Cracking Chirality

IN THE CLASSROOM

CLASSROOM LESSON PLAN

GRADES 9–12

CHEMISTRY SHORTS™

Overview

This lesson plan contains student activities, teacher notes, and additional resource suggestions that are intended for use with the *Chemistry Shorts*™ film "Cracking Chirality". The film is freely available for viewing online either at the link above or http://chemistryshorts.org. The activities stand alone, with no additional background material needed. The activities are aimed at grades 9–12. Teachers may adjust or extend discussion of the chemistry involved depending on the students' level. The plan is designed for use as a complete package, although teachers may choose individual activities.

The lesson and materials are suitable for both in-person and virtual classrooms.

Classroom Materials

- Method for viewing *Chemistry Shorts*™ film "Cracking Chirality" (12 min., 23 sec.)
- Student Activity handouts (paper or digital copies)

Student Activities with Estimated Times

Pre-Class Activity Origin of Life: The Big Questions	(5–10 min.)
In-Class Activity Chirality Basics	(20–25 min.)
In-Class Activity Handedness and Life (including watching the film)	(20–25 min.)
In-Class Activity Cracking Chirality on Early Earth (including watching the film)	(20–25 min.)
After-Class Activity The Big Questions: Are They Answered?	(5–10 min.)

Related Standards

NGSS HS-PS2-6
Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials.

NGSS HS-PS3-5
Develop and use a model of two objects interacting through electric or magnetic fields to illustrate the forces between objects and the changes in energy of the objects due to the interaction.

NGSS HS-LS1-1
Construct an explanation based on evidence for how the structure of DNA determines the structure of proteins, which carry out the essential functions of life through systems of specialized cells.

NGSS HS-ESS1-6
Apply scientific reasoning and evidence from ancient Earth materials, meteorites, and other planetary surfaces to construct an account of Earth's formation and early history.

NGSS MS-PS1-1
Develop models to describe the atomic composition of simple molecules and extended structures.

CCSS.ELA-Literacy.RST.9-10.5
Analyze the structure of the relationships among concepts in a text, including relationships among key terms (e.g., *force, friction, reaction force, energy*).

CCSS.ELA-Literacy.RST.9-10.7
Translate quantitative or technical information expressed in words in a text into visual form (e.g., a table or chart) and translate information expressed visually or mathematically (e.g., in an equation) into words.

CCSS.ELA-Literacy.RST.9-10.4 & 11-12.4
Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context relevant to grades 9-10 texts and topics/grades 11-12 texts and topics.

CCSS.ELA-Literacy.W.11-12.2
Write informative/explanatory texts to examine a topic and convey ideas, concepts, and information through the selection, organization, and analysis of relevant content.

CCSS.ELA-Literacy.WHST.9-12.2
Write informative/explanatory texts, including the narration of historical events, scientific procedures/experiments, or technical processes.

Pre-Class Activity Teacher Notes
Origin of Life: The Big Questions

Suggested Extensions

- "How Did Life Begin on Earth? We Asked a NASA Expert." NASA: https://youtu.be/3ynnrrXz_9I

  Brief video (1 min, 42 sec) that highlights theories related to how life may have originated on Earth. It also makes it clear that it is a multidisciplinary question. Students could watch it before answering Questions 1 and 2, to brainstorm ideas, or they could watch it afterward, to see how their ideas mesh with the video's.

- "The Science of How Life Started." American Chemical Society: https://youtu.be/f44OWIsLeT0

  Video (8 min, 8 sec) that discusses how scientists are searching for the possibility of life on other planets, along with information on past research and theories about how life may have begun on Earth.

- "Can We Find Life?" NASA: https://exoplanets.nasa.gov/search-for-life/can-we-find-life/

  Article that discusses questions related to life outside Earth. How are scientists looking for life elsewhere in the universe? How will they know if they've found it?

Question 3

The two scientists in the film are part of the Origins of Life Initiative, a community of researchers in different disciplines who are all interested in the "big questions" of origins of life. It is described as "Faculty members share their work with their colleagues in other disciplines and departments, seeking deeper connections through an understanding of the work of others." The different disciplines include astrophysics, evolutionary chemistry, oceanography, planetary science, prebiotic chemistry, systems biology, and more. Teachers could further highlight this multidisciplinary aspect using the brief descriptions of other projects in the Initiative.
https://origins.harvard.edu/pages/overview (Origins of Life Initiative, Harvard University)

In-Class Activity Teacher Notes
Chirality Basics

Suggested Extensions

- This activity pairs well with the experiment included in this lesson plan. The activity offers a foundation for understanding chirality with real-life objects. Then, the experiment extends into showing it with hands-on molecular models.

- “A Brief Guide to Types of Isomerism in Organic Chemistry.” Compound Interest: https://www.compoundchem.com/2014/05/22/typesofisomerism/

  This infographic shows types of isomers, explaining that they have the same molecular formula, but different types of arrangements. The post that accompanies it also briefly touches on the naming of *R* and *S* compounds. More explicit details of this naming system are beyond the scope of this lesson plan; search online for “Cahn-Ingold-Prelog rules.”

- “Stereoisomers and Chiral Centers.” ChemTalk: https://chemistrytalk.org/stereoisomers-and-chiral-centers/

  This article defines many of the important topics in chirality, including key vocabulary and images of how to appropriately label molecular models.

Question 2c
“How a Snail’s Shell Gets Its Twist.” PBS News Hour: https://www.pbs.org/newshour/science/how-a-snails-shell-gets-its-twist

Read more about how the clockwise or anti-clockwise spiral of a snail’s chiral shell is determined.

Question 3d
An older system is used to indicate handedness of amino acids and sugars. It uses D and L, which also relate to Latin words: D (right—*dexter*) and L (left—*laevus*). The *R*/*S* convention does not necessarily match up with the D/L convention.

Question 3e
“Molecule of the Week Archive: Thalidomide.” American Chemical Society: https://www.acs.org/molecule-of-the-week/archive/t/thalidomide.html

Thalidomide is a common example of enantiomers that have vastly different effects in the body. One is a sedative also used to treat morning sickness in pregnant women, while the other interferes with normal fetal development.

In-Class Activity Teacher Notes
Handedness and Life

Suggested Extensions

- "Introduction: Louis Pasteur and the Discovery of Molecular Chirality. *Organic Chemistry with a Biological Emphasis*: https://chem.libretexts.org/Bookshelves/Organic_Chemistry/Book%3A_Organic_Chemistry_with_a_Biological_Emphasis_v2.0_(Soderberg)/03%3A_Conformations_and_Stereochemistry/3.01%3A_Prelude_to_Conformations_and_Stereochemistry

  This excerpt recounts interactions between Pasteur (then 25 years old) and another scientist, related to Pasteur's surprising observations of tartaric acid.

Question 3b

- "An Amino Acid Mystery." *Chemical & Engineering News*: https://cen.acs.org/articles/95/i14/amino-acid-mystery.html

  D-amino acids (right-handed) are present in higher concentrations in the brain. Scientists suspect that undiscovered enzymes may be present that are able to convert one handedness into the other.

- "What Makes Up the Chemical Structure of DNA?" Compound Interest, Andy Brunning: https://www.compoundchem.com/2015/03/24/dna/

  This infographic shows chemical structures that are components of DNA and summarizes the process of moving from DNA to RNA to proteins.

In-Class Activity Teacher Notes
Cracking Chirality on Early Earth

Suggested Extensions

- "A Shallow Lake in Canada Could Point to the Origin of Life on Earth." CNN: https://www.cnn.com/2024/02/17/world/last-chance-lake-origin-of-life-phosphate-scn/index.html

  A current lake could provide a modern-day location to study what may have been present on early Earth that could have contributed to the origin of life.

After-Class Activity Teacher Notes
The Big Questions: Are They Answered?

Suggested Extensions

- "Left Life? Right Life? Chirality in Action." ACS *ChemMatters*: https://teachchemistry.org/chemmatters/april-2015/left-life-right-life-chirality-in-action

  This article written at high school level connects chirality with the molecules of life, then extends it into what the chirality of extraterrestrial life might be.

- "Open for Discussion: The Case for Extraterrestrial Teenagers." ACS *ChemMatters*: https://www.acs.org/education/resources/highschool/chemmatters/past-issues/2020-2021/april-2021/case-for-extraterrestrial-teenagers.html

  This article written at high school level asks what other types of locations in the universe could support life and what could such life look like.

- "Are We Alone in the Universe?" ACS *Tiny Matters*: https://www.acs.org/pressroom/tiny-matters/are-we-alone-in-the-universe.html

  This podcast discusses the book "The Possibility of Life: Science, Imagination, and Our Quest for Kinship in the Cosmos" with its author Jaime Green.

Question 2
"Electron Transport Chains as a Window into the Earliest Stages of Evolution." *Proceedings of the National Academy of Sciences*: https://www.pnas.org/doi/10.1073/pnas.2210924120

Instructors could touch on the ideas of "bottom-up" vs. "top-down" origin of life research in connection with a discussion of whether the experiment in the film can be seen as a definitive answer. The abstract states,

> "Prebiotic chemistry and early Earth geochemistry allow researchers to explore possible origin of life scenarios. But for these 'bottom–up' approaches, even successful experiments only amount to a proof of principle. On the other hand, 'top–down' research on early evolutionary history is able to provide a historical account about ancient organisms, but is unable to investigate stages that occurred during and just after the origin of life."

Question 3a
"Designs of Alien Life." PBS: https://www.pbs.org/exploringspace/aliens/designs/index.html

Based on the conditions on Mars or Jupiter's moon Europa, what form of life would be likely to develop in those locations?

Cracking Chirality

STUDENT ACTIVITY

Name ______________________________ Date ____________

Pre-Class Activity
Origin of Life: The Big Questions

1. The introduction to the *Chemistry Shorts*™ film, "Cracking Chirality," refers to some of the "big questions" that scientists have considered and studied:

- How do chemical molecules, like those that may have been found on early earth, transform into life as we know it?
- Can this origin of life happen elsewhere in the universe? Has it happened?

    a. Describe your current knowledge related to these questions. What do you already know?

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    b. Briefly summarize your answers to the "big questions" listed above.

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2. How do you think scientists study the origin of life on Earth, since we weren't present then?

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Name ______________________ Date ______________

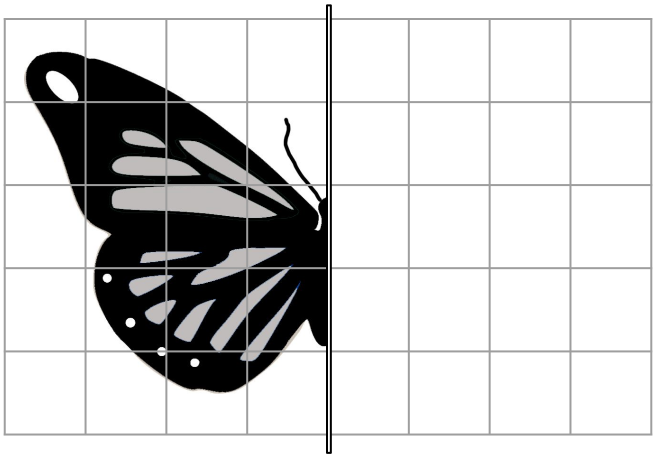
Pre-Class Activity
Origin of Life: The Big Questions (continued)

3. One of the scientists in the film does chemistry research and is also an astronomer who studies exoplanets. These are any planets beyond our solar system. How might work in each of these disciplines support new findings about the origin of life?

Name ______________________________________ Date ________________

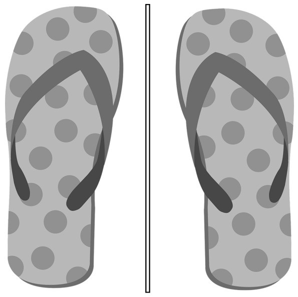
In-Class Activity
Chirality Basics

1. Many creatures today have mirror symmetry. In the drawing below, only half of the butterfly is shown, along its line of symmetry. If a mirror was placed along this line facing the drawing, what would the reflection look like? Try it. On the right side of the grid, draw the remaining part of the butterfly, as would be seen in its mirror image.



2. An object is said to be *chiral* if its mirror image is not superimposable on the original object. This means that not all parts of the object and its mirror image would align with each other, even if the object is flipped and/or rotated. It is *achiral* if its mirror image is superimposable on the original object. All parts of the object and its mirror image would align.

   a. The illustration below represents a flip flop (left), a mirror, then what the shoe's mirror image would look like from above (right). Imagine wearing the left flip flop on your left foot. If you were able to pull its mirror image from the mirror, would it fit on your left foot correctly? Is the flip flop chiral or achiral? Explain.



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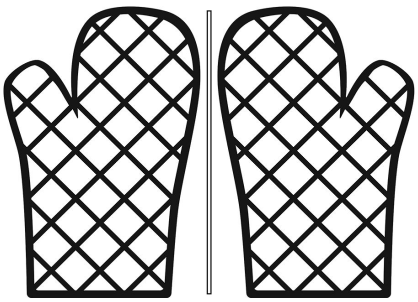
Name ______________________________ Date ______________

In-Class Activity
Chirality Basics (continued)

b. The illustration below represents an object (left), a mirror, then what the object's mirror image would look like from above (right). Imagine wearing the object—the oven mitt—on your left hand. If you were able to pull the mirror image of the mitt from the mirror, would it fit on your left hand correctly? Is the oven mitt chiral or achiral? Explain.



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c. What are real-world objects that would fit the definition of being chiral?

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d. The word *chiral* is related to the Greek word *chiros*, which means hand. How does this connect to your answers for parts a and b?

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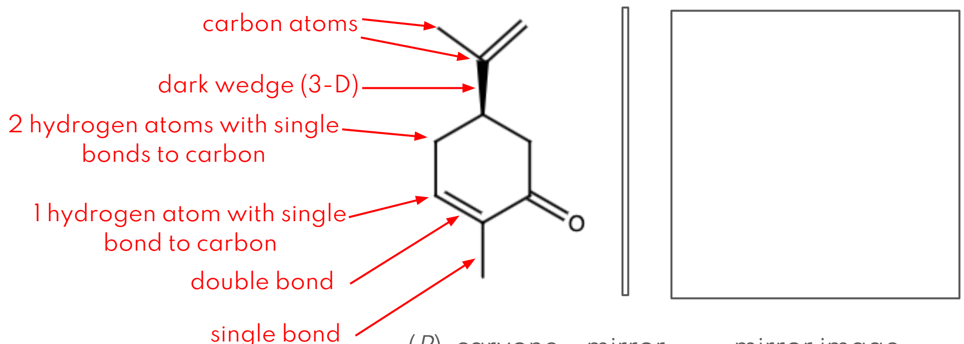
Name ______________________________ Date ______________

In-Class Activity
Chirality Basics (continued)

3. Chemical compounds can also be chiral. One example is carvone.

   a. Below, in the box on the right, draw a mirror image of the skeletal structure of R-carvone seen on the left. Use the same structure shorthand:
      - Carbon atoms are present where lines meet and also at their ends if no other element is there.
      - A dark wedge represents the bond coming out of the paper toward you; a dashed wedge going out the back of the paper away from you.
      - Hydrogen atoms are present where needed so that each carbon has four bonds.
      - Single bonds are one line, double bonds two.



(*R*)-carvone mirror mirror image

   b. Based on the shorthand, write the chemical formula for each structure.

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   c. A pair of chiral compounds such as this, with the same connectivity, but the mirror images not superimposable on each other are *enantiomers*. Their physical properties match: appearance, boiling point, density, and solubility. How is this possible, based on your answers for a and b?

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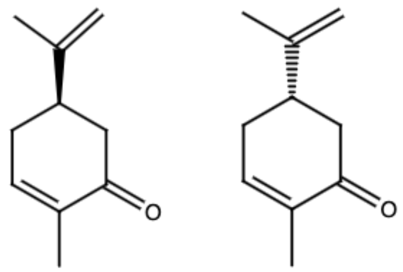
Name ______________________________ Date ________________

In-Class Activity
Chirality Basics (continued)

d. The two molecules in Question 3a, (*R*)-carvone and the mirror image you drew, are different in that they are not superimposable on each other and rotate light in different directions. They are two different compounds. Because of this, their names must indicate which they are. Naming conventions relate to handedness. The mirror image is (*S*)-carvone. *R* indicates right, from Latin for right, or "correct"—*rectus*; *S* indicates left, from Latin for left—*sinister*.

(*S*)-carvone is not superimposable on (*R*)-carvone. If (*S*)-carvone were rotated, so that the structures matched as closely as possible, they would be represented as below. Circle any differences between the two structures.



(*R*)-carvone (*S*)-carvone

e. Enantiomers can have different biological effects in the body. For example, (*R*)-carvone smells like spearmint, while (*S*)-carvone smells like caraway, a seed used in rye bread. When the molecule binds to a protein-based odor receptor, our brains are sent a message for a particular smell. These receptors can also be chiral. How could this explain the difference in smell between the two enantiomers?

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Name ______________________________ Date ______________

In-Class Activity
Handedness and Life

Louis Pasteur significantly contributed to the understanding of molecular chirality through his experiments with tartaric acid. Aside from successfully separating crystals of tartaric acid into its two separate right-handed and left-handed forms, he also observed something unusual related to chirality and fermentation. The bacteria that fermented tartaric acid would only use the left-handed molecule, and not the right-handed form.

1. In the film "Cracking Chirality," Dr. Sasselov states, "At the molecular level, the mirror world is eliminated and only one set of molecules exists."

   a. How do Pasteur's observations support this statement?

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   b. How are Pasteur's observations and Dr. Sasselov's statement both related to the film's title, "Cracking Chirality?"

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   c. In the film, what is the term of a group of chiral molecules that is all one type of handedness, rather than a mixture of handedness?

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Name ______________________________ Date ______________

In-Class Activity
Handedness and Life (continued)

2. Nature has a bias toward either left- or right-handed molecules for its main molecules of life. What are the two main types of molecules mentioned in the film? Which set of molecules exists for each group, left- or right-handed?

Molecule of life	Handedness

3. While the opposite handedness of the molecules of life you listed in Question 2 do exist, organisms cannot use them in the same way.

a. Which "molecule of life" group in the table is used to form a protein structure, which our bodies need to consume or make to survive?

b. If we consumed both left- and right-handed molecules in proteins we eat, would we be able to digest both? Explain.

Name ______________________________ Date ______________

In-Class Activity
Cracking Chirality on Early Earth

1. What question are Dr. Sasselov and Ozturk investigating with their experiments using ribose-aminooxazoline (RAO), an RNA precursor?

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2. Near the start of the film, the habitat in an aquarium is likened to that of early Earth. What characteristics made up early Earth, as described in the film?

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3. Their experiments aim to mimic what it would have been like on early Earth, but in the lab. Which properties of early Earth that you listed in Question 2 did they recreate in the experiment and how? Describe them in the spaces below.

Property of early Earth	**How it was recreated in experiment**

Name ______________________________ Date ________________

In-Class Activity
Cracking Chirality on Early Earth (continued)

4. Their experiments used a 50/50 mixture of left-handed and right-handed RAO.

a. If no outside bias was placed on the system, and the 50/50 mixture of RAO was allowed to crystallize, what would the resulting crystals be? Circle your choice.

All left-handed	50/50 mixture of left-handed and right-handed	All right-handed

b. An outside bias was placed on the experiment system when electron spin orientation was polarized in one direction with a magnetized surface. What happened when RAO crystallized on this surface? What happened when the electron spin was flipped to its opposite polarity?

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c. How did these results answer the question you listed for Question 1?

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Name ______________________________ Date ______________

After-Class Activity
The Big Questions: Are They Answered?

1. Question 1 in the Pre-Class Activity "Origin of Life: The Big Questions" asked you to describe your current knowledge about the question, "How do chemical molecules, like those that may have been found on early earth, transform into life as we know it?" and to summarize your answer to it. Compare and contrast your answers in the Pre-Class Activity with what you would answer now, after watching the film.

2. The scientists in the film present experimental evidence for how they would answer this question. Dr. Sasselov says, "So maybe that primordial soup with the magnetite pot under it was actually the right thing for life." Are the results the definitive answer for what occurred on early Earth? Explain.

3. If the origin of life can occur elsewhere in the universe, we may have neighbors somewhere. The science that may have transformed them to life could be radically different from our own. What might the chirality of alien life look like at the molecular level?

Name ____________________ Date ____________

After-Class Activity
The Big Questions: Are They Answered? (continued)

4. What further questions do you have about the origin of life and the possibility of life on other planets?

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Chemistry Shorts™ is a film series that communicates the breadth and depth of chemistry's impact on humankind in an approachable manner, sponsored by the Camille and Henry Dreyfus Foundation. These films will celebrate the science and the people who share a passion for the vital role chemistry plays in the biggest issues, including human health, renewable energy, the nature of life, sustainability, new materials, and climate change. Each film incorporates a lesson plan that offers ideas for ways they may be incorporated into the classroom. We welcome your feedback at: chemistryshorts.org.

SHORT FILMS ABOUT CHEMISTRY

SHORT FILMS ABOUT CHEMISTRY

Cracking Chirality

IN THE LABORATORY

CHEMISTRY SHORTS™

LAB EXPERIMENT

GRADES 9–12

Overview

This lab experiment complements the *Chemistry Shorts™* film "Cracking Chirality". The film is freely available for viewing online either at the link above or http://chemistryshorts.org. The experiment is aimed at grades 9–12. Teachers may adjust or extend discussion of the chemistry involved depending on the students' level.

Materials

- Student Handout "Hands-on Chirality"
- Experiment materials per student pair/group
  - Molecular model kit (or alternative materials - see Tips section of Teacher Notes)
  - Mirror

Estimated Times

Model building	25 min.
Analysis	20 min.
Total	**45 min.**

Related Standards

NGSS HS-PS2-6
Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials.

NGSS MS-PS1-1
Develop models to describe the atomic composition of simple molecules and extended structures.

Cracking Chirality

STUDENT HANDOUT

Name ______________________________ Date ________________

Hands-on Chirality

An object is said to be *achiral* if a mirror image of it is able to be superimposed on the original object. To be superimposed means that all parts of the original object and its mirror image would align with each other. It is *chiral* if its mirror image is not superimposable on the original object. Not all parts of the object and its mirror image would align.

While real world chiral objects like your hands or a pair of shoes are easier to see that they are not superimposable, it can be more difficult to visualize molecules. In this activity, you will make the examples more concrete by using a molecular model kit to build hypothetical molecules and their mirror images, along with amino acids, to analyze.

Materials

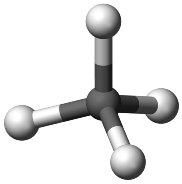
- ❏ Molecular model kit (or an alternative, see Tips section in Teacher Notes)
- ❏ Mirror

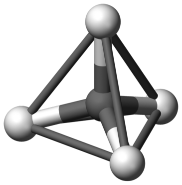
Safety

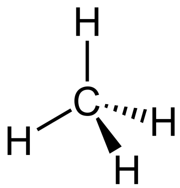
There are no specific safety concerns associated with this experiment.

Procedure

1) Using a molecular model kit or alternative, build a model that has a carbon atom in its center, with four atoms attached to it that are all the same color (combination A in the table), arranged tetrahedrally using single bonds. Illustrations are below, particularly if you are using an alternative to a molecular model kit. The left hand illustration shows the model you need to construct. The center illustration shows the same model, but with additional lines added to emphasize the tetrahedral shape it makes in space. On the right is a structural formula.







2) Place the model you built in front of a mirror. Build a second model, this time of the model as it appears in its reflected image.

3) Take both models and try to superimpose them on each other, so that all parts match, rotating and moving the models in any direction, but not breaking any bonds. Are they superimposable? Fill in yes or no in the table below. Is it chiral? Fill in yes or no.

4) Repeat steps 1–3, for combinations B–D in the table.

Cracking Chirality

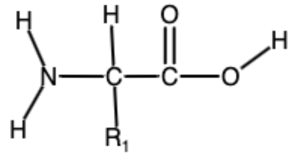
STUDENT HANDOUT

Name ______________________________ Date ______________

Hands-on Chirality (continued)

	Combinations of substituents to place on central carbon				Super-imposable?	Chiral?
Combination	**Color 1**	**Color 2**	**Color 3**	**Color 4**		
A	4					
B	3	1				
C	2	1	1			
D	1	1	1	1		

5) A generic model of an amino acid is below. The “R_1” stands for a side group—a different substituent would attach here to make each different amino acid. Build a model of the amino acid glycine, using the generic structure below, with R_1 a hydrogen atom.



a) Look at one of the carbon atoms in the model. How many different, or unique, substituents are attached to it? Draw or write each substituent.

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b) Look at the other carbon atom in the model. How many different, or unique, substituents are attached to it? Draw or write each substituent.

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Cracking Chirality

STUDENT HANDOUT

Name ______________________________ Date ______________

Hands-on Chirality (continued)

c) Predict whether this molecule will be superimposable on its mirror image. Explain your reasoning.

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d) Build the mirror image of glycine. Is it superimposable on the original? Fill in yes or no in the table below. Is it chiral? Fill in yes or no.

5) Build a model of the amino acid alanine, using the generic structure, with the R_1 a methyl group, CH_3.

a) Predict whether this molecule will be superimposable on its mirror image. Explain your reasoning.

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b) Build the mirror image of alanine. Is it superimposable on the original? Fill in yes or no in the table on the data sheet. Is it chiral? Fill in yes or no.

Amino acid	Superimposable?	Chiral?
glycine		
alanine		

Cracking Chirality

STUDENT HANDOUT

Name ______________________________ Date ______________

Hands-on Chirality (continued)

Questions

1) How did your predictions in steps 5c and 6a compare with your observations in steps 5d and 6b? What appears to be necessary for a carbon-based molecule to be chiral?

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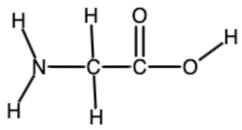
2) If a molecule is chiral, it has two different forms that are not superimposable on each other. A pair of chiral molecules that have the same connectivity, are mirror images of each other, but not superimposable are called *enantiomers*. For amino acids, the two enantiomers are labeled L and D for left and right.

   a) Is glycine an enantiomer (see right)? Why/why not?



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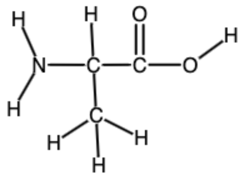
   b) Is alanine an enantiomer (see right)? Why/why not?



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Name ______________________________ Date ______________

Hands-on Chirality (continued)

Questions

3) Nature has a bias toward either left- or right-handed molecules for its main molecules of life. This includes amino acids; the body uses left-handed forms. Does this matter for both of the amino acids you modeled? Explain.

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4) If a protein were produced that used both left-handed and right-handed forms of amino acids, would your body be able to effectively use it for fuel? Explain.

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Teacher Notes (continued)

Tips

- If molecular model kits are not available, students could also use toothpicks to represent bonds, with items such as marshmallows or modeling clay/play dough. For example, a large marshmallow could be the central carbon atom, with miniature marshmallows bonded to it. Some stores may have fruit-flavored miniature marshmallows that are colored different colors. Or, different colored clay balls could be used. Care should be taken to maintain a tetrahedral molecular geometry if using alternate materials.
- The mirror image models can be built without a mirror if needed. However, using a mirror helps to reinforce the sequences in the film and the idea of the mirror world of molecules. A cell phone's rear-facing camera could also be used.
- The models in steps 1–4 are hypothetical molecules. No specific elements are assigned to the colors for ease and kit flexibility.
- Teachers and students are strongly encouraged to use (or at least read through) the two student activities "Chirality Basics" and "Handedness and Life" that are part of the "Cracking Chirality" lesson plan. These contain background information and extensions that can connect with this experiment. Teachers could point out (or students could research) that the remaining 18 amino acids are all chiral.

Chemistry Shorts™ is a film series that communicates the breadth and depth of chemistry's impact on humankind in an approachable manner, sponsored by the Camille and Henry Dreyfus Foundation. These films will celebrate the science and the people who share a passion for the vital role chemistry plays in the biggest issues, including human health, renewable energy, the nature of life, sustainability, new materials, and climate change. Each film incorporates a lesson plan that offers ideas for ways they may be incorporated into the classroom. We welcome your feedback at: chemistryshorts.org.

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