Part A: Chirality
(How can you tell if an object is chiral?)

Model 1: Criterion for Identical-ness
Two molecules are identical if models of the two molecules can be superimposed without breaking any bonds.

Critical Thinking Questions
1. Make two identical models of the following molecule and confirm that they can be superimposed on one another. Use different colored balls for each of the four substituents. If your set has green, orange and purple, use the following color code.

   H
   Cl C I
   Br

   green ball = chlorine atom
   orange ball = bromine atom
   purple ball = iodine atom

2. Switch any two balls on one of your models (leave the other model unchanged). Is this new model identical to your original model?

3. Which of the following words describe the relationship between these two models? Circle more than one choice, if appropriate.

   A. Identical (or conformers = can be made identical via single bond rotation)
   B. Stereoisomers (same atom connectivity, but not identical)
   C. Constitutional isomers (same formula, different atom connectivity)
   D. Mirror images (look like reflections of one another in the mirror)
4. Consider the following set of molecules. Note: assume each molecule is in its simplest conformation, even if it is not the lowest energy conformation. In this case, assume each cyclohexane ring is in a planar conformation (rather than a chair).

\[ \text{A} \quad \text{B} \quad \text{C} \]

a) Label each of A-C with the word *cis* or *trans*, as appropriate.
b) Are any two of the set an identical pair? If so which ones.
c) Which are more similar A&B or B&C [circle one]?
d) What do A&B have in common that B&C do not?

**Definitions:**

- **chiral** = not identical to its mirror image. 
  (a property of an object) 
  (*chir* is Greek for “hand.”)

- **enantiomers** = a pair of objects that are mirror images but not identical. 
  (a relationship between two objects) 
  (*enantio* is Greek for “opposite.”)

- **diastereomers** = a pair of objects that are stereoisomers but not enantiomers 
  (a relationship between two objects)

- **racemic mixture** = a 1:1 mixture of a pair of enantiomers. 
  (a special sample of objects)

**Critical Thinking Questions**

5. Give an example of an everyday object that is **chiral** and one that is **not chiral**.

6. Give an example of a pair of everyday objects that are enantiomers.

7. Circle each structure in CTQ 4 that is chiral (it may help to draw the mirror image of each).
   a) What is the relationship between A&B (be as specific as possible)?
   b) What is the relationship between B&C (be as specific as possible)?
   c) What is the relationship between A&C (be as specific as possible)?
8. T or F: All chiral objects have exactly one enantiomer. If false, give an example from CTQ 4.

9. T or F: All diastereomers are chiral. If false, give an example from CTQ 4.

**Model 2: Internal Plane of Symmetry (Mirror Plane)**

It is always true that an object (or molecule) with an internal plane of symmetry is not chiral (not chiral = achiral = identical to its mirror image).

![Diagram of internal plane of symmetry with objects A and B]

**Critical Thinking Questions**

10. Object C has a very obvious plane of symmetry (marked with a dotted line), and a not so obvious one. Where is this second plane of symmetry? (Assume the balls are uniform spheres.)
11. Objects D and E are NOT chiral. Indicate the internal mirror plane in each.

Object D (tetrahedron)

Object E

Part B: Absolute Configuration
(How can you tell if a chiral center is right handed "R" or left handed "S"?)

Model 3: A Trick for Determining If a Molecule Is Chiral

![Chemical structures for chiral and not chiral molecules]

chiral center = atom with four different groups attached to it.
(also called a "stereogenic center")

- By convention, chiral centers are marked with an *
- A molecule with one chiral center is always chiral.

Critical Thinking Questions

12. Construct an explanation for why each carbon indicated with a "1" is considered to have **two identical groups**, while the carbons with an * are chiral, with four different groups. (Hint: It has to do with whether the ring is symmetrical or not.)

![Chemical structures for not chiral and chiral molecules]

Not Chiral

Chiral

considered two identical groups

considered two different groups
13. Consider the following structures, some of which are chiral.

For some of the chiral centers above (for example, the first one), the H is not shown. How can you tell if an H is going into the page or coming out of the page?

Mark each chiral center on the structures above with an * (there are 9).

Circle the three structures at the top of the page that are NOT chiral, and for each circled structure, indicate the plane of symmetry (mirror plane).

One of the structures you circled is an example of the rare case where a structure contains chiral centers but is not chiral. These molecules are called meso compounds. Label the meso compound above.

**Information**
Like gloves each chiral center is either right or left handed. The convention for determining handedness requires we rank four atoms attached to a chiral center.

**Rules for ranking the atoms from largest (1) to smallest (4):**
- The higher the atomic number of an element, the higher its rank. For example: N (atomic # = 7) beats C (atomic # = 6), and everything beats H (atomic # = 1).
- If two atoms have the same atomic #, the heavier one wins.
  
  For example: $^{12}$C beats $^{13}$C; and deuterium ($^2$H) beats hydrogen ($^1$H).

Often there is a tie. For example, on the molecule below there are two C’s ($C_a$ & $C_b$) attached to the chiral carbon ($C^*$), so we need a tie breaker to determine the ranking.

**Tie Breaker Card Game**
- In this case the two tied "players" are $C_a$ & $C_b$.
- Each atom’s "cards" are its bound atoms.
  
  This means $C_b$ is "holding" 2 C's and 2 H's (circled at left) and $C_a$ is holding CHHH.
- Simple comparison of the hands by highest card gives $C_b$ as the winner ...CHHH ($C_b$’s hand)

**Critical Thinking Questions**

14. For the example above (2-chlorobutane),
a) Circle together the four atoms in C₆'s "hand".
b) Explain why C₄'s "hand" beats C₆'s "hand".
c) Label the four atoms attached to the chiral carbon 1-4 to show their ranking.

15. Sometimes (as in the example below) the 1st round of the card game results in a tie. When this happens you must play another round using the next atoms in the chain.
a) Confirm that C₂ and C₄ both hold the same cards: CCHH, and therefore tie.
b) Play the card game with the next atoms in the chain to break the tie.
c) Label the four atoms attached to the chiral carbon 1-4 to show their ranking.

Model 4: Nomenclature for Chiral Centers
- Each chiral center is designated as either right handed (R) or left handed (S).
  Right handed chiral centers are called R from the Latin word for right: rectus.
  Left handed chiral centers are called S from the Latin word for left: sinister.
- The R or S assignment is called the absolute configuration of that chiral center.
- To determine the absolute configuration of a chiral center such as the one below:

I. Start with either hand, make a hitchhiker thumb, and point your thumb in the direction of the atom ranked 4.
   (In this case point your thumb slightly out of the page!!)

II. In your imagination touch the atom ranked #1 with your pinky finger.

III. Curl your pinky finger to touch that atom ranked #2, then the atom ranked #3.

IV. If this progression from 1-to-2-to-3 does not match the natural curl of your finger then try with the other hand.

Try your technique on the following examples. Rankings are shown for you.
Critical Thinking Questions
16. Determine the absolute configuration of each chiral center in the following structures.

17. Note that the structures in the previous question are the enantiomers of the row of examples at the top of the page. What happens to the absolute configuration of a molecule if you switch exactly two groups (e.g. Cl and H) attached to a chiral center?

18. Determine the absolute configuration (R or S) of each chiral center in CTQ 13.

Exercises for Part A:
1. Draw an example of a pair of stereoisomers that are NOT enantiomers. What is the name for the relationship between such structures?

2. Shade or mark the balls on the object below to generate a chiral object.