Intermolecular Forces
Suggested student answers are shown in purple text.

Background
Compounds interact with each other differently depending on their polarity. These interactions are called intermolecular forces (IMFs), and physical properties of compounds can be inferred by the type of IMFs. In this activity, you will have the opportunity to “feel” the strength of different intermolecular forces with the help of a computer simulation, and then you will consider what that means about some of the compounds’ physical properties. Remember, the IMFs are hydrogen bonds, dipole-dipole interactions, induced dipole attraction, and London dispersion forces.

Procedure
2. From the dropdown menu “select a pair of molecules” choose “pull apart Br\textsubscript{2} and Br\textsubscript{2}.”
3. Predict how difficult it will be to pull apart the two molecules in the data table.
4. Using the green star, move one Br\textsubscript{2} away from the other. Comment on how easy or difficult this was in the data table.
5. From the dropdown menu, choose “pull apart H\textsubscript{2} and H\textsubscript{2}.”
6. Predict how difficult it will be to pull apart the two molecules in the data table.
7. Using the green star, move one H\textsubscript{2} away from the other. Comment on how easy or difficult this was in the data table.
8. From the dropdown menu, choose “pull apart HBr and HBr.”
9. Predict how difficult it will be to pull apart the two molecules in the data table.
10. Using the green star, move one HBr away from the other. Comment on how easy or difficult this was in the data table.
11. From the dropdown menu, choose “pull apart Br\textsubscript{2} and HBr.”
12. Predict how difficult it will be to pull apart the two molecules in the data table.
13. Using the green star, move Br\textsubscript{2} away from HBr. Comment on how easy or difficult this was in the data table.
14. In the last two columns, determine whether the molecules are polar or nonpolar and identify the type of intermolecular forces the molecules exhibit.

Data

<table>
<thead>
<tr>
<th>Molecules</th>
<th>Predict</th>
<th>Actual</th>
<th>Polar/nonpolar?</th>
<th>IMF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Br\textsubscript{2} &amp; Br\textsubscript{2}</td>
<td>Answers will vary</td>
<td>easy</td>
<td>nonpolar</td>
<td>London disp.</td>
</tr>
<tr>
<td>H\textsubscript{2} &amp; H\textsubscript{2}</td>
<td>Answers will vary</td>
<td>easy</td>
<td>nonpolar</td>
<td>London disp.</td>
</tr>
<tr>
<td>HBr &amp; HBr</td>
<td>Answers will vary</td>
<td>hard</td>
<td>polar</td>
<td>Dipole-dipole</td>
</tr>
<tr>
<td>Br\textsubscript{2} &amp; HBr</td>
<td>Answers will vary</td>
<td>Easy-ish</td>
<td>Nonpolar &amp; polar</td>
<td>Induced dipole</td>
</tr>
</tbody>
</table>

Analysis
1. Explain why you classified the intermolecular forces the way you did for each pair of molecules taking into account polarity.
   a. Br\textsubscript{2} & Br\textsubscript{2}
      The two atoms bonded together are the same, so they have an equal sharing of electrons. Equal shared electrons leads to a nonpolar molecule, which
exhibits London dispersion IMFs.

b. H₂ & H₂
   The two atoms bonded together are the same, so they have an equal sharing of electrons. Equal shared electrons leads to a nonpolar molecule, which exhibits London dispersion IMFs.

c. HBr & HBr
   The two atoms bonded together aren’t the same, so they have an unequal sharing of electrons. Unequal shared electrons lead to a polar molecule, which exhibits dipole-dipole IMFs.

d. Br₂ & HBr
   One molecule is nonpolar while the other is polar. The polar molecule induces a dipole moment in the nonpolar molecule, so it’s an induced dipole IMF.

2. If you had samples of HBr(aq) and Br₂(l) in real life and you mixed them together, would you expect them to mix or separate into two layers? Explain.
   Because HBr is polar and Br₂ is nonpolar, they will not dissolve in one another. Like dissolves like because of the way IMFs interact with one another, so the HBr molecules will be more interested in each other than in the Br₂ nonpolar molecules. Thus, two layers will form and they will not stay mixed together.

3. If HF was used in the simulation instead of HBr, how easy or difficult would it be to separate the molecules? What kind of polarity and IMFs would the molecules experience? Complete the following data table with your predictions:

<table>
<thead>
<tr>
<th>Molecules</th>
<th>Predict</th>
<th>Polar/nonpolar IMF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Br₂ &amp; Br₂</td>
<td>Easy</td>
<td>Nonpolar</td>
</tr>
<tr>
<td>HF &amp; HF</td>
<td>Difficult</td>
<td>Polar</td>
</tr>
<tr>
<td>Br₂ &amp; HF</td>
<td>Easy-ish</td>
<td>Nonpolar/polar</td>
</tr>
</tbody>
</table>

Explain your IMF classifications, taking into account polarity.
   Because Br₂ is nonpolar, they molecules aren’t attracted to each other and LD IMFs result. HF is polar, so it should exhibit dipole-dipole IMFs, however this is a special exception and it exhibits even stronger IMFs, hydrogen bonds. Br₂ and HF are a pair of a polar and nonpolar molecule, so the IMFs they have are induced dipole because of the polar nature of HF.

4. How would you expect HF’s boiling point to compare to HBr? Explain. You can use the Molecular Workbench simulation Boiling Point to help you.
   Because the IMFs in HF are so much stronger than HBr (hydrogen bonds vs. dipole-dipole), I would expect HF to have a much higher boiling point than HBr. Stronger IMFs are more difficult to overcome and require a higher temperature.

5. If F₂ was used in the simulation instead of Br₂, how easy or difficult would it be to separate the molecules? What kind of polarity and IMFs would the molecules experience? Complete the following data table with your predictions:

<table>
<thead>
<tr>
<th>Molecules</th>
<th>Predict</th>
<th>Polar/nonpolar IMF</th>
</tr>
</thead>
<tbody>
<tr>
<td>F₂ &amp; F₂</td>
<td>Easy</td>
<td>Nonpolar</td>
</tr>
<tr>
<td>HBr &amp; HBr</td>
<td>Difficult</td>
<td>polar</td>
</tr>
</tbody>
</table>
F₂ & HBr

Easy-ish

Nonpolar/polar

Induced dipole

Explain your IMF classifications, taking into account polarity.

Because F₂ is nonpolar, they molecules aren’t attracted to each other and LD IMFs result. HBr is polar, so it exhibits dipole-dipole IMFs. F₂ and HBr are a pair of a polar and nonpolar molecule, so the IMFs they have are induced dipole because of the polar nature of HBr.

6. How would you expect F₂’s boiling point to compare to Br₂? Explain.

Because F₂ and Br₂ have the same IMFs, and F₂ is less massive than Br₂, I would expect F₂ to have a lower boiling point than Br₂. It’s easier to move F₂ molecules away from each other because of their smaller size, so it would boil at a lower temperature.

7. How would you expect HBr’s boiling point to compare to Br₂? Explain.

HBr has stronger IMFs than Br₂, so I would expect HBr to boil at a higher temperature than Br₂.

8. Consider the familiar compound water (H₂O). How would water’s boiling point compare to HBr and HF? Explain.

Of the three compounds, HBr should have the lowest boiling point because it has the weakest IMFs (HBr is dipole-dipole, HF and H₂O are hydrogen bonds). Between water and HF, I would expect HF to have a lower boiling point because it has less mass than water and should be easier to boil. Water also has two opportunities to hydrogen bond with the oxygen, so it will be more difficult to separate the molecules into the gas phase. So expect: HBr<HF<H₂O

9. Look up the boiling points of H₂O, Br₂, F₂, HBr, and HF. Were your predictions correct? Explain.

H₂O: 100 °C
Br₂: 59 °C
F₂: -188 °C
HBr: -66 °C
HF: 19.5 °C

Br₂ and F₂ are nonpolar, so they low boiling points, and F₂ should be lower than Br₂ because of its smaller size/mass (it is less polarizable). Br₂ has a higher boiling point than HF because of its large mass and size, which makes it more polarizable. H₂O has the highest boiling point because it has the strongest/most IMFs. HF has a higher boiling point than HBr because of hydrogen bonds.

10. Of the two original compounds you investigated in the simulation (HBr and Br₂), which would be soluble in water? Explain.

HBr would be soluble in water because of its polar properties. Like dissolves like.

11. Rank the vapor pressures of water, HBr, and HF from lowest to highest. Explain.

H₂O < HF < HBr because of IMF strength – stronger IMF means lower VP.

Conclusion

When considering physical properties, are IMFs the only factor to consider? Explain.

Mass and size are also considerations when using IMFs to predict trends in physical properties.