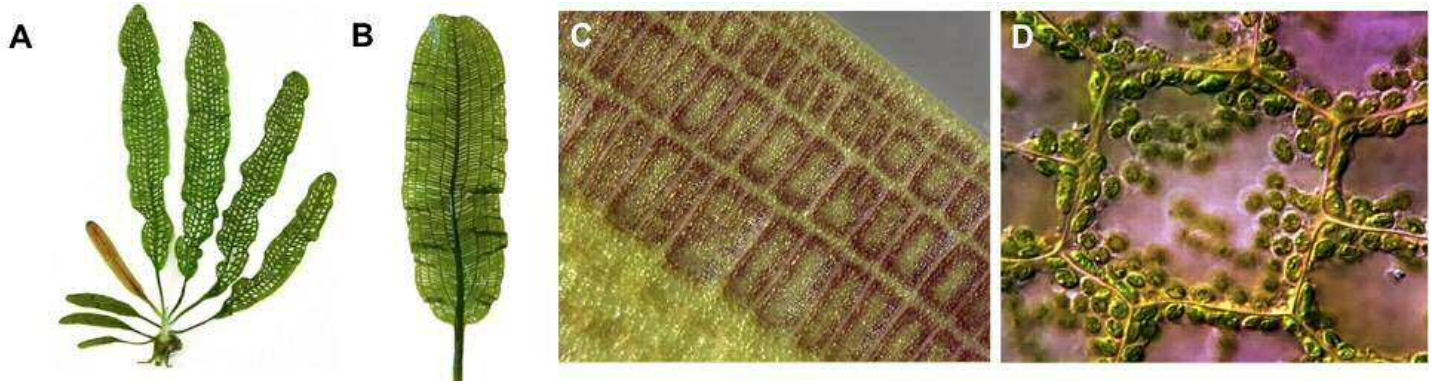

Figure 1. (A) Individual: The lace plant is an aquatic plant found in tropical streams and rivers. (B) Organ: The lace plant leaf has holes that form at a precise time and location during development. (C) Tissue: Epidermal cells make up the exterior surface of lace plant leaves. These cells contain a waxy substance to prevent excess water loss. (D) Cells: The cells of early stage leaves in the lace plant are red due to the presence of anthocyanin, a powerful antioxidant.

Organelles: Organelles are structures within a cell that perform specialized functions for the cell to live. Plants and animal cells are structurally complex and organized by interior compartments, such as a true nucleus that contains chromosomes and DNA. Plant and animal cells share many common features, including the nucleus, endoplasmic reticulum, mitochondria, cytoskeleton, cytoplasm, peroxisomes and plasma (cell) membranes. However, there are a few key characteristics that help us differentiate between plant and animal cells. Plant cells have **plastids**, a **large central vacuole** and a **cell wall**. Plastids have specialized functions that produce and store important chemical compounds. Certain plastids, such as chloroplasts, contain pigments used in photosynthesis in order to convert solar energy into food. A large central vacuole holds water and nutrients that and can take up to 90% of the cell! The rigid cell wall is located just outside the cell membrane and provides structural support and protection.

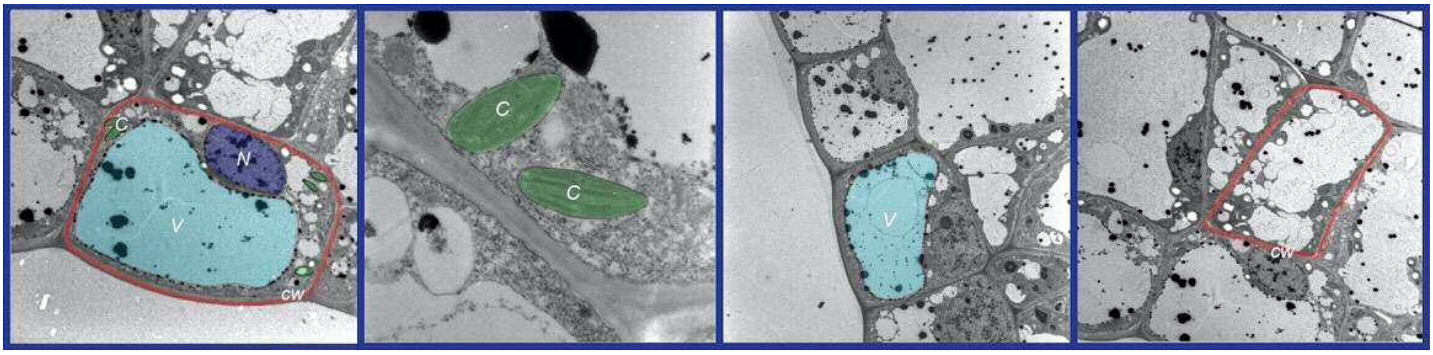

Figure 2. Transmission electron micrographs (TEM) showing the nucleus, chloroplasts, vacuole and cell wall in healthy lace plant cells. N (dark blue) = Nucleus, C (green) = Chloroplasts, V (light blue) = Vacuole, CW (red) = Cell Wall.

DNA: Deoxyribonucleic acid, otherwise known as DNA, makes up the blueprint of life. These DNA molecules are made up of a sugar molecule called deoxyribose, various nitrogen bases and phosphate group. Together they form long, helical chains of DNA containing all the genetic information of a cell. These negatively charged molecules make up the organelle known as the nucleus. The nucleus is a ball of condensed DNA, which can be read as instructions for the growth, development, functioning and reproduction of all individuals.

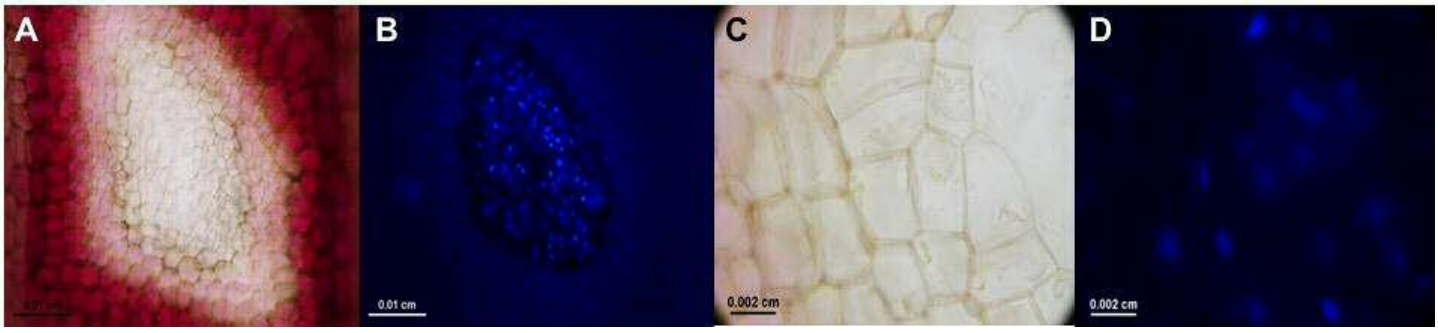

Figure 3. Light micrographs and corresponding DAPI staining showing nuclei in window stage leaves at low (A-B) and high magnification (C-D).

Death's role in development

Programmed cell death (PCD) is a highly organized process fundamental for the development and defense of multicellular organisms. Plants and animals undergo this process throughout their lifespan to remove unnecessary or unwanted cells in order to shape tissues, which will eventually be organized into functional organs.

Why study the lace plant?

The lace plant (*Aponogeton madagascariensis)* is a freshwater flowering plant that has emerged as a novel model organism to study developmentally regulated PCD in plants due to the predictability of perforation formation (Figure 4A), established sterile cultures (Figure 4B), as well as thin and transparent leaves that are ideal for microscopy (Figure 4C). The lace plant utilizes PCD to produce holes throughout the leaf surface, creating a unique lace-like appearance (Dauphinee and Gunawardena, 2015). The process of PCD occurs at a predictable time and location during lace plant growth. PCD is first initiated in young leaves (or window stage leaves) that are red in colour due to the pigment anthocyanin. The cells initially lose their anthocyanin pigmentation, followed by their chlorophyll pigmentation, eventually leading to the death of the cell. This produces a hole that radiates outwards towards the veins before it stops at maturity when the perforation is completed.

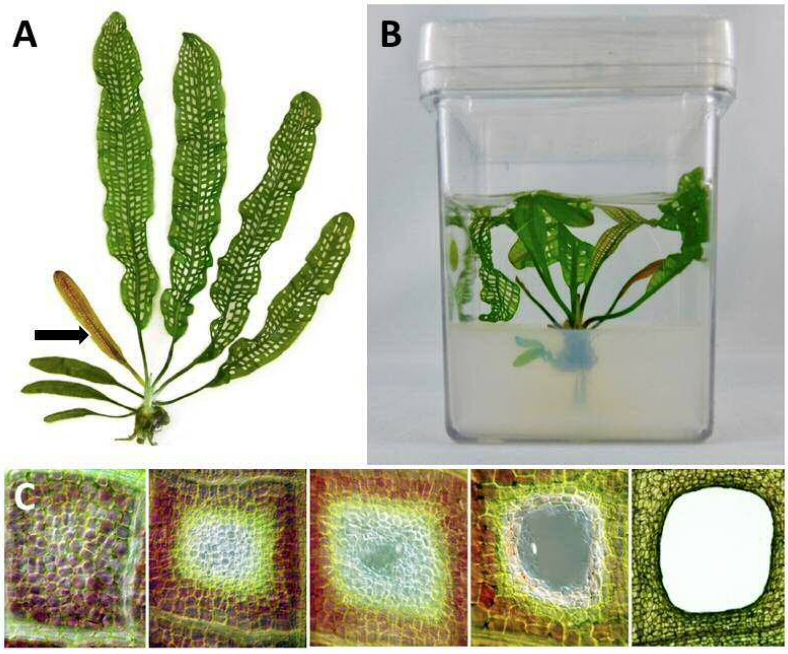

Figure 4. The lace plant is a model system for programmed cell death due to the (A) predictability of cell death, (B) established sterile cultures, and (C) it's easy microscopic observation. PCD begins in window stage leaves (black arrow), forming a hole that expands towards the leaf veins.

At the beginning of the PCD process in window stage leaves a gradient of cell death can be observed within a single field of view (Lord et al., 2011). Healthy window stage cells are known as the non-PCD cells (NPCD) as they do not die during perforation formation. Moving inwards are the early-PCD (EPCD) cells that have lost their anthocyanin pigmentation and are destined to die. In the center are the late-PCD (LPCD) that are nearly transparent and close to death. Some frequently observed features in plant cell death includes a loss of all pigmentation, lack of movement (cytoplasmic streaming), the breakdown of organelles that clump together in the vacuole and cell wall, rupture of the tonoplast (vacuole membrane) and shrinkage of the plasma (cell) membrane.

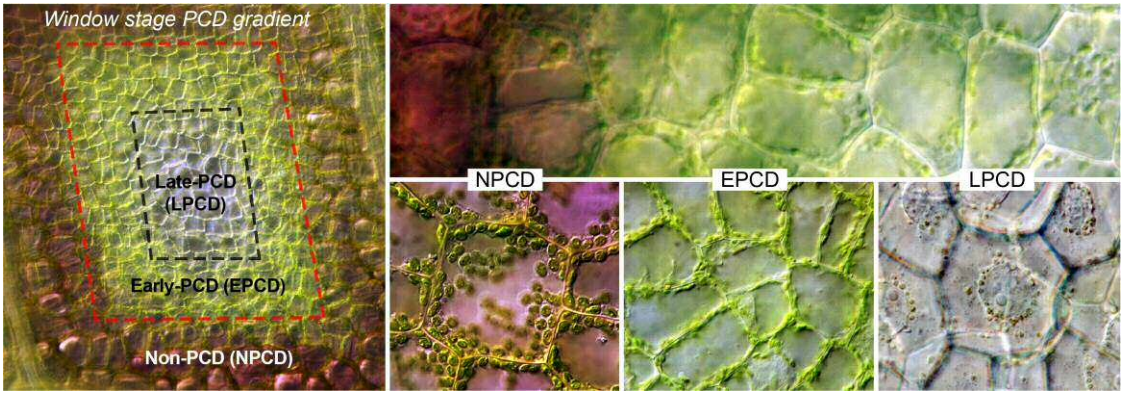

Figure 5. A unique gradient of PCD can be seen in window stage leaves of the lace plant. Cells progressively lose all of their pigmentation as they become closer to the late stage death. NPCD stage cells that do not undergo cell death during leaf morphogenesis have anthocyanin, as well as chlorophyll pigmentation. EPCD stage cells in the early phases of PCD have lost their anthocyanin but maintain chlorophyll pigmentation. LPCD stage cells that are in the later stages of death are nearly transparent.

Objectives:

1. Examine and understand the different levels of organization that make up all living things
2. Study the differences between living and dying cells in the lace plant
3. Utilize staining techniques to reveal organelles within the cells
4. Isolate and purify DNA from living plant tissues

Methods:

Part 1: Cellular structure in healthy and dying plant cells

Required materials:

1) Lace plant window stage leaves
2) Toluidine Blue O (TBO) stain
3) Weighing scale
4) Weighing paper or parchment paper
5) Scoopula
6) Glass beaker
7) Razor blade or scalpel
8) Forceps or tweezers
9) Petri plate
10) Tinfoil
11) Transfer pipettes
12) Glass slides and coverslips
13) Water (distilled preferably)
14) Compound light microscope (40x objectives are sufficient)

Procedure:

Observing healthy and dying plant cells with and without stain

1) Prepare Toluidine Blue O (TBO) stain. Toluidine blue is a dye that selectively binds to acidic tissue components, such as DNA (Sridharan and Shankar, 2012).
2) Using a scale and weighing paper, measure 1 g of TBO stain. Dissolve the TBO stain in a beaker containing 100 mL of water. The samples must incubate overnight in the stain, so plan your experiment in advance.
3) Take an aquatic leaf specimen and rinse it thoroughly under tap or distilled water to remove algae, diatoms, etc.
4) Cut out a small piece of tissue using a razor blade or scalpel. Remove any areas with large veins - the sample must be as flat as possible to avoid focal plane issues and to get a clear image.
5) Use forceps to place the leaf piece on a petri plate and add a drop of the prepared TBO stain to fully submerge the leaf. Cover the top of the petri plate with tin foil and place in the fridge to incubate overnight.

6) Remove the samples from the fridge.
7) Remove the stain with a transfer pipette and add a drop of water to the sample. Repeat this step two more times in order to sufficiently rinse the leaf piece.
8) Use forceps to place the leaf piece on a clean glass slide, add a drop of water with a transfer pipette and then a glass coverslip.
9) Repeat steps 3, 4 and 8 to observe leaf pieces without staining.
10) View the specimen with a compound light microscope.
11) Start at low magnification (10x objective) to see the gradient of cell death found at perforation sites between the leaf veins.
12) Identify NPCD and PCD cells (refer to Fig. 5) in leaves with and without staining. Go to a higher magnification (40x), and complete the observations in Table 1.

Observations:

Fill out the table on the next page based on your observations of the unstained and stained leaf sections.

*Tips for observations:
Compare the stained and unstained leaf pieces under the microscope.
What colour are the stained cells?
Which cells were stained more than others? Why?
Which organelles were revealed in the stained leaves that you could not see in the unstained leaves?

Table 1. Observations for *Part 1: Cellular structure in healthy and dying plant cells*

	Unstained		**Stained**	
Organelles	**Healthy Cells**	**Dying Cells**	**Healthy Cells**	**Dying Cells**
Cell colour				
Plasma (cell) membrane				
Chloroplast characteristics				
Cell wall				
Vacuole				
Additional observations				

Part 2: DNA Extraction from living plant material

Required Materials:

1) Ice and ice bucket
2) Liquid dishwashing soap
3) Salt
4) Baking soda
5) Water (distilled preferably)
6) Test tubes in test tube rack
7) Glass beaker
8) 30 mL Erlenmeyer flask or Glass beaker
9) Mortar and pestle (or plastic sandwich bag)
10) 95% ethanol or isopropanol
11) Funnel
12) Coffee filters
13) Plant tissue (ex. Strawberry, spinach, banana etc.)

Procedure:

Isolating and separating DNA from plant materials

Note: Keep samples on ice at all times. This following procedure also releases enzymes that will break down the DNA. Keeping samples on ice will keep DNA from being digested.

1) Fill a bucket with ice and place mortar and pestle on ice to cool.
2) Prepare buffer solution: Measure 0.3 g of salt, 1 g of baking soda, 1 ml of dishwashing soap and add it to 24 mL of distilled water in a beaker. Gently mix so as not to create bubbles. The soap helps to break down fats, including the fats making up the cell membrane. The baking soda aids in the breakdown of pectin bonds that hold the cell wall together.
3) Collect plant tissue. The source of DNA can be from any plant available in the lab such as strawberry, spinach, banana, broccoli etc. Place the plant tissue in the mortar and pestle and grind until you have a slurry. The slurry can also be made by crushing tissues in a plastic sandwich bag.
4) Add 5 mL of the slurry (~1 tsp) to a clean test tube. Add 10 mL of ice cold lysis buffer. Return sample to ice to avoid DNA degradation.
5) Place parafilm over the opening of the test tube. Slowly and gently invert tube for 30 seconds. Careful to not create suds. Slowly invert the test tube for 30 seconds to mix the lysis buffer and slurry. Return to ice.
6) Fold coffee filter in a cone shape by folding in half twice. Place inside a funnel.
7) Filter out the solid into a new clean 30 mL Erlenmeyer flask or beaker. Save the filtered liquid containing the DNA and place it back on ice. Dispose of filter.
8) Precipitate the DNA. Slowly pour ethanol or isopropyl down the side of the test tube. Since the alcohol is less dense it will form a layer on top of the solution containing the DNA. The salt that was previously added to the lysis buffer deactivates the positive charge of the phosphate backbone and removes the

overall negative charge of DNA. This allows the DNA to come out of solution and form a solid in the ethanol.

9) Answer critical thinking questions.

Procedure for running gel electrophoresis with the extracted DNA:

1) *Spool extracted DNA on a glass rod and place in a microcentrifuge tube. Pipette out smaller pieces of DNA if needed.*
2) *Centrifuge DNA at 100xg for 30 seconds.*
3) *Remove any remaining ethanol.*
4) *Add 20µl of TE buffer to each microcentrifuge tube. Let DNA dissolve in the TE buffer.*
5) *Prepare a gel with 5mL of TBE buffer, 45mL of distilled water, 0.6g of agarose and 5µL cybrsafe stain.*
6) *Microwave for 70 seconds and pout into gel mold. Let sit for 15 minutes.*
7) *Mix 2µL of each DNA solution with 8µL of loading dye.*
8) *Add each sample to a well of the gel in a gel loading dock. Add a DNA ladder to the final well.*
9) *Run the gel in 1x TBE buffer at 90 volts for 45-50 minutes.*
10) *Observe under UV light.*

Critical thinking questions:

What was the purpose of mashing up the plant materials into a slurry?

_____
_____
_____

What does the DNA that you extracted look like?

_____
_____
_____

Compare the DNA extracted from different plant sources. Did you see the same amount of DNA precipitate for all plant types? Why or why not?

_____
_____
_____

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Dauphinee, AN and Gunawardena AN. 2015. An overview of programmed cell death research: From canonical to emerging model species. In A. N. Gunawardena and P. F. McCabe [eds.], Plant programmed cell death, 1-31. Springer International, New York, New York, USA.

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Sridharan G and Shankar AA. 2012. Toluidine blue: A review of its chemistry and clinical utility. J Oral Maxillofac Pathol. 16(2):251-5.

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LAB 2: Ecology leads to Evolution

The relationship between the environment and the shapes of marine mollusc shells

Developed by: Elizabeth Welsh, Department of Biology, Dalhousie University

Contact: elizabeth.welsh@dal.ca

Background:

Octopuses, snails, and scallops are all members of a group or phylum called molluscs. The first molluscs appeared a very long time ago in our earth's history. The earliest ancestral types were small, crawling animals that probably scraped algae off rocks for food.
The many types of molluscs we see today are the result of an evolutionary process in which the ancestral forms became better adapted with each generation to each new environment that they explored. An ancestral species gained a hold in a new environment, succeeded and then advanced into new territory. This process was repeated many times so that no other group perhaps, has been able to adapt to such a wide range of habitats and occupy so many niches. They can be found burrowing in the sand or mud, swimming in the sea, crawling over rocks and hiding under them, catching fish, and even attacking whales (Harding 1991).

There are several groups of molluscs including the three more well known ones listed below.

i) Bivalves (examples – clams, mussels, scallops).
ii) Gastropods (examples – snails, nudibranch).
iii) Cephalopods (examples – octopuses, squid, cuttlefish, nautilus).

In this lab we are going to focus on the shells of bivalves and gastropods since only one species of cephalopods have shells and they are relatively hard to find.

Questions to ask:

Why would an organism want a shell? They take energy to make, are heavy to cart around, and slow down any escape.
Why do we see so many shapes and styles of shells? Think about the history of these species on earth, and why they may have changed over a very long time (evolved) into their present-day forms?

Activity:

Study your shells with your group members.

A) Arrange the shells so that those that are most similar in appearance are grouped together. Generally, things that are similar in physical appearance are more closely related and had a common ancestor (much like you may look like your cousins since you share the same grandparents).

B) Note the physical features on the labelled shells using the following guidelines 1-7 and enter that information in Table 1.

Table 1 The physical features of various molluscs shells and the probable habitat of each species.

Species	Type of mollusk	Shell style	Aperture features	Shell surface	Shell thickness	Sculpture	Probable habitat and predator avoidance strategy
A							
B							
C							
D							
E							
F							
G							

1. Type of mollusk: Enter bivalve or gastropod in Table 1.
Bivalve – when alive these molluscs had two shells joined together.
Gastropod – when alive these creatures had one shell.

2. Shell style: Enter either low profile, coiled, tall spire, flat or rounded in table 1.
low profile - a shell that is low to the ground
coiled - you should be able to see the multiple whorls or coiling
tall spire – (turriform), when the shell stretches out to a long point like a tower or a narrow ice cream cone (figure 4).
if the shell is a bivalve, decide if your shell is flat or rounded

3. Aperture features: List the features of the aperture for each gastropod shell in table 1.

The aperture is the opening for the mollusc foot. State whether the opening is large, medium, small or narrow. In addition, the aperture may have a thickened edge, or ridges along the edge called “teeth”.

4. Shell surface: Is the exterior of the shell mostly smooth or rough? Enter your answer in table 1.

5. Shell thickness: Does the shell appear to be fairly thin and lightweight or thickened and strong but heavier? Make note of this in table 1.

6. Sculpture: Identify in table 1 any additional designs to the basic shape of each species shell including spines, knobs, or ridges.

7. Probable habitat and predator avoidance strategy: Make a guess as to where in the ocean this species lives in table 1. The surface (of the ocean floor), rocks (clinging to them), or burrowing (in the sand or mud). Use the information on the next page to help you.

Habitats:

Surface of the ocean floor. Molluscs living here are usually more flattened to spread out the surface area so they do not sink. If not heavily armored they may need to have lighter shells, so they can move to escape predators.
Clinging to rocks. Species in this environment often must withstand the action of waves and currents, so need to stay stuck onto the rocks by having a way to anchor themselves usually by their muscular foot so need a larger aperture opening, having a flatter more compact body. Shells with sculpture are unlikely to live in turbulent waters because the shells would get caught up in the water movement.
Burrowing in the sand or mud. Molluscs that live in this environment usually have a smoother shell and may have a large aperture.

Looking back in time:

Shells are preserved very well over a long period of time just like fossils. The work done by one of the world’s leading experts on molluscs, Geerat Vermeij, has produced the following graphs (figure 1). The graphs show how the molluscs were adapting to their environment, especially to their predators who along the way were also adapting to the increasing amour of their prey. This is what is known as an “arms race” amongst different groups, all fighting to survive in their environment with other species.

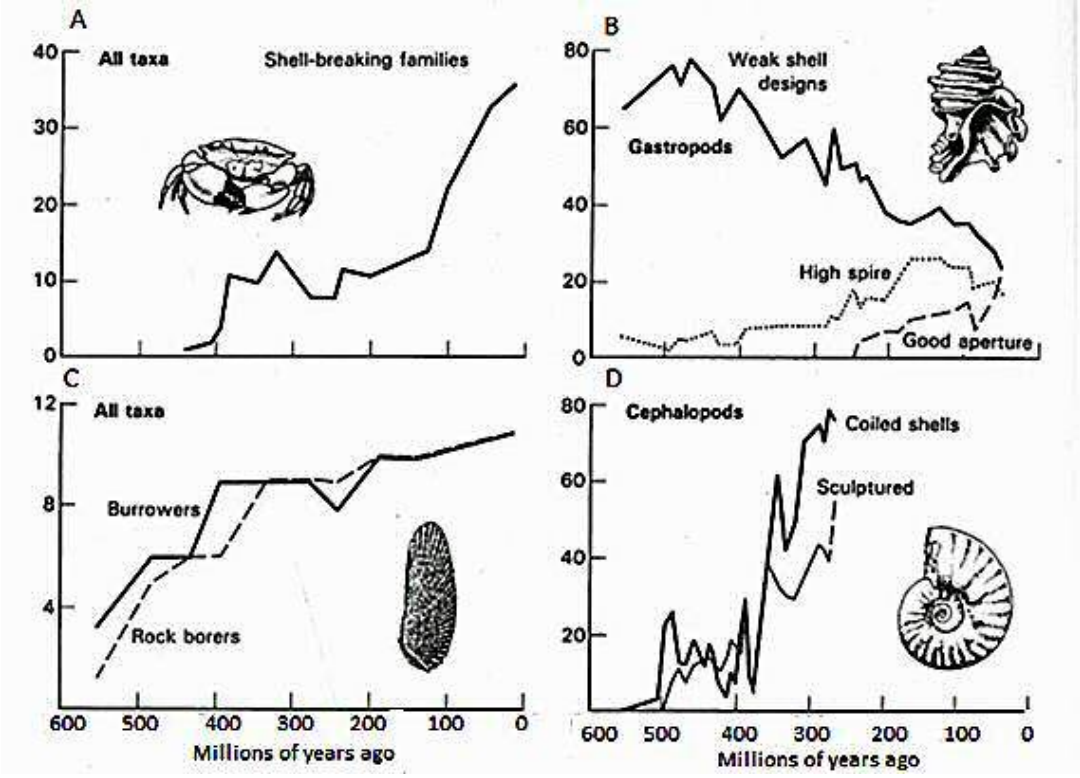

Figure 1. The four graphs depict the change over time or evolution of predator and prey during the last 600 million years. (A) The traits of mollusc predators that crush shells. The corresponding change of traits in the (B) gastropods, (C) bivalves and (D) cephalopods. On the vertical axis, graph (A) shows the number of families, while the other three graphs (B-D) indicate percentages. The graphs are from Endler (1991) and are based on the work of Vermeij (1987).

The following figures 2 - 5 are photographs of shells found in your collections and are easily available to purchase.

Figure 2. Moon snails whose shells are seen in the top row, are a carnivorous mollusc species that prey upon other molluscs. They use their radula to drill holes in the shells of their prey. (shells of prey species are in the bottom row, photo R Rajaselvam).

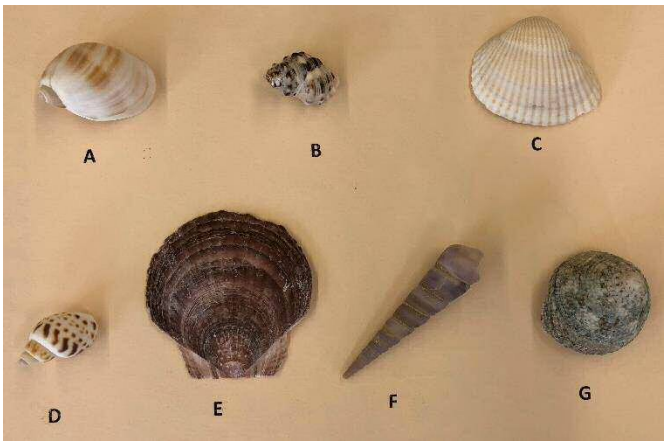

Figure 3. Mollusc shells that are in your collection which include both gastropods and bivalves (photo E Welsh).

Figure 4. Gastropod shells with a tall spire shape and coiling (photo R Rajaselvam).

Figure 5. Various Gastropod species with coiling and a variety of sculpture styles used to deter predators (photo R Rajaselvam).

Instructor notes:

Why would an organism want a shell?
Shells can provide protection against the environment such as wave action, tides, currents, or exposure to the sun in intertidal zones. But a shell can also provide protection from predators. Why else would a hermit crab or an octopus use a borrowed shell from a mollusc?

Why do we see so many shapes and styles of shells? Think about the history of these species on earth, and why they may have changed over a very long time (evolved) into their present-day forms.
Mollusc species have had to adapt to their environment as well as adapt to the species that prey on them for food. The evolution of shells seems to be in direct response to the predator – predator prey relationships as can be seen in figure 1, as well as to the different abiotic environments.
Shells have enabled the mollusk species to distribute themselves throughout the marine environment, such as clinging to rocks withstanding wave action, inhabiting the intertidal zone, and burrowing into or living on the surface of the ocean floor.

Predator strategies:

According to Vermeij (1987), predators have different methods to acquire a mollusc meal. These include swallowing them whole (fish, birds), breaking the shells (crabs, lobsters), extracting prey (sea stars, octopuses) or drilling holes (moon snails).

Mollusc strategies:

Shell style:
Limpet-like or low profile - this shell style allows the creature to adhere to rocks despite rough waters.
Coiled - provides internal strength for the shell when an attempt to crush it is made. It also provides a safe place for the soft body of the mollusc to be retracted into. Sea stars can be fooled this way. Uncoiled shells are a weaker shell design (figure 1) and are not good for resisting being broken (Vermeij 1987).
High spire or turriform – this shape makes the mollusc very hard to eat whole (Vermeij 1987).

Aperture features: - A smaller or narrow aperture makes it difficult for a predator to pull out the mollusc (Vermeij 1987). Ridges or "teeth" may also make this more difficult for predators to gain access to the mollusc soft body parts.

Shell surface: - A smooth shape is usually easier for burrowing into the mud or sand of the ocean floor.

Shell thickness: Thicker shells provide more protection from attack. They are more difficult to break and harder to drill holes through (Vermeij 1987).

Sculpture: These extra features can have several advantages for the mollusc. They can reduce the places where a predator can grip the shell to crush it, make the species more difficult to swallow, offer a disguise and increase the size of the mollusc without the added weight (Vermeij 1987). The downside is that these features add weight, making it more difficult to move quickly and more likely to get caught up in waves or currents.

Resources:

Sources for shells. Shells are easily obtained at dollar stores or ordered online through Amazon or collected on the beach.
We have given you a small sample of a few different kinds of snails to take back to work with you.

Expanding the lesson. You may wish to accompany the lab with the following online resources.

a) a video about Geerat Vermeij, the evolutionary biologist and leading expert on mollusc shells.
https://www.shapeoflife.org/video/geerat-vermeij-evolutionary-biologist-reading-shell%E2%80%99s-story
This website, Shape of Life, also contains lots of information about molluscs and other teaching ideas.

b) an online or paper activity for sorting seashells from the Howard Hughes Medical Institute.
We have given you the shell cards and a video to accompany this activity.
https://www.hhmi.org/biointeractive/sorting-seashells

Acknowledgements:

Many thanks go to
Rajesh Rajaselvam for his suggestion to do this activity, taking photographs, the HHMI activities, helping with supplies and above all his constant enthusiasm for the project.
Kevin Goff from the Chesapeake Bay Governor's School, Biology, Marine & Environmental Science, for his generous sharing of information especially in sourcing the graphs.
John Lindley and Lara Gibson for collecting local shells.

References:

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Vermeij G. 1987. Evolution and Escalation an Ecological History of Life. Princeton: Princeton University Press. 527p.

LAB 3: Earth Sciences

Minerals and crystal structures

Developed by: Richard Cox, Department of Earth Sciences, Dalhousie University

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Introduction:

Minerals are the building blocks of our planet. The rocks, sediments and soils that make up the surface and interior of the Earth are all composed of minerals and by studying them we can construct a record of the very long history of our planet. The natural resources which are used to make products we have become dependent on in our society, things we use on a daily basis, are all ultimately composed of, or are derived from, different minerals. The physical properties of minerals are controlled by their crystal structures, their chemical compositions, and these are in turn related to the wide range of different conditions under which minerals crystalize and grow. This module follows the format of a number of lectures given to our second year students in Mineralogy.

Definition of a Mineral: A naturally occurring inorganic element or compound having orderly internal structure and characteristic chemical composition, crystal form, and physical properties.

Objectives:

The goal of this module is to help students to understand what minerals are and that their physical properties such as hardness, their shapes, their colours, densities, etc., are all properties they have because of their crystal structures ***and*** chemical composition. This general concept in mineralogy is called ***crystal chemistry*** and is the way most modern mineralogy courses are taught. Following these exercises students can be encouraged to participate in follow-up exercises where they can begin to understand the continuing importance of minerals as natural resources for our modern world.

Materials:

Some of the materials for the exercises will be provided so that we can demonstrate the learning concepts. This will include:

Some minerals specimens for illustrating different properties;

A hardness testing kit;

Some HCl for reactivity tests;

Red/blue 3D glasses which will be needed for looking at the 3D versions of the mineral models.

There are a number of additional items that may be obtained to help create more in depth lessons for your students. These are:

Glass beakers or similar, and string for growing crystals;

A hand lens or pocket microscope;

Some graduated measuring beakers (preferably plastic and with a scale in ml);

An inexpensive digital balance available from most seasonal stores.

A small bottle of dilute HCl will be provided but it is advised that this only be used to demonstrate the reactions to the students (Ex.6). HCl is actually muriatic acid which can be purchased in hardware stores. It should be no more concentrated than 10% HCl for use in reactivity tests. So you may have to dilute this using appropriate plastic bottles and safety precautions. A WHIMS sheet with important safety information has also been provided.

Access to a Bunsen burner or a propane torch will be required for any simple flame emission tests. The latter can also be purchased at hardware stores.

Crystal Viewer is very important for several of these exercises and can be downloaded at: http://www.crystalmaker.com/index.html.

This is the free viewing software for looking at crystal structure models. We will provide the virtual crystal models (both 2D and 3D versions) that are related to the exercises on a download site for you to access.

It is recommended that a simple mineral guidebook be purchased and there are many available. One that is commonly recommended to students as an introductory guide is the National Audubon Society Guide to Rocks and Minerals. However, every mineral guide will be arranged in the same way, using the mineral's chemical grouping (the Dana Classification), and every guide will have the physical properties of each mineral listed. Two excellent on-line databases are: https://www.mindat.org/ and, http://webmineral.com/. Both of these online resources are strongly recommend to our students and are routinely updated by the geoscience community to provide the most comprehensive information.

PART 1 - Crystal structures: Minerals have properties that are closely related to their crystal structure such as form, hardness and cleavage. In the first part of this module we will examine the properties which are largely controlled by the structure of a suite of minerals.

Ex. 1 Growing crystals (Halite (NaCl) and Sylvite (KCl))

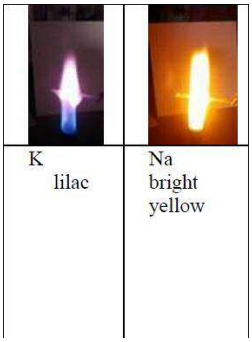
In order to show crystal growth and forms to the students you can also grow halite and sylvite crystals using table salt which is of NaCl and LoSalt which is 66% KCl. You will need a small beaker or glass (about the size of a small juice glass is fine).

1) Fill the glass about half way with warm water, add salt and stir until it dissolves.

2) Continue until it appears that the salt is no longer dissolving.

You have effectively made a saturated saline solution. You should now leave the beaker in a bright widow undisturbed. NOTE: The warmer the water the more salt you can dissolve and the larger and faster the crystals will grow. You can also place a pencil with some string or thread tied around it over the glass and let the string sit in the solution. It is interesting to compare the size and the rate of growth of crystals on the threads versus those that grow on the sides and bottom of the glass. If you are lucky they will look like the crystals in (a) below.

(a) Halite crystals in a saturated solution (Na)



(b) Flame emission colours for sylvite (K) and halite

You can also get the students to look at the forms of the halite crystals. These will generally be small cubes stacked together. The crystals will be the same form (cubes) as for both halite and sylvite. So, how do we tell them apart?

For this test you will need a Bunsen burner or propane torch and a small fire-proof metal spatula.

1) Grind up some of the crystals and place a small amount of the powder on the the spatula

2) Hold the power over the flame. The pure NaCl will flare a bright yellow (see in (b) above).

3) The sample with the KCl will flare a lilac/white and will always be less bright (see in (b) above).

Ex. 2(a and b) Hardness, cleavage and crystal structures

(a) Hardness: Following on from the discussion structures we can use the hardness kits which will be provided to create a Mohs Harness Scale. They can then be encouraged to look at the example of diamond and graphite using the 2D and 3D crystal models to determine why minerals have different harnesses and how this relates to crystal structures.

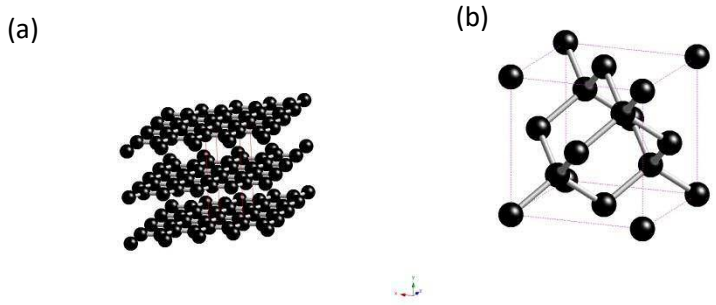
1) Use the common objects shown on the scale below to initially group the nine minerals, e.g. harder than copper coin but softer than steel blade.

2) Once this is done the students can then test the mineral hardness against each other, i.e. 1 is softer than 2 and so on.

3) They should have created a Mohs Scale of minerals as show in the previous slide.

4) Note that the numbers on the mineral specimens do in fact correspond to their hardness but you can leave your students to figure this out themselves.

So what controls hardness in minerals? Examine graphite and diamond using Crystal viewer. It is clear that they are both made of carbon (native elements, the formula is simply C). Graphite is composed of single hexagonal (graphine) sheets which are only loosely bonded together essentially by electrostatic forces. Diamond is cubic and each carbon atom is bonded to four other carbon atoms to form small tetrahedral shapes. This means there are no clear weaknesses in the structure.

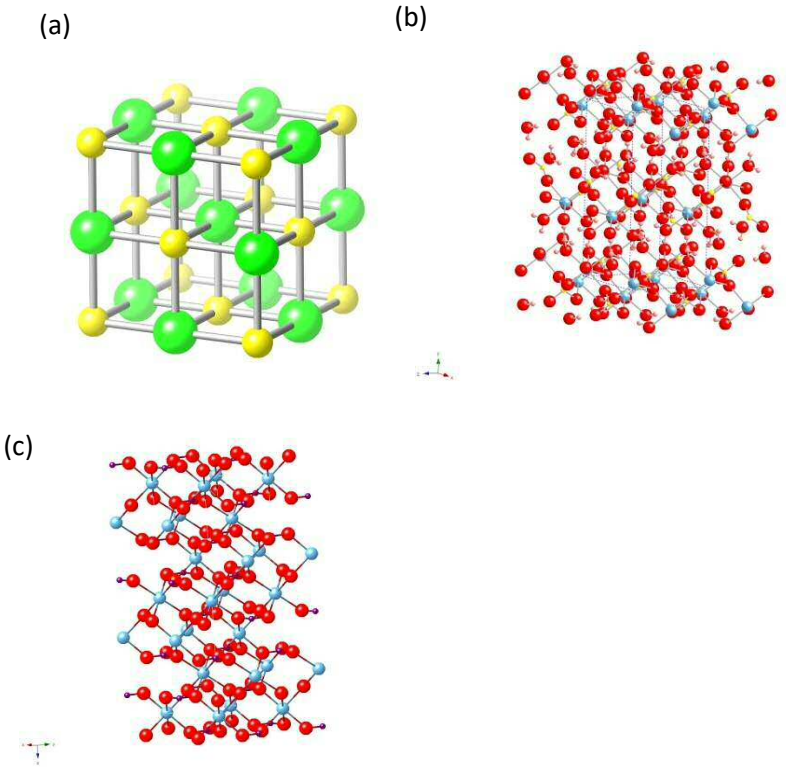


(a) Hexagonal graphite showing weak planes between the individual graphine sheets, (b) cubic diamond structure with no obvious planes of weakness.

(b) Crystal cleavage: Cleavage is visible as a break which can produce what appears to be flat crystal faces. Cleavage occurs in minerals that have specific planes of weakness and these are inherent in the structure of the mineral. Look at samples of gypsum (selenite, ($CaSO4.2(H_2O)$), halite (NaCl) and calcite ($CaCO_3$) which are of a similar hardness, but break to form different shapes along cleavage planes.

1) Look at gypsum, halite and calcite using Crystal viewer (3D viewing can also be used to help here) and find the smallest reproducing unit (shape) in the model.

2) Halite (a) is essentially a series of simple cubes. Gypsum (b) forms thin, rhombic shapes which is why the crystals have angular cleavage planes you can see in the real sample. Calcite (c) is similar to gypsum in that it forms rhombic shapes but has 60/120^{o} cleavage angles, so forms more regular rhombic fragments which look like 3D parallelograms.



(a) Cubic halite structure showing why is breaks into cubes and (b) the more complex gypsum structures which forms angular cleavage planes which can be seen in the mineral sample. The calcite structure (c) has cleavage planes at 60/120^{o} angles and forms more regular rhombic blocks when broken.

Part 1 Conclusion

Harness, and the way a mineral bends and breaks (cleavage), are controlled by the structure of the crystal, i.e. the way the atoms are bonded together within the mineral. This can be demonstrated on a hand specimen scale using the models and samples provided.

PART 2 - Crystal chemistry: The properties of minerals which are in part related to their chemical compositions can now be examined. It should be noted that these properties are still controlled by the crystal structure of a mineral as well (hence the term crystal chemistry).

Colour can be a misleading property as it only takes a small amount of a chromophore (colour causing element) such as Fe, to cause significant changes to mineral colour. However, if two minerals have similar structures, then colour is more than likely due to the increase of a particular element.

Transparency and ***luster*** are also related to chemical composition. Minerals which have a metallic luster tend to have high levels of transition metals in their structure and of course are opaque, i.e. you can't see through them. Minerals like quartz are transparent and glassy as they contain little or no transition metals.

Ex. 3 Colour in minerals with the same structure

Look the two different samples of mica (a) muscovite and (b) biotite (see images below). You can also use Crystal viewer to show the small-scale structures as well.

(a)

(b)

What obvious physical property suggests that these mineral have a similar structure? The answer is that they have a very clear basal cleavage which causes them to break into flat sheets. These minerals are in fact called *sheet silicates*. What obvious physical property suggests that these minerals have different formulas, i.e. elements present in their crystal structures? The answer is of course that biotite is dark brown and muscovite is clear.

Look at the formulas for these minerals. Which is likely to represent muscovite and which is biotite?

1) $KAl_2(AlSi_3O_{10})(F,OH)_2$ 2) $K(Mg,Fe)_3(AlSi_3O_{10})(F,OH)_2$

Mineral (b) is biotite as shown by Fe in the formula. The lack of any transitional metals (including Fe) is why muscovite is generally colourless. Both minerals are actually transparent and have a dull luster as can be demonstrated by peeling off a thin sheet from each sample.

Specific gravity (SG) is a measure of the density of a mineral versus a reference material. For most tests a mineral's SG is determined using the density of the mineral divided by the density of water. Water's density is of course 1 gm/cm^3. Therefore a mineral's specific gravity is expressed in gm/cm^3. Simply picking up two <u>similar volumes</u> of two minerals would tell you immediately that one is more dense (heavy) or less dense (light).

Ex. 4 Measuring specific gravity (SG)

Specific gravity (SG) is the density of a substance compared to a reference material. For minerals this is the density of the mineral compared to water. You will need a graduated measuring vessel of some kind and a simple digital balance. Two sulphate samples, barite ($BaSO_4$, *SG = 4.8*) and anhydrite ($CaSO_4$, *SG=2.97*) have been provided. The specific gravity of any material (in gm/cm^3) can be calculated as:

SG $_{sample}$ = (Mass $_{Sample}$ / Vol $_{sample}$) / (Mass $_{water}$ / Vol $_{water}$)

Obviously the mass of water / volume of water would tend to be 1 as water has an SG of 1 gm/cm^3 at room temperature, i.e. if you measured out 100 ml of water it would weigh 100 gm. Measuring the mass of the sample is also easy, you can just weigh it on a balance.

So how do we measure the volume of an irregularly shaped sample?

(1) Put some water (say 200ml = Vol_{water}) in a graduated beaker.

(2) Place the beaker on the balance and tear (zero) the balance.

(3) Place the mineral specimen into the beaker and measure the new volume (Vol_2).

The volume of the mineral sample is: **Vol_{sample} = Vol_2 – Vol_{water}** ***(let's say the sample = 135 ml)***

(4) Record the sample's weight. (***say 400 gm***)

(5) Use the formula above to calculate the SG $_{sample}$.

So now it is simply mass (400) / volume (135) = 2.96 gm/cm_3. The sample would be <u>anhydrite</u>.

So why do these minerals have such different specific gravities (densities)?

In the case of these sulphate minerals: Anhydrite is: **$CaSO_4$**. Barite is: **$BaSO_4$**.

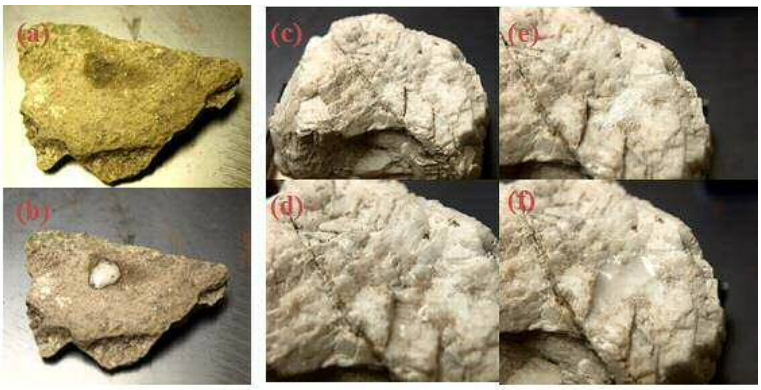
So they actually have identical structures and formulas and therefore have the same number of atoms in a given volume. O has a mass number of 16 and S has a mass number of 32. However Ba has a mass number of 137 and Ca has a mass number of 40 (see periodic table to the left). So the total mass per unit of anhydrite is 40 + 32 + (16 x4) = 120. The mass per unit for barite is 137 + 32 + (16 x 4) = 217. Barite has 1.81 times more mass per unit than anhydrite.

Reactivity: Minerals can be described in general terms such as <u>soluble</u>, normally in reference to water, or <u>reactive</u> in reference to another reagent (such as dilute HCl).

Ex. 5 Reactivity: The acid test

Limestone **(a)** is a rock composed essentially of ***Calcite***. A strong and instantaneous reaction:

$2HCl + CaCO_3 \rightarrow CO_2 + H_2O + CaCl_2$ is apparent in **(b)**.



Dolomite **(c)** and the carbonate rock dolostone is composed of $MgCa(CO_3)_2$. As shown in **(d)** there is no reaction with HCl. However, if a small portion is powdered **(e)** the reaction with HCl is strong **(f)**, although not quite as vigorous as with calcite. The reaction is:

$4HCl + MgCa(CO_3)_2 \rightarrow 2CO_2 + 2H_2O + CaCl_2 + MgCl_2$

From the above reactions it is clear that dolomite requires twice as much acid to produce a reaction as calcite, and also produces twice as much water and metal-salts. This explains why the observed reaction with HCl is less vigorous.

Part 2 Conclusion

Minerals are chemical compounds and have properties which record there chemical compositions. They have different colours, densities and can react with acids and other reagents just as any other material can. This provides a link between mineralogy and chemistry.

PART 3 - Mineral Identification: Now that we have established a basic understanding of crystal chemistry and the tests that can be used to show the link between crystal structures and their physical properties, you can construct simple diagnostic testing exercises for your students. In the kits you have been supplied with there is a set of sulphide minerals, which are of course common ore minerals, commonly mined for their base metals. Their physical properties are listed in the table below. We will demonstrate how to identify each mineral in this set using these properties, and this exercise can of course then be used to help build similar exercises for different mineral groups.

Ex. 6 Identification of common ore minerals (sulphide minerals)

Examine the table below and use the physical properties listed to correctly identify each of the sulphide minerals in the kit.

	Mineral and mineral Formula					
	Galena	*Molybdenite*	*Pyrite*	*Pyrrhotite*	*Chalcopyrite*	*Sphalerite*
	PbS	MoS	FeS_2	$Fe_{x-1}S$	$CuFeS_2$	ZnS
Colour / Luster / Transparency	Silver to grey, bright metallic luster. Opaque.	Silver to grey, bright metallic luster. Opaque.	Yellow to golden yellow or white, bright metallic luster. Opaque.	Bronze to brown, with a dull metallic luster, Opaque.	Brass yellow, with a metallic luster. Oxidizes to iridescent luster. Opaque.	Brown to red, dull luster. Sometimes transparent.
Crystal Habit / Form	Forms cubes with striations on surfaces. Commonly twinned.	Platy, sheets with hexagonal form, tabular.	Forms cubes with striations on surfaces. Commonly twinned.	Mainly massive and granular habit.	Massive, but can show prims with twinned crystals.	Octahedral (cubic) crystals with twinning.
Hardness / Streak	~2.5 with a lead grey streak.	~1-1.5.	~6-6.5. Dark green to dark brown streak.	~3.5-4.5. Grey to black streak.	~3.5-4.5. Dark green to black streak.	~3.5-4. Yellow to brown streak.
Cleavage / Fracture	Perfect cubic cleavage.	Perfect basal cleavage.	Poor cubic cleavage, uneven fracture.	Uneven fracture with a basal parting.	Uneven fracture and highly brittle.	Conchoidal fracture.
Density (SG)	Very high density (>7)	High density (~4.7)	High density (~4.9-5.2)	High density (~4.7)	Medium to high density (~4.2)	Medium to high density (~4)
Other properties		Highly malleable.		Commonly, (weakly) magnetic.		Sulphurous odour when crushed.

One of the best ways to complete an exercise such as this is to make a "from – by" table or flow chart. For example, pyrite, pyrrhotite and chalcopyrite are all types of Fe-bearing sulphide minerals and are also yellow to brown coloured and metallic. So, at first glance they may appear to be very similar. However, it is quite clear that pyrite is much harder than either pyrrhotite or chalcopyrite. So;

*Pyrite can be distinguished **from** pyrrhotite and chalcopyrite **by** hardness.*

From the table it is also apparent that pyrite tends to form cubes and has a brighter yellow colour and luster as well. So these properties will confirm that you have indeed identified pyrite. How do we tell pyrrhotite from chalcopyrite? Again, from the table above pyrrhotite is commonly magnetic whereas chalcopyrite is not. So;

*Pyrrhotite can be distinguished **from** chalcopyrite **by** magnetism.*

Chalcopyrite also shows a brassy colour and brighter luster due to the high Cu content. So again, we have several properties that can be used to confirm the correct mineral identification. If you follow this "from-by" methodology you will quickly be able to identify all of the minerals in the table, and of course this approach can be applied to any group of minerals.

Summary and further exercises

An all too common public perception is that natural resources are no longer required by modern society in the volumes that fueled the industrial revolution. This leads many to the conclusion that mining and mineral processing are industries of the past. This is of course a ridiculous conclusion and nothing could be further from the truth. Ask your students to look up the minerals in these exercises using a simple internet search. The reality is that all of them have significant industrial uses or are mineral for base metals. Another simple exercise is to look up the range of materials used in the production of a cell phone and the sources of these materials. These are varied and in many cases are extremely rare. The search for mineral resources and the technology required to process these minerals is therefore one for the future with an increasing demand for some of the rarest and most difficult to find elements on our planet. Furthermore, or understanding of the impacts on the natural environment that exploiting these resources can have has clearly improved over time. It is therefore incumbent upon future geologists to not only find new resources, but to exploit them in a safe and ethical manner. Environmental geoscience is therefore a rapidly growing field of research. Companies are therefore continuing to seek highly skilled and versatile scientists to follow an increasingly wide range of careers in the geosciences.

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