Science Assessment System
Through Course Task

Binary Compounds and Their Properties

Grade Level:
9, 10, 11, 12

Phenomena:
Compounds Have Different Characteristic Properties

Science & Engineering Practices:
Developing and Using Models
Analyzing and Interpreting Evidence
Engaging in Argument from Evidence

Crosscutting Concepts:
Patterns
Cause and Effect

Designed and revised by Kentucky Department of Education staff
in collaboration with teachers from Kentucky schools and districts.

Preparing to implement Through Course Tasks in the Classroom

What is a TCT?

- TCTs are 3-dimensional tasks specifically designed to get evidence of student competency in two dimensions, Science and Engineering Processes (SEPs) and Crosscutting Concepts (CCC), untethered from Performance Expectations (PEs)/standards. Tasks are sense-making experiences.
- Tasks are to be used formatively. The goal is for both students and teachers to understand areas of strength and improvement for the SEP(s) and CCC assessed within the task.

How do I facilitate a Through Course Task (TCT)?

- TCT facilitation is a collaborative process in which teacher teams calibrate understanding of the expectations of the task and refine strategies to be used during task facilitation.

Before the task:

1. Complete the TCT as a learner – compare understanding of task through the lens of success criteria (identified in the task) in order to understand expectations.
   Success criteria include:
   - What is this task designed to get evidence of?
   - What is the task asking the students to do?
   - What might a student response look like?
2. Identify the phenomenon within the task. Consult resources to assure teacher teams have a deep understanding of associated science concepts.
3. Collaborate to generate, review and refine feedback questions during facilitation.
4. Identify potential "trouble spots" and plan for possible misconceptions.

During the task:

5. Collect defensible evidence of each student's competencies in 3-dimensional sense-making for the task.
6. Ask appropriate feedback questions to support student access and engagement with the task in order to elicit accurate evidence of student capacities.

After the task:

7. Reflect on the task as a collaborative team.
8. Review student work samples to identify areas of strength and areas of need.
9. Determine/plan next steps to move 3-D sense making forward through the strengthening of the use of SEPs and CCCs.

Using the materials included in this packet:

- **Task Annotation:**
  - The task annotation is a teacher guide for using the task in the classroom. Additionally, the annotation gives insight into the thinking of developers and the task overall.

    - Each task has science and engineering practices, disciplinary core ideas, and crosscutting concepts designated with both color and text style:
        - **Science and Engineering Practices**
        - *Disciplinary Core Ideas*
        - Crosscutting Concepts
- **Student Task:** The materials to be used by students to complete the TCT.

Binary Compounds and Their Properties Task Annotation

After **analyzing and interpreting data** of *binary compounds (their structure and some bulk properties)*, make a **qualitative claim about the** *relationship between the structure and bulk properties* **supported with evidence** from the trends/patterns that you identify. **Given a structural model** of a different compound, **predict** *some of its bulk properties* based on the causal **relationship** previously identified in your claim.

Phenomenon within the task

Why do compounds have different properties? Chemical names, formulas, and structural models can be used to differentiate the different types of compounds (covalent vs. ionic) that are composed of elements/ions bonded to each other. Each type of compound has different bulk properties such as state of matter, melting point, boiling point, electrical conductivity, density, etc. These bulk properties can be predicted based on the type of bonding within the substance and/or intermolecular forces.

Possible struggles

Students typically struggle with recognizing the fact that smaller molecules are composed of nonmetals bonded to nonmetals, while "extended structures" aka crystal lattices are composed of metals bonded to nonmetals. This is especially true if students have not been exposed to the specific content yet. Students may also struggle with the definitions or distinctions between structure and composition. Composition refers to which type(s) of elements makes up the compound whereas structure refers to the arrangement or bonding patterns of the atoms/ions in the substance. While we think it is important to help students understand this distinction, we also think that teachers should omit discussing the types of elements (metals/nonmetals) in the compound during the task.

Possible misconceptions

Many students think that all representative particles of compounds are called "molecules." The fact that ionic compounds exist in crystal lattices is a new concept to most students. They do not recognize that a crystal lattice is composed of repeating formula units. However they are able to recognize that there are a lot of "atoms" (ions) in the crystal. In addition, students tend to struggle with the concept that all substances can exist as either a solid, liquid, or gas, depending upon the temperature and pressure. Students especially struggle with the fact that gases have a melting or boiling point. They think that, because it's already a gas, it can't be boiled or melted. They fail to recognize the fact that if the temperature is reduced low enough, it will condense and then freeze if the temperature is reduced even further. Additionally, many students do not recognize that melting point and freezing point are the same temperature for a pure substance at a given pressure. This misconception may appear through class discussion. These misconceptions should not have an effect on the outcome of the task.

How the phenomenon relates to DCI

- **HS-PS1.A: Structure and Properties of Matter Disciplinary Core Idea:** The structure and interactions of matter at the bulk scale are determined by electrical forces within and between atoms.
- **HS-PS2.B: PS2.B: Types of Interactions Disciplinary Core Idea:** Attraction and repulsion between electric charges at the atomic scale explain the structure, properties and transformations of matter, as well as the contact forces between material objects.
- **MS-PS1.A: Structure and Properties of Matter Disciplinary Core Ideas (DCIs taught in middle school.)**
    - Substances are made from different types of atoms, which combine with one another in various ways. Atoms form molecules that range in size from two to thousands of atoms.
    - Each pure substance has characteristic physical and chemical properties (for any bulk quantity under given conditions) that can be used to identify it.
    - Solids may be formed from molecules, or they may be extended structures with repeating subunits (e.g., crystals).
- **MS-PS2.B: Types of Interactions Disciplinary Core Idea (DCI taught in middle school.):** Electric and magnetic (electromagnetic) forces can be attractive or repulsive and their sizes depend on the magnitudes of the charges, currents or magnetic strengths involved and on the distances between the interacting objects.

The disciplinary core ideas, HS-PS1.A and HS-PS2.B, address why different types of compounds have different bulk properties. Ionic substances, composed of a metal and a nonmetal that form a crystalline lattice of cations and anions, are solids having high melting points, high boiling points, and high densities. They are also good conductors once dissolved in water. These properties are the result of alternating cations and anions tightly packed in a crystalline lattice; very strong electrostatic forces, aka ionic bonds, hold the lattice together which takes a lot of energy to break apart. On the other hand, covalent (molecular) substances are composed of nonmetals only that are bonded to each other through a sharing of electrons to make individual molecules of the substance. There are weaker attractive forces (than in ionic substances), called intermolecular forces, holding the individual molecules together. The difference in the electrical forces involved results in different bulk properties.

What information/data will students use within this task?

Prior knowledge of the content in HS-PS1.A may help students complete the task with more rigor and scientifically-appropriate vocabulary, but we do not think it is necessary for students to have this background knowledge to complete this task. In this task, students are given a large table of data that includes physical properties of 11 different compounds and a structural model of each. Of these 11 compounds, 6 are covalent and 5 are ionic; however, students are not informed of the nature of the compound. Students are given the name, formula and a brief description of where they might encounter this compound in everyday life, as well as the structural model, state of matter, melting and boiling points, electrical conductivity and density. One organizational pattern is provided (Alex and Annie's) that groups the 11 compounds by their state of matter at standard temperature and pressure (solids, liquids, and gases).

Students are given instructions that will guide them to organize the compounds based on another property of their choosing in order to look for a relationship between the structure/composition and the bulk properties of the compound. We suggest students cut the rows of information into strips that can be reorganized and glued onto a large piece of construction paper (minimum 12 x 17.5 inches). The students will use one of the organized data sets to make a claim about the relationship between the structure/composition of the compounds to the property examined.

After considering the trends/patterns in the two organized data sets (Alex/Annie and James/Janie (your students)), students make a qualitative claim to explain a relationship between the structure and composition of each compound to the property (or properties) examined. Students must cite specific evidence from the data in the task to support the relationship made in their claim. Because our students struggled with how to develop the relationship between the structure/composition and properties (due to no prior content knowledge related to HS-PS1.A), we have added a set of guiding questions (before they are asked to make their claim) to make students look more closely at the structural models and comment on the similarities of the models in each state of matter grouping in Alex and Annie's organization. Later in the task, students are given the formula and structural model of another compound and are asked to predict 3-4 physical properties based on their organization and analysis.

Ideas for setting up the task with students

- This task could be used in two places in your curriculum: first, before any lessons on bonding (ionic and covalent) and then later, after a thorough unit on bonding and/or intermolecular forces. It is suggested that students have already been exposed to organization of the Periodic Table. The current student work posted is prior to our bonding unit. We plan on posting revised student work after the bonding unit so teachers can compare the quality and level of scientific vocabulary used by students before and after the content is taught.

- Print pages 1-3 single-sided and give these to students first. Print pages 4-7, single-sided and stapled, for later use in the task.
- Students should read the introduction on page 1 of the task (we did this as a class) and examine the information given in Table 1. For scaffolding, teachers may want to review any terms and their corresponding definitions for the column headings given. This includes letting students know that the electrical conductivity data is for the substances dissolved in water.
- Students cut the introduction, one of the rows of column headings and each row of the compounds into strips. The teacher should be sure that students have a total of 13 pieces of paper (introduction, column headings and 11 compounds from Table 1).
- At this point, the teacher should hand out a large piece of construction paper, glue and pages 4-7 of the task single-sided and stapled.
- Students read Part A (we did this as a class) and examine Alex and Annie's organization (Table 2 by states of matter). Teachers can scaffold their amount of discussion based on the needs of their students.
- Students should organize the strips of data based on a property other than the state of matter as described in Part A.
- Once they are satisfied with their organization, students should glue the strip of column headings onto the construction paper and each of the 11 strips of paper accordingly. Note: The teacher should encourage the students to lay out all 12 paper strips before gluing to ensure that they all fit on one side of the construction paper. Make sure students put their name on construction paper.
- One issue arose during this step when students organized by melting point. It is stated in the table that sodium oxide does not melt. Students did not know where to put this strip in their organization. The teacher might discuss this with individual students by questioning, "What does it mean that it does not melt?" Further probing questions might be, "What state is it at low temperatures?" and "What state is it at high temperatures?" Following this line of questioning, students should conclude that this substance has the highest melting point.
- Additionally, when students organized by boiling points, two substances do not boil, but rather sublime. A discussion of sublimation might be needed, although students did not seem to struggle here because they simply paid attention to the numerical value of boiling point.
- Note: As an opportunity for differentiation for students who struggle with number sense, mathematical reasoning, etc., the teacher may ask students to decide which property might be easier for them. As a result of this discussion, the student should conclude that organizing the compounds by electrical conductivity will be easier because words, instead of numbers, are used in the organization.

- After students have organized their compound strips and finished gluing their strips onto the construction paper, students should answer Part A and write the property they used for their organization on their construction paper. This helps the teacher check their organization for accuracy. Also, make sure they write their name on the construction paper in case you have to split the task over two days. Our classes spent one day on Part A and one day on the rest of the task (Parts B, C and D).
- In order to process the information in Table 1 and Alex and Annie's organization in Part A, we decided to add a series of guiding questions (Part B) to our original task in order to prompt students to think more about where information about structure and composition is given in the task. Since this was added after we completed the task with some of our students, you will not find this page posted in some of our student work. These questions were added because our students did struggle with how to develop the relationship between the structure/composition and properties (due to no prior content knowledge related to HS-PS1.A). We are hoping that this set of guiding questions will help students, especially those who have not been exposed to the content, look more closely at the structural models to build their claim relating structure/composition to properties (Part C). This set of questions could be completed collaboratively in order to have student discussion aid in developing a more complete understanding of the meaning of the words "structure" and "composition".
- Parts C and D are intended to be completed by students individually. If Part B is being completed collaboratively, teachers should advise students not to start on Parts C and D until all student groups have completed Part B. This is to ensure individual work on Parts C and D. However, keep in mind that for lower-level students, the teacher may need to scaffold by questioning to make the task more accessible for them. Collect construction paper and Parts B, C and D.

Intent of the Task for Assessment

This task was designed to meaningfully engage students in the idea that the composition and structure at the atomic (particulate) level of compounds can affect their bulk properties. In the storyline, students are provided text that prompts thinking about why so many different compounds exist that are produced from such few elements. Most high school students should know that different compounds have different properties, but may not know or ever thought about why. In Table 1, students are provided with a large table of unorganized data that includes the physical properties of 11 different compounds and a structural model of each. In order for students to process that the data is not currently organized in a format that shows trends/patterns, one organizational pattern is provided (Alex and Annie's) that groups the 11 compounds by their state of matter at standard temperature and pressure (solids, liquids, and gases).

In Part A of the task, students are asked to organize the Table 1 data according to a different physical property in order to reveal a pattern by cutting and gluing the strips of compound data onto a piece of construction paper. Teachers should circulate during Part A to aid any students having trouble with organizing the data (see ideas for setting up the task with students for suggestions regarding the issues we encountered during task implementation). A set of guiding questions is then completed by students to prompt them to think about what the terms "structure" and "composition" mean and where that information about compounds can be found in the task. If students have not been exposed to the content involved in the DCI HS-PS1.A, it may be helpful to allow students to complete Part B in pairs or groups to facilitate discussion about their understanding of the terms "structure" and "composition."

Parts C and D of the task are intended to be completed individually by students and provide evidence about a student's ability to develop a claim and support it with evidence. Specifically, students should make a qualitative claim to explain a relationship between the structure and composition of each compound to the property (or properties) examined. Finally, students are given the formula and structural model of another compound and are asked to predict 3-4 physical properties based on their organization and analysis, essentially a cause and effect relationship.

Success Criteria

Evidence of Learning Desired based on Progression from Appendices

Analyzing and Interpreting Data

- Analyze data using models in order to make valid and reliable scientific claims.
- Organize data sets to reveal patterns that suggest relationships (this is from the 3-5 grade band but this is an essential skill).

Patterns

- Different patterns may be observed at each of the scales at which a system is studied and can provide evidence for causality in explanations of phenomena.

Engaging in Argument from Evidence

- Make and defend a claim based on evidence about the natural world that reflects scientific knowledge.
- Make and defend a claim based on evidence about the natural world that reflects scientific knowledge.

Cause and Effect

- Cause and effect relationships can be suggested and predicted for complex natural systems by examining what is known about smaller scale mechanisms within the systems.
- Cause and effect relationships can be suggested and predicted for complex natural systems by examining what is known about smaller scale mechanisms within the systems.

Success Criteria

- Student chooses a property (other than state) and organizes the 11 compounds in order of this property in a way that shows a pattern or trend.
- Student identifies similarities in composition and structure among each state of matter.

- Student writes a qualitative claim to explain a relationship between structure/composition and bulk property.
- Student cites evidence that supports the claim.

- Student uses the claim (from Part C) to infer 3-4 physical properties of C_2H_6 given its formula and structural model.
- Student supports these properties with evidence and explains reasoning.

Possible Student Responses

Analyzing and Interpreting Data

- Students successfully choose a property (melting point, boiling point, electrical conductivity, or density) and organize the data by this property. Quantitative data can be arranged as an increasing or decreasing trend, by numerical ranges, etc.
- Student states that the formula tells about a compound's composition.
- Student states that the model tells about the structure.
- Student states that solids are made of metals and nonmetals. Liquids and gases are made of nonmetals.
- Student states that solids have extended structures (or many atoms) while liquids and gases have fewer atoms.

Engaging in Argument from Evidence

Expectation of Student Response:

Possible Claims:

Compounds with extended structures (aka lattice or many atoms) are composed of metals bonded to nonmetals and have high melting point (or boiling point). Compounds with smaller structures (few atoms) are composed of nonmetals bonded to nonmetals and have low melting point (or boiling point).

OR

Compounds with extended structures (aka lattice or many atoms) are composed of metals bonded to nonmetals and are good conductors of electricity. Compounds with smaller structures (few atoms) are composed of nonmetals bonded to nonmetals and are poor conductors of electricity.

OR

Compounds with extended structures (aka lattice or lots of atoms) are composed of metals bonded to nonmetals and have densities greater than 1. Compounds with smaller structures (few atoms) are composed of nonmetals bonded to nonmetals and have densities much less than 1.

Evidence:

Students reference a few of the compounds with their respective property values (actual numbers) from the table.

Reasoning:

Compounds composed of metals and nonmetals form ionic bonds. The ions are attracted to many other ions of opposite charge and therefore create a crystal lattice structure.

Compounds composed of nonmetals bond covalently. Because no ions are formed, the attractive forces are weaker and therefore form smaller molecules.

Note: When using this task prior to any bonding unit, the above reasoning will not be expected in terms of the appropriate level of scientific vocabulary.

Students not exposed to content may provide the reasoning with little to no underlying scientific principle such as:

Compounds with lots of atoms have structures that are more highly compacted (atoms are closer together).

Compounds with fewer atoms were either farther apart or loosely held together.

The ball-and-stick model versus the space-filling model may be a factor that leads students to this conclusion. However these were the only images available without copyright issues.

Engaging in Argument from Evidence
Expectation of Student Response:
C_2H_6 is probably a gas or liquid, has a low melting point, low boiling point, is not a conductor in water, and has a very low density.

Post-bonding unit justification: Since C_2H_6 is composed of two nonmetals, it must be bonded covalently. Covalent compounds (or compounds with few atoms or nonmetals) do not form extended structures (crystal lattice) like compounds with ionic bonding (or with many atoms or metal and nonmetal). NH_3, CO_2, CCl_4, CF_4, N_2O and H_2O are all made of nonmetals and therefore covalently bonded. Each of these has low melting and boiling points (water has the highest at 0^oC and 100^oC respectively, but all other molecules have lower melting points (for example, $-23\,^oC$ and 76.8^oC for carbon tetrachloride)). None of these compounds conducts electricity in water except ammonia which is a poor conductor.

All of these covalent compounds have low density with carbon tetrachloride (1.59 g/mL) and water (1 g/mL) having the highest but all others <1 g/mL.

Pre-bonding unit justification: C_2H_6 is a small molecule with only a few atoms and composed of nonmetals. Its structural model is similar to that of NH_3, CO_2, CCl_4, CF_4, N_2O and H_2O. Therefore it should have properties similar to these substances. Numerical quantity ranges for properties should be noted as evidence similar to above.

Other information teacher teams might find useful when preparing to use this task in the TCT process
Claim, Evidence, Reasoning Information: At the beginning of the year, this website was used to make a general outline (occurs right before the Bozeman video) for students regarding what should be included in the claim, evidence, and reasoning (CER) of a scientific argument. If students are not familiar with CER (or continue to struggle with it), a general outline, such as the one on this website, may be helpful to handout or discuss during the task.

Extensions and/or other uses after the task is implemented

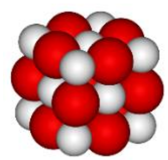
- **HS-PS1-3** Plan and conduct an investigation to gather evidence to compare the structure of substances at the bulk scale to inter the strength of electrical forces between particles. Teachers should provide an opportunity for students to develop their own lab procedure to distinguish between ionic and covalent compounds. For example, the teacher could provide two white solids (salt and sugar- we often use Kosher or sea salt and raw sugar so students do not guess their identity) and ask students to develop a procedure to identify which is ionic and which is covalent based on some of the properties studied in the task.
- Labs on surface tension or intermolecular forces such as evaporation rate can be used to help students develop an understanding of intermolecular forces in covalent substances.

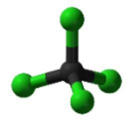
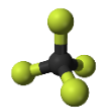
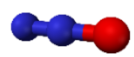
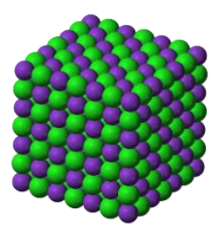
Through Course Task – Binary Compounds and Their Properties

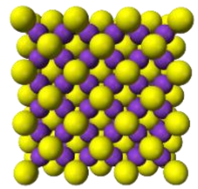
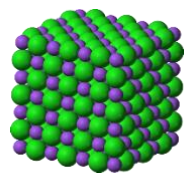
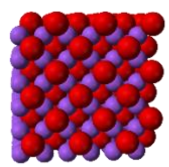
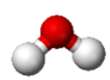
In their chemistry class, Alex and Annie are studying matter. The teacher says that all matter is made of some combination of the existing 100 or so elements. Alex asks Annie, “How can this be? There are so many different types of stuff?”

Annie agrees, saying “There must be millions of different types of matter! How can they all be made of the same 100 elements?”
Their teacher suggests that they look at substances called compounds. The teacher selected 11 different compounds and creates a table of a few of their properties. Consider the data of these 11 binary compounds (composed of two elements) in the following table.

Table 1

Chemical Name/Formula	Model	State at $25^{\circ}C$	Melting Point, °C	Boiling Point, °C	Electrical Conductivity	Density
Ammonia (Nitrogen trihydride) NH_3 Used to clean, bleach and deodorize		Gas	-77.7	-33.35	Slight conductor	0.00077
Calcium oxide, CaO Used to purify or melt metals		Solid	2614	2850	Good conductor	3.25
Carbon dioxide, CO_2 Gas produced during respiration of some animals		Gas	-56.6	-78.5	Not a conductor	0.001977

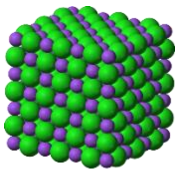
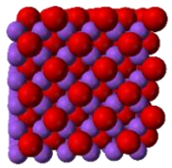
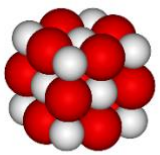
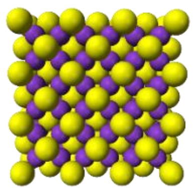
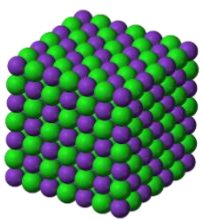
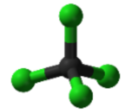
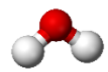
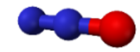
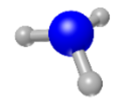
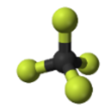
Chemical Name/Formula	Model	State at 25°C	Melting Point, °C	Boiling Point, °C	Electrical Conductivity	Density
Carbon tetrachloride, CCl_4 (aka Tetrachloromethane) Cleaning fluid, degreasing agent		Liquid	-23	76.8	Not a conductor	1.59
Carbon tetrafluoride, CF_4 (aka Tetrafluormethane) Used as a refrigerant gas (such as Freon)		Gas	-183.6	-127.8	Not a conductor	0.00372
Dinitrogen monoxide, N_2O Laughing gas, used as an anesthetic		Gas	-131.5	-127.3	Not a conductor	0.00196
Potassium chloride, KCl Used in fertilizers and to treat low potassium levels in blood		Solid	770	1500 sublimes	Good conductor	1.984

Chemical Name/Formula	Model	State at 25°C	Melting Point, °C	Boiling Point, °C	Electrical Conductivity	Density
Potassium sulfide, K_2S Used in medicine and depilatories		Solid	840	1349*	Good conductor	1.805
Sodium chloride, NaCl Table Salt, found in sea water, used to flavor foods		Solid	801	1413	Good Conductor	2.165
Sodium oxide, Na_2O Used in ceramics and glass		Solid	Doesn't melt	1275 (sublime)	Good conductor	2.27
Water, H_2O Sustains life, universal solvent		Liquid	0	100	Not a conductor	1.0

Cut the data into rows so that each compound and its properties are on a single strip of paper.

Alex and Annie organized the 11 compounds into 3 categories based on the state of matter. Below is their classification.

Table 2

<table>
<tr><th>Solid</th><th>Liquid</th><th>Gas</th></tr>
<tr>
<td>
NaCl

Na_2O

CaO

K_2S

KCl</td>
<td>
CCl_4

H_2O</td>
<td>
CO_2

N_2O

NH_3

CF_4</td>
</tr>
</table>

Part A) James and Janie suggest that they can organize these compounds using a different property. Choose a property other than state of matter and organize the rows of data for each of the compounds based on this property in such a way that your organization exhibits a trend or pattern. Based on this organization, glue the rows of data for each compound onto a large piece of construction paper. In the space below, state the property you used to organize the compounds.

____

____

Part B)

Composition tells us which elements make up the compound. Determine where in the table (which column) you would locate information about the compound's composition. ____

Compare the compositions of the solids to that of the liquids as well as to the gases. Make note of any similarities and differences in as much detail as possible.

Structure tells us how the compound is built or put together. Determine where in the table (which column) you would locate information about the compound's structure. ____

Compare the structures of the solids to that of the liquids as well as to the gases. Make note of any similarities and differences in as much detail as possible.

Part C) Analyze the two organized data sets (Alex/Annie and James/Janie (yours), and consider the trends or patterns observed in both organizations. Make a qualitative claim to explain a relationship between the **structure and composition** of each compound to the **property** (**or properties**) examined. Cite evidence that supports this relationship.

____

____

____

____

____

____

____

____

____

____

____

____

____

____

____

____

Part D) The teacher gives the students a model of a compound (pictured right) having the chemical formula, C_2H_6. Based on your analysis of the two organized data sets, infer 3-4 physical properties of this compound. Support with evidence and explain your reasoning.