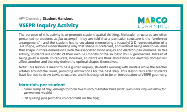
Understanding VSEPR/IMFs

Duration

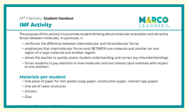
One online class session of approximately 90 minutes

Resources

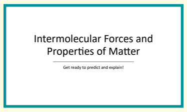
1. VSEPR Inquiry Activity



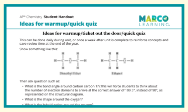
2. IMF paper lab



3. Review Deck Unit 3



4. Ideas for Quick Assessment



College Board Objectives from the 2019–20 *CED*

- **Topic 2.7 VSEPR and Bond Hybridization (LO SAP-4.C)**
  Based on the relationship between Lewis diagrams, VSEPR theory, bond orders, and bond polarities:
  (a) Explain structural properties of molecules.
  (b) Explain electron properties of molecules.
- **Topic 3.1 Intermolecular Forces (LO SAP-5.A)**
  Explain the relationship between the chemical structures of molecules and the relative strength of their intermolecular forces when:
  (a) The molecules are of the same chemical species.
  (b) The molecules are of two different chemical species.

TOPIC 2.7 SUGGESTED SKILL 6.C

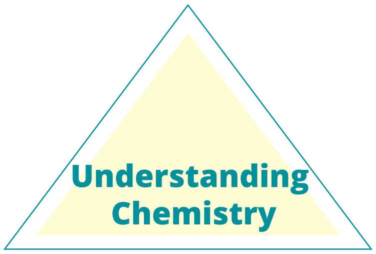
Support a claim with evidence from representations or models at the particulate level, such as the structure of atoms and/or molecules.

TOPIC 3.1 SUGGESTED SKILL 4.D

Explain the degree to which a model or representation describes the connection between particulate-level properties and macroscopic properties.

Levels of Understanding for this lesson

Macroscopic Level:
What do I see/observe?
(use of labs/demos)



Sub-microscopic Level:
What is happening on the molecular level?
(use of particulate level drawings/manipulatives)

Symbolic Level:
How can I represent this?
(use of chemical formulas, symbols, equations)

How to Use This Lesson Plan

This lesson plan emphasizes the understanding of what VSEPR actually is—and why molecules assume the shape they do. The key idea is that instead of giving students a list of shapes to memorize, they derive those shapes logically. Based on the models they construct, students are prompted to determine shape names, bond angles, polarity, and hybridization.

In a follow-on activity for the next unit (IMFs), students are given Lewis structures to cut and paste onto a mini-poster, orienting the molecules to show different types of IMFs.

Student Activities

- VSEPR Models Using Clay and Pins Lab (2 class periods)
- IMF Paper Lab (1 class period)
- Review Deck Unit 3
- Ideas for Quick Assessment

The following represent FRQs related to this lesson plan:

- 2014 #5, 6; 2015#2d-f; 2017 #1c,d; 2018 # 2d, 4a; 2019 #1a,b, 2c,
- Pre-revision: 2011#6; 2010#5; 2008 #6

NOTES

Write or type in this area.

VSEPR Inquiry Activity

The purpose of this activity is to promote student spatial thinking. Molecular structures are often presented to students as a *fait accompli*—they are told that a particular structure is the "preferred arrangement"—and the student has to set about memorizing a (usually) 2-D representation of a 3-D shape (without understanding why that shape is preferred, and without being able to visualize that shape in three dimensions), with the associated bond angles and electron pair domains. In this activity, students will construct their own 3-D models of the five basic VSEPR geometries. Instead of being given a model to replicate, however, students will think about how one electron domain will affect another and thereby derive the optimal shapes themselves.

Note: This lesson is meant to be a guided inquiry activity, students working with models while the teacher rotates around the room, providing prompts for the next step. This lesson falls after students have learned to draw Lewis structures, and it is designed to be an introduction to VSEPR geometry.

Materials per student

- Small lump of clay, enough to form five ½-inch diameter balls *(note: oven bake clay will allow for permanent models)*
- 20 quilting pins (with the colored balls on the tips)

Procedure

Have student complete the first three columns of the accompanying worksheet (Lewis structures, # electron domains, # lone pairs) before beginning this activity.

A. Model Construction

Note: there is a video demonstration that accompanies this lesson

1. Have students use their clay to form 5 balls ½ inch in diameter. Tell students these represent the central atom. The pins represent electron pair domains.
2. Direct students to begin with 1 ball and 2 pins (one central atom with 2 electron domains). Have students arrange the 2 electron pair domains in a way than minimizes the repulsion between electron pairs. *Resist the urge to tell students the name of the structure or the bond angles! They will do this themselves in Part B*. Set this model aside.
3. Have students replicate the 2-electron pair domain model with the next ball of clay. Then have students add a third electron pair domain. Have students think about how the addition of this third domain will affect the spatial arrangement of the first two domains. *This is where the spatial thinking comes into play. Students will begin with a T-shaped model, but should be able to see that there is a lot of unused space at the top of the T. They will be able to see that the third electron pair domain will cause the first two domains to shift away from it, resulting in a trigonal planar configuration. Again, do not discuss terminology or bond angles at this point. Also, if they present the T-shape as the correct model, prompt them to think about their model ("What about this unused space?") rather than telling them how to correct it.* Set this model aside.
4. Repeat these steps with the remaining models, always beginning a new model by recreating the previous model, then adding one more domain. Each time a new domain is added, students will have to think about how that additional domain affects the domains already present, and how the distance between all of them can be maximized.

5. This activity is powerful in that students are given the opportunity to use a physical manipulative to help them visualize what is happening on the molecular level. This gives them the ability to understand that VSEPR shapes actually are due to electron pair repulsion forces!

B. Naming and Determining Bond Angles

1. Students are now ready to name their models, and to determine the bond angles associated with each structure. Hold up model 1 (one central atom with 2 electron domains), and ask students, "What shape does it look like?" Someone will come up with "a line"—and at that point you can say, *"Yes, that's it! The name of this shape is linear!"*

2. Repeat for each model, allowing students to name the shape they SEE before telling them the name assigned, with minor prompting as needed. This will allow students to see that the shape names are simply reflections of the actual shapes represented.

Model	Shape	Name
2-domains	Line	Linear
3-domains	Triangle (prompt them to see that it lies in a plane)	Trigonal planar
4-domains	Trickier! Have students count the faces. Then asked them the math word for "four-faced figure."	Tetrahedral
5-domains	Pyramid shape with triangular base, and there are two of them	Trigonal bipyramidal
6-domains	Eight-faced figure	Octahedral

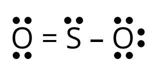
3. Students can also use their models to determine the bond angles for each shape.

Fill out corresponding sections on worksheet

C. Non-bonding pairs of electrons

1. Up to this point, all of the models discussed had terminal atoms (all electron pairs were bonding pairs). We will now address non-bonding pairs.

2. Begin by examining the Lewis structure of SO_2. Ask the students to count the electron pair domains, and to determine how many non-bonding pairs there are. Students should see that there are three electron domains, and one of those is a non-bonding pair:



Discuss with students: there are three regions of space that are needed to accommodate electrons—which model has three electron domains? Hold up the 3-electron domain model and count the domains together (one pin each for the two bonding regions, and the third pin for the non-bonding pair).

3. Point out that the nonbonding pair is REALLY THERE—and occupies one of the domains—but we don't see it. Cover up the pin with your fingers. Ask: "What shape remains?" (Ask them what kind of line it is, someone will come up with "bent").

4. Continue with remaining models/lone pairs. As in part B, prompt student for shape names.
5. The key takeaway for students is that one MUST begin by counting electron pair domains, which allows this sequence to ensue:
    - ○ Count the number of electron pairs.
    - ○ Use that number to determine the underlying shape.
    - ○ The underlying shape determines the bond angles (and the hybridization).
    - ○ Use the number of lone pairs to determine the actual molecular shape that ensues.

Notes:

- ○ You may elect to inform students that the bond angles are slightly affected by non-bonding pairs of electrons (109.5 becomes "slightly less than 109.5").
- ○ Use the models to correlate to hybridization.

Fill out corresponding sections on worksheet.

D. Polarity

Use the models to help students visualize what factors determine the polarity of molecules, and to better prepare them to explain why a molecule is or is not polar.

- ○ Models with no lone pairs and that have the same terminal atoms are all non-polar BECAUSE THE BOND DIPOLES CANCEL.
- ○ Models with no lone pairs but different terminal atoms are polar because the BOND DIPOLES DO NOT CANCEL.
- ○ Models with lone pairs of electrons, with two exceptions (5/3 and 6/2), are polar.

Fill out corresponding sections on worksheet.

	Lewis Structure	# Electron pair domains	# lone pairs	hybridiza-tion	Name (shape)	Bond Angles	Polar or Nonpolar
CO_2							
BF_3							
SO_2							
CH_4							
NH_3							
H_2O							
PF_5							
SF_4							
ClF_3							
XeF_2							
SF_6							
BrF_5							
XeF_4							

IMF Activity

The purpose of this activity is to promote student thinking about molecular orientation and attractive forces between molecules. In particular, it

- reinforces the difference between intermolecular and intramolecular forces
- emphasizes that intermolecular forces exist BETWEEN one molecule and another (or one region of a large molecule and another region)
- allows the teacher to quickly assess student understanding and correct any misunderstandings
- forces students to pay attention to how molecules and ions interact (and orientate with respect to one another)

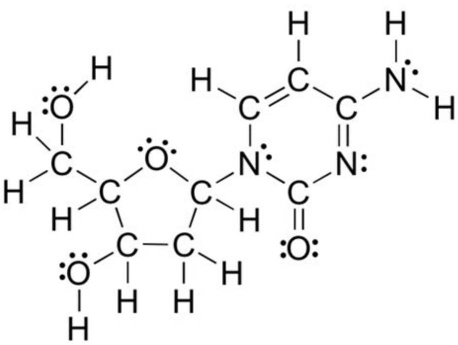
Materials per student

- One piece of paper for mini poster (copy paper, construction paper, colored copy paper)
- One set of Lewis structures
- Scissors
- Glue

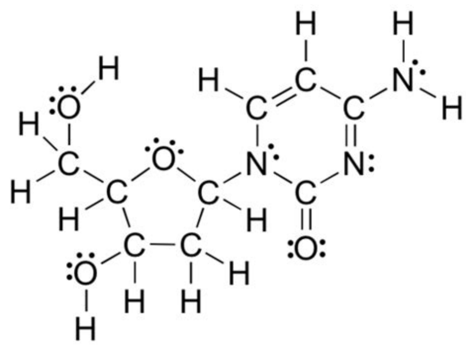
Instructions to Students

Cut and paste examples of the following types of intermolecular forces/attractive forces. Use dotted lines to show the attractive force.

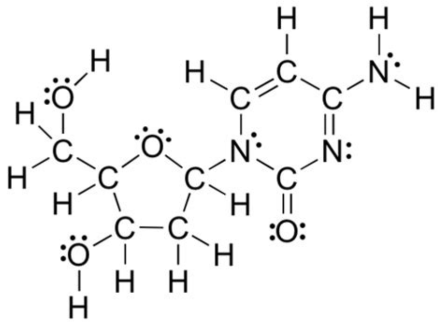
- LDF
- Dipole-dipole
- Hydrogen bonding
- Ion-dipole
- Dipole-induced dipole



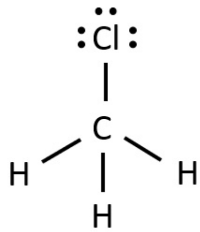
2'-deoxycytidine

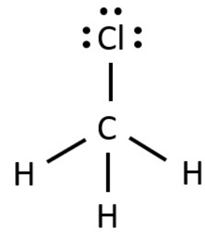


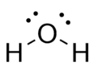
2'-deoxycytidine

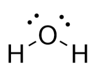


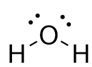
2'-deoxycytidine

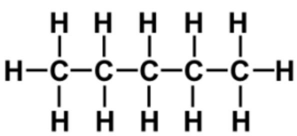


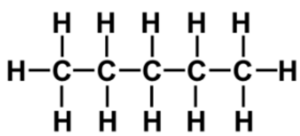


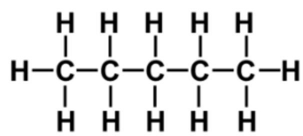


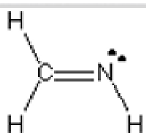




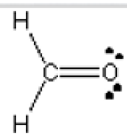








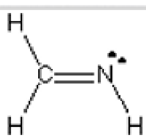
formaldimine



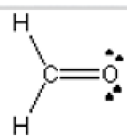
formaldehyde

Na^+

Cl^-



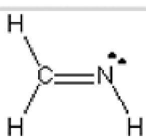
formaldimine



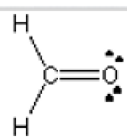
formaldehyde

Na^+

Cl^-



formaldimine



formaldehyde

Na^+

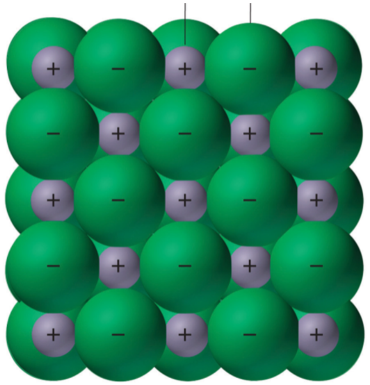
Cl^-

Intermolecular Forces and Properties of Matter

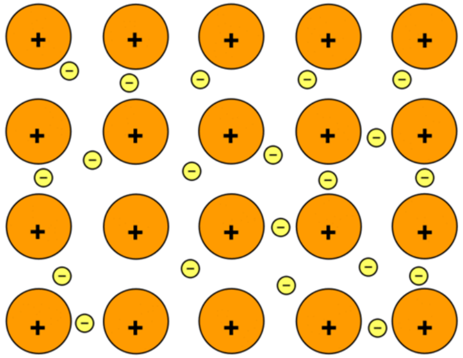
Get ready to predict and explain!

Four Types of Solids

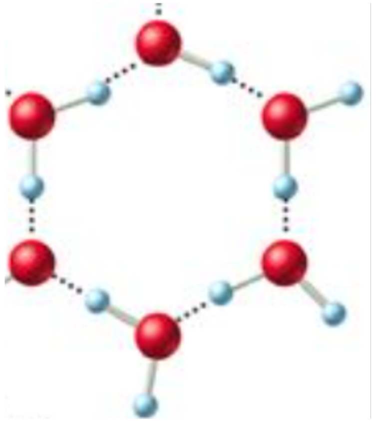
IONIC



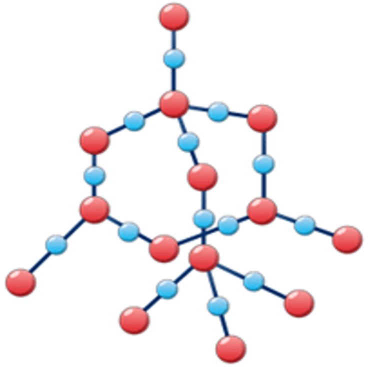
METALLIC



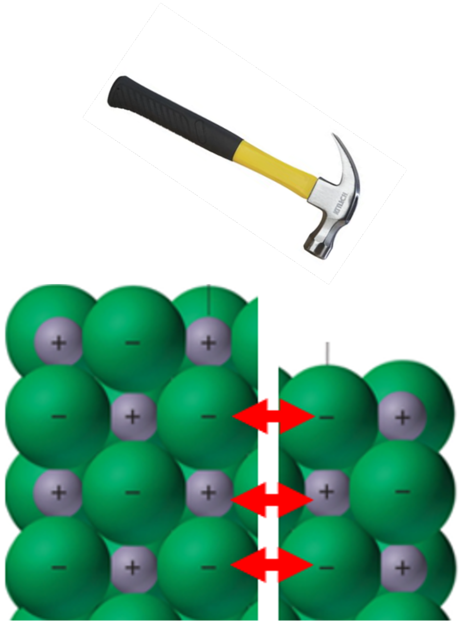
COVALENT (MOLECULAR)

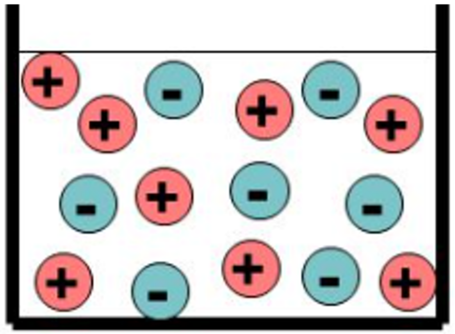


NETWORK COVALENT

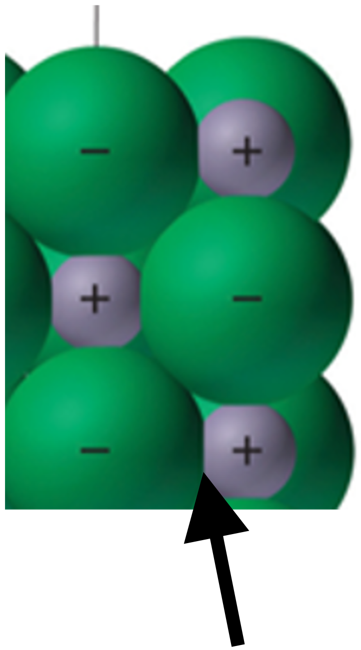


Properties of Ionic Solids





Coulombic (ion-ion) Attractions
Relatively High MP, BP
Brittle
Conduct electricity ONLY when molten or aqueous

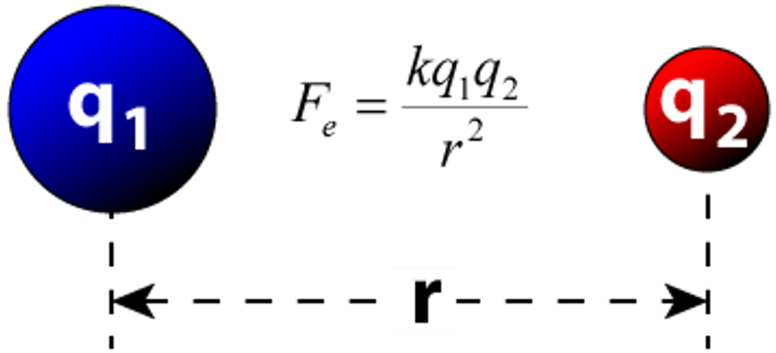


strong Coulombic attraction

Explain

Substance	Melting Point, °C
NaF	995
KF	856
MgF_2	2260
MgO	2852
BaO	1918

DO THIS:
Use Coulomb's Law



Step 1: Start with the data - it tells you the answer

Step 2: Determine the "why"

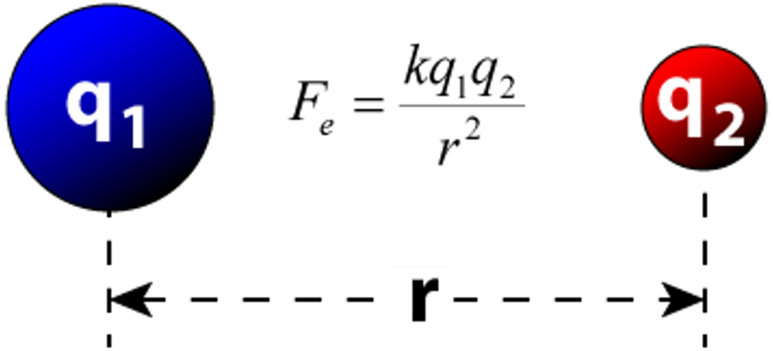
1st check the ion charges (if different, use this)

The larger the charge on the ion, the greater the force of attraction

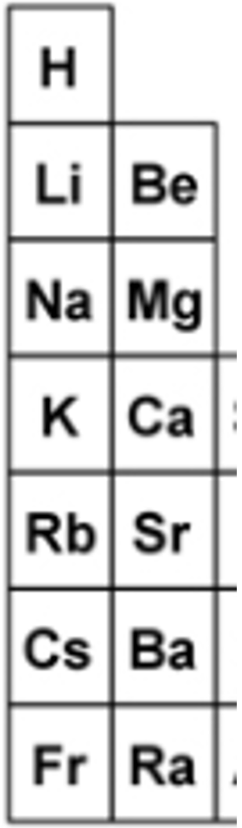
2nd check ion size

The larger the ion size, the SMALLER the force of attraction

Step 3: End with energy…*therefore it takes more energy to overcome the ion-ion force of attraction.*



$$F_e = \frac{kq_1q_2}{r^2}$$



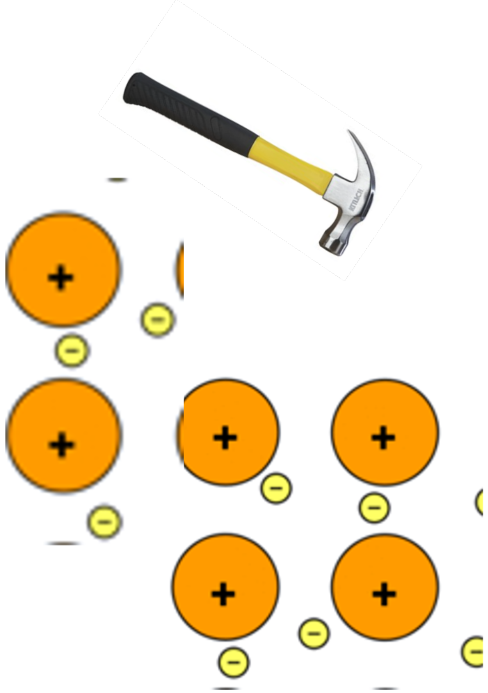
Substance	Melting Point, ◦C
NaF	995
KF	856
MgF_2	2260
MgO	2852
BaO	1918

Question 1

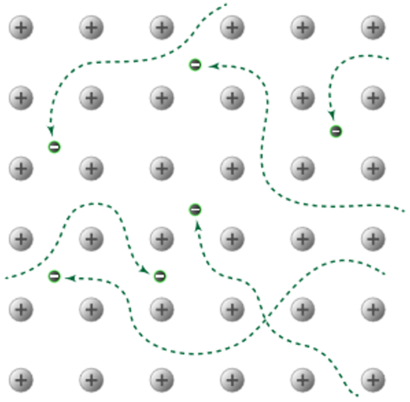
Explain the difference in melting points between:

- NaF and KF
- MgO and NaF

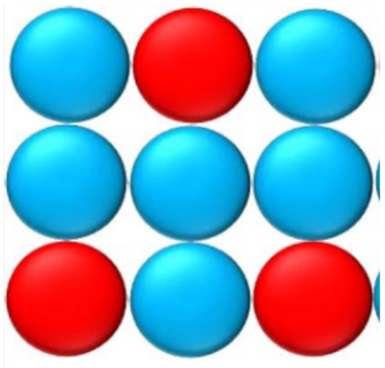
Metallic Solids



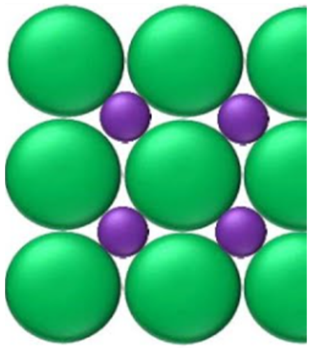
Metal cations in a sea of delocalized electrons
Relatively high MP, BP
Malleable
Conducts electricity even as solid
Alloys: substitutional and interstitial

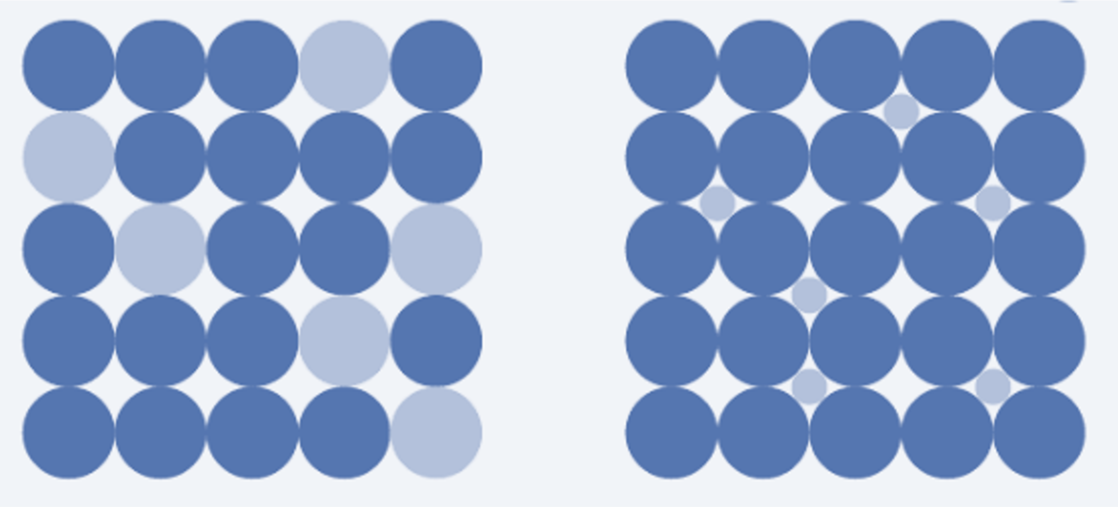


Substitutional



Interstitial





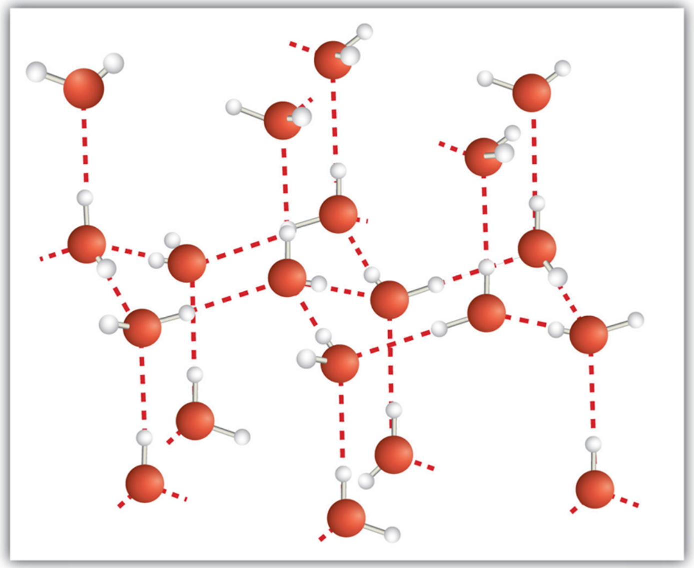
Element	Atomic radius, pm
Copper	145
Zinc	142

Question 2

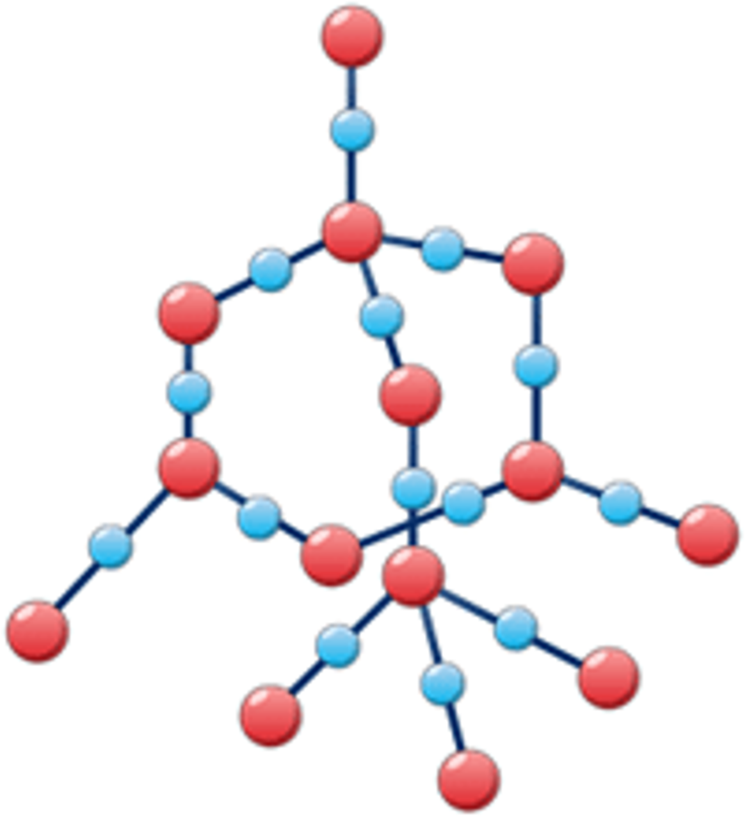
Brass is an alloy of the elements copper and zinc. The atomic radii of copper and zinc are given in the table above. Which diagram is a better representation of brass?

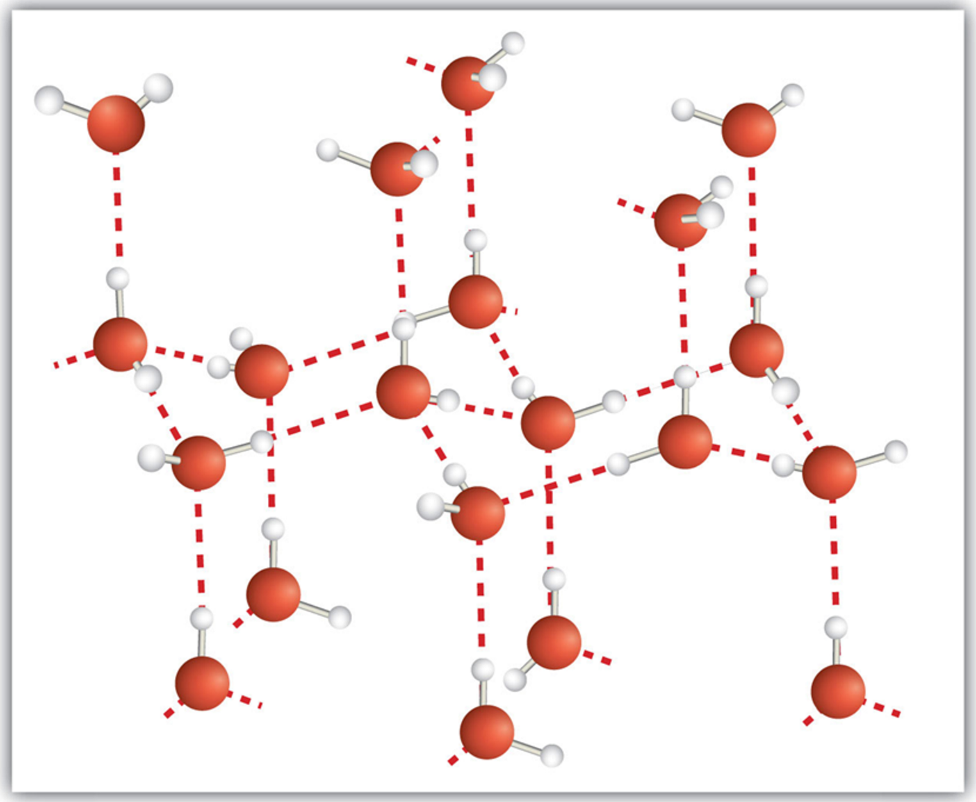
Molecular (aka Covalent) Solids

Discrete, individual molecules held together by IMFs
Relatively low MP, BP
Do not conduct electricity
IMFs: LDF, Dipole-Dipole, Hydrogen Bonding

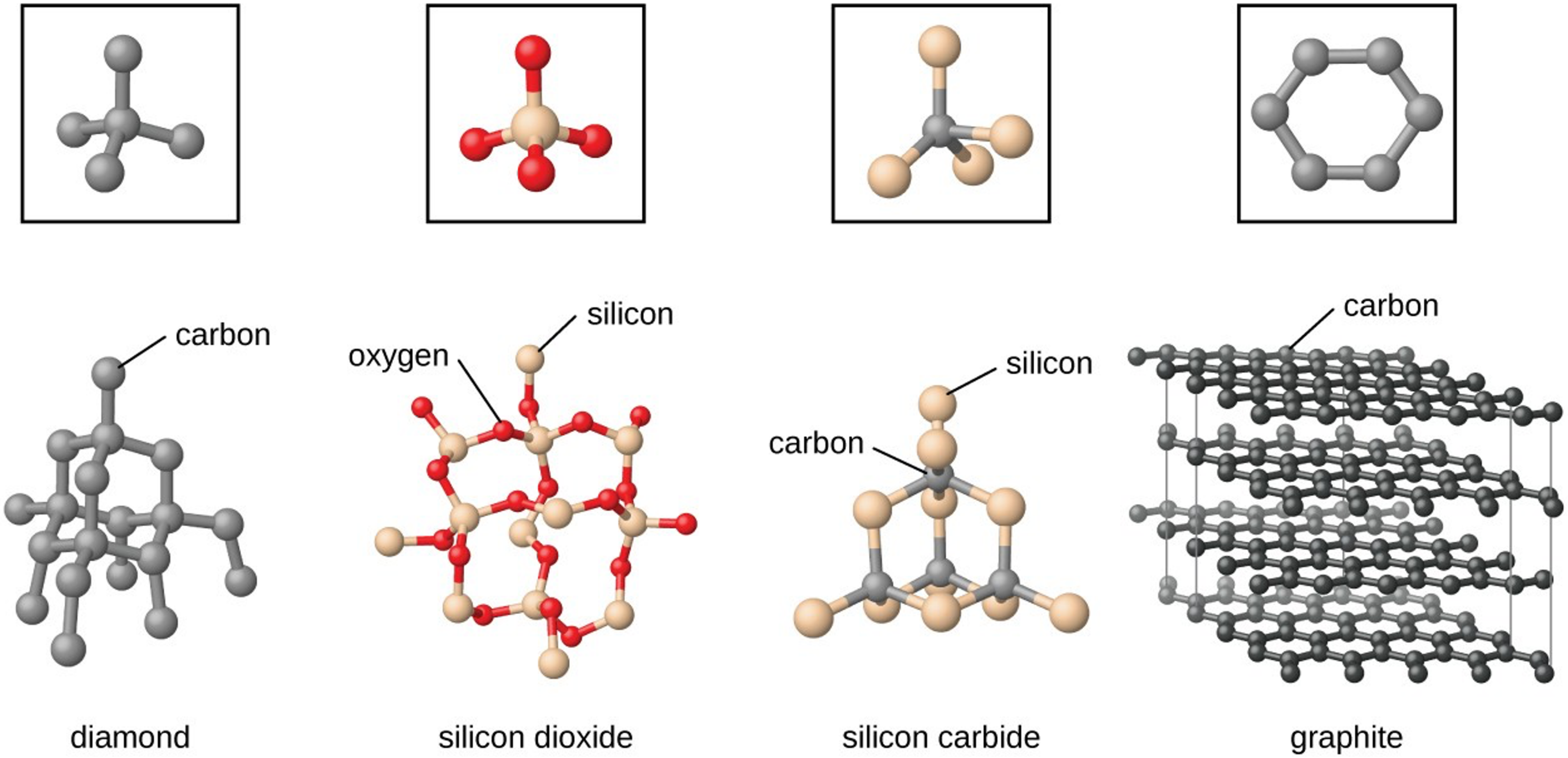


What is different here?



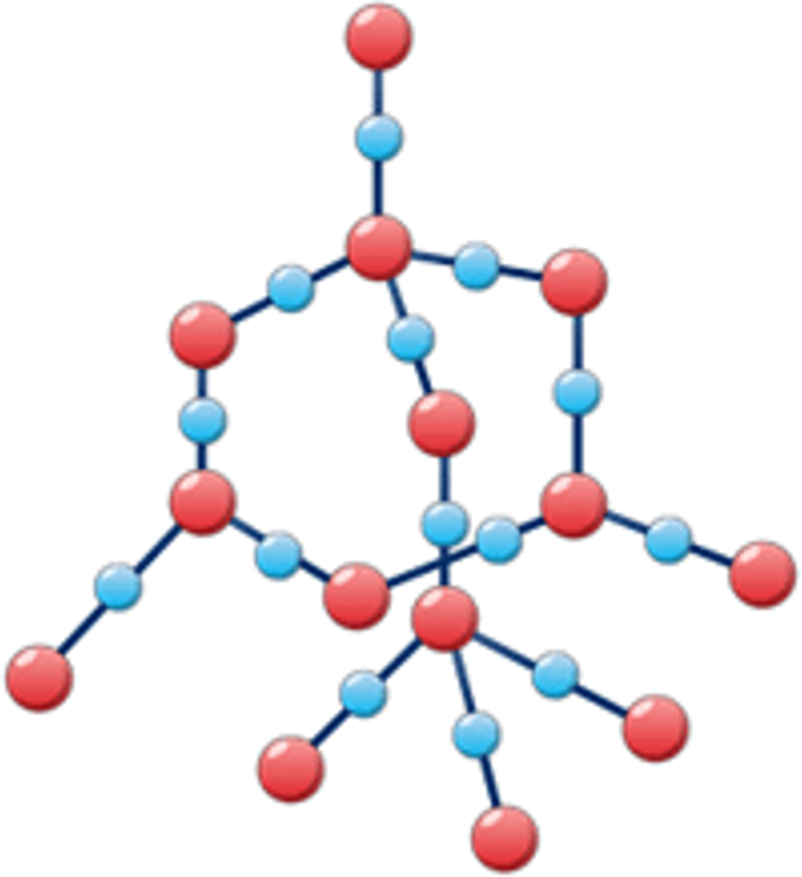


Network covalent solids



Network covalent solids

Massive network of covalent bonds
HIGH MP, BP
Watch for carbon and silicon compounds as an additional clue



Question 3

A student is given the task of identifying four crystalline solids which exhibited the properties shown in the table. He tests each substance to determine its melting point, as well as its conductivity. Correctly place each substance with the appropriate experimental results.

NaCl $C_{12}H_{22}O_{11}$

SiO_2 Fe

Substance	Properties
	MP: 801°C Does not conduct electricity as a solid. Conducts electricity when molten.
	Melting point: 1538°C. Conducts electricity as a solid and when molten.
	MP: 1710°C Does not conduct electricity
	MP: 186°C Does not conduct electricity

Molecular Solids and IMFs

- Boiling Point
- Melting Point
- Vapor Pressure
- Solubility

Use the three step method to compare:

Step 1 — identify the attractive forces/IMFs in BOTH compounds

Step 2 — state which is stronger - USE THE DATA

Step 3 — answer the specific question

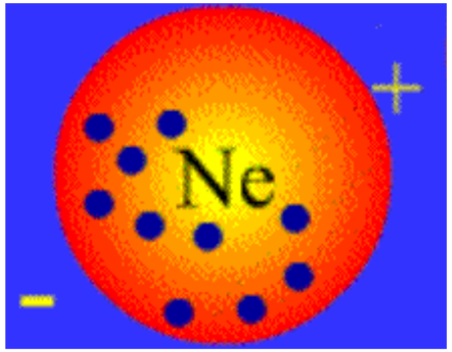
(...therefore it takes more energy to overcome the attractive force in ___________)

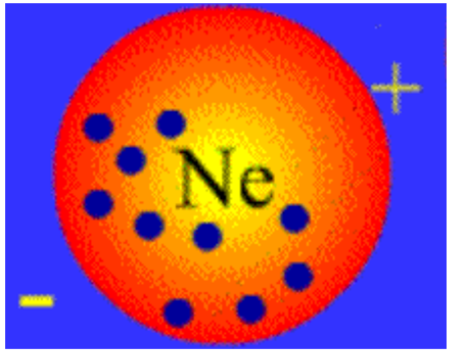
London Dispersion Force (LDF)

a temporary attractive force that is caused by momentary (short lived) electron displacement

All substances have LDFs. LDFs are the only attractive force for nonpolar compounds.

The larger the electron cloud, the more polarizable it is and the stronger the LDF



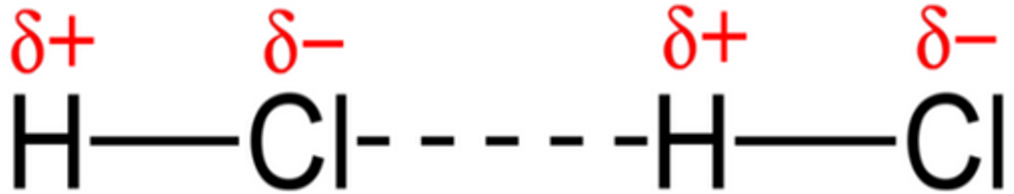


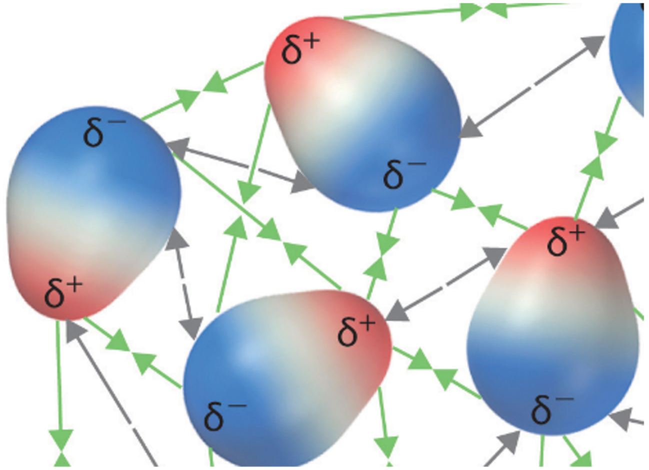
Argon

Dipole – Dipole

A force of attraction between two polar molecules.

The δ+ end (dipole) of one molecule is attracted to the δ– end (dipole) of the other.





Hydrogen Bonding

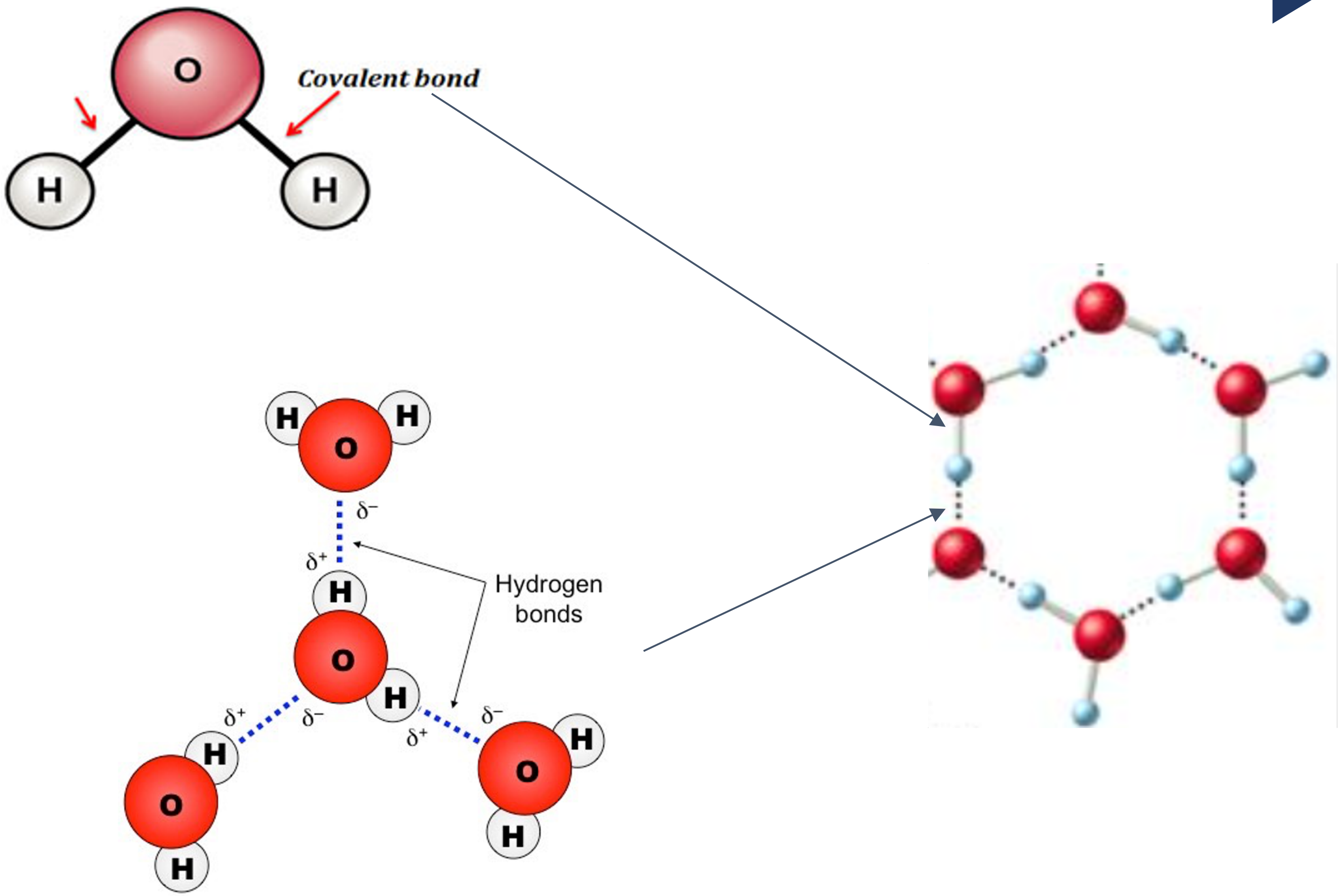
An especially strong dipole – dipole attractive force between:

H – O and H – O

H – N and H – N

H – F and H – F

(or other combinations of these three)



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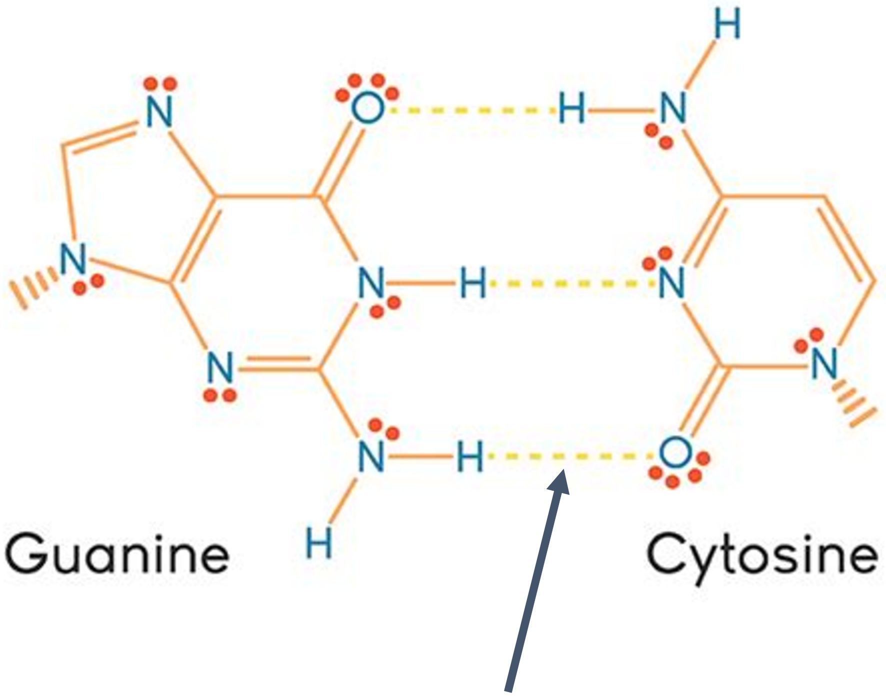
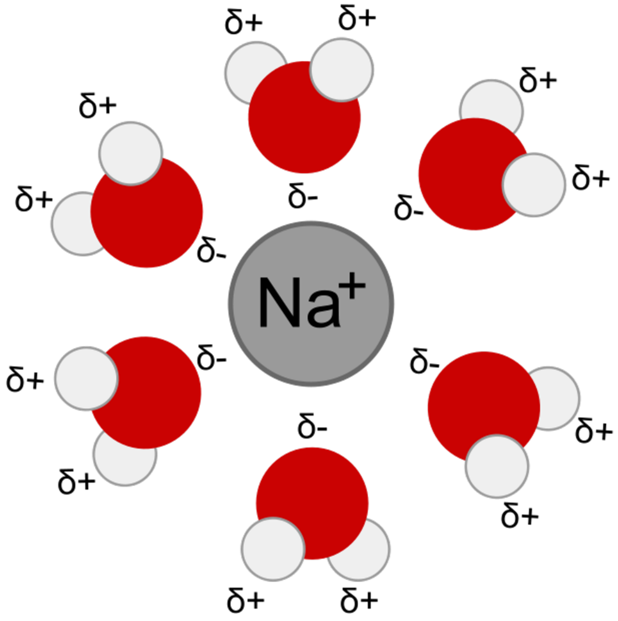


Ion – Dipole

A force of attraction between an ion and a polar molecule

This is what allows ionic substances to dissolve in water



Use the three step method to compare:

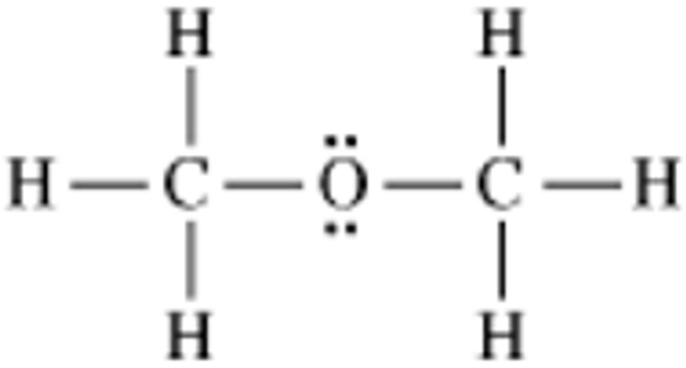
Step 1 identify the attractive forces/IMFs in BOTH compounds

Step 2 state which is stronger - USE THE DATA

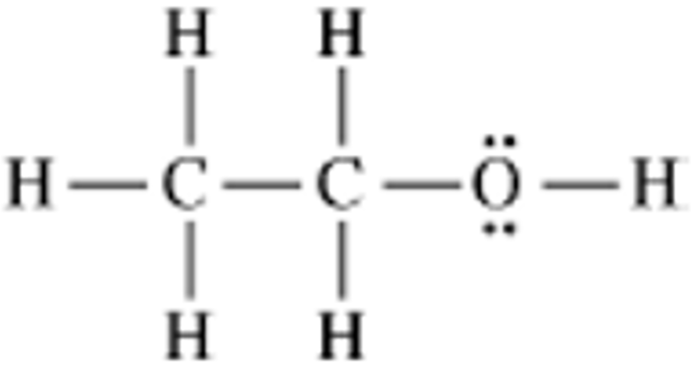
Step 3 answer the specific question

(*…therefore it takes more energy to overcome the attractive force in ___________*)

Dimethyl ether boils at 250K.
Ethanol boils at 351K.
Explain.

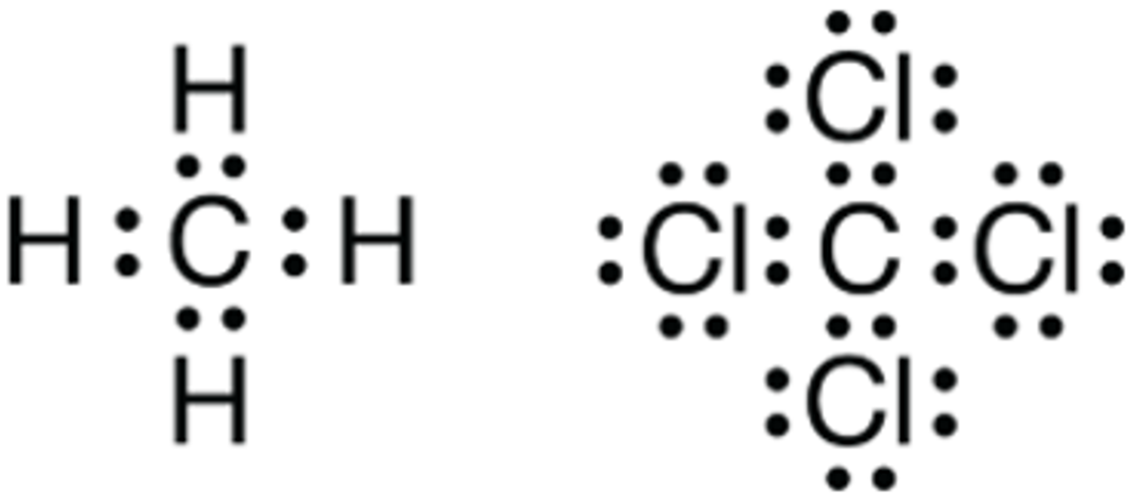


Dimethyl Ether



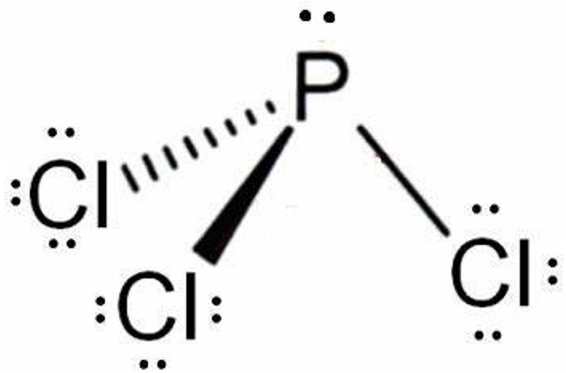
Ethanol

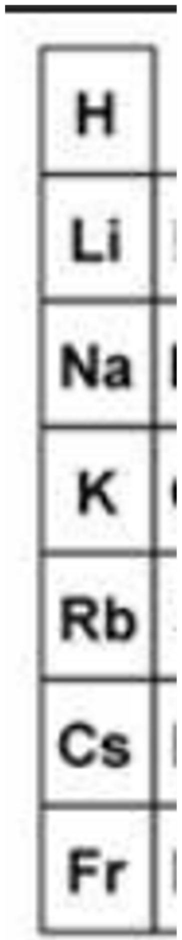
Which compound would have the higher melting point? Explain.



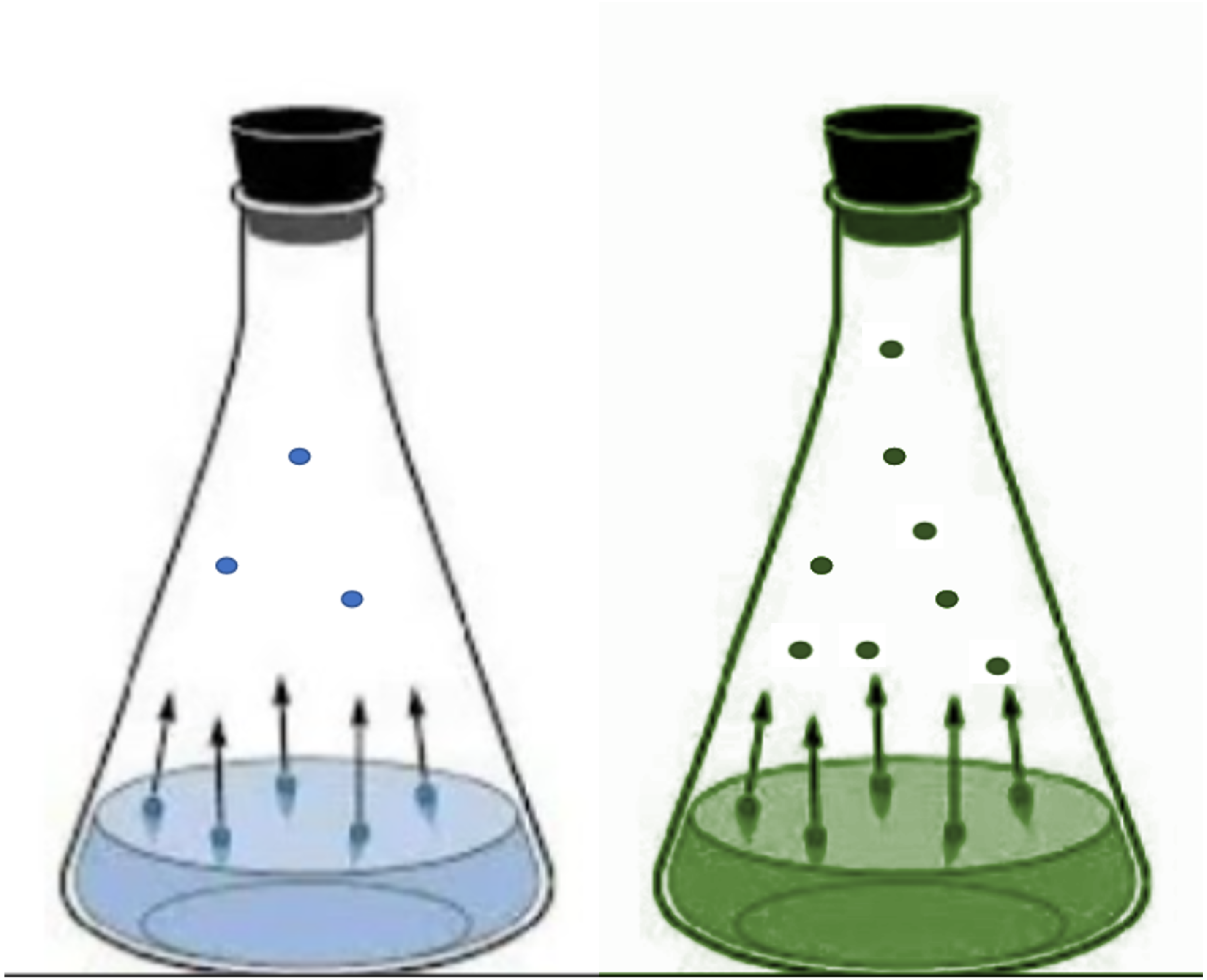
Explain these melting points:

Substance	Melting Point
PCl_3	– 93.9°C
KCl	776°C
NaCl	801°C





Explain the difference between the melting point of SO_2 (201 K) and SiO_2 (1883 K).

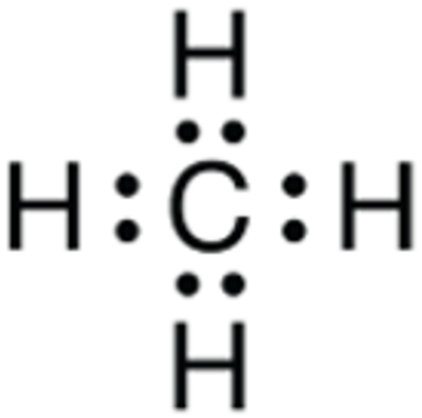


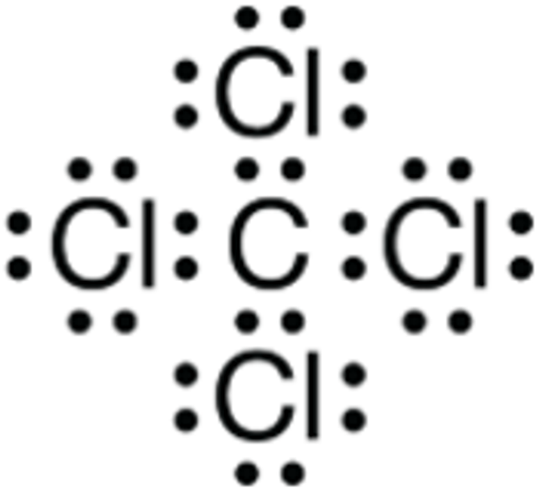
Vapor Pressure – be careful!

Rank these two images in terms of:

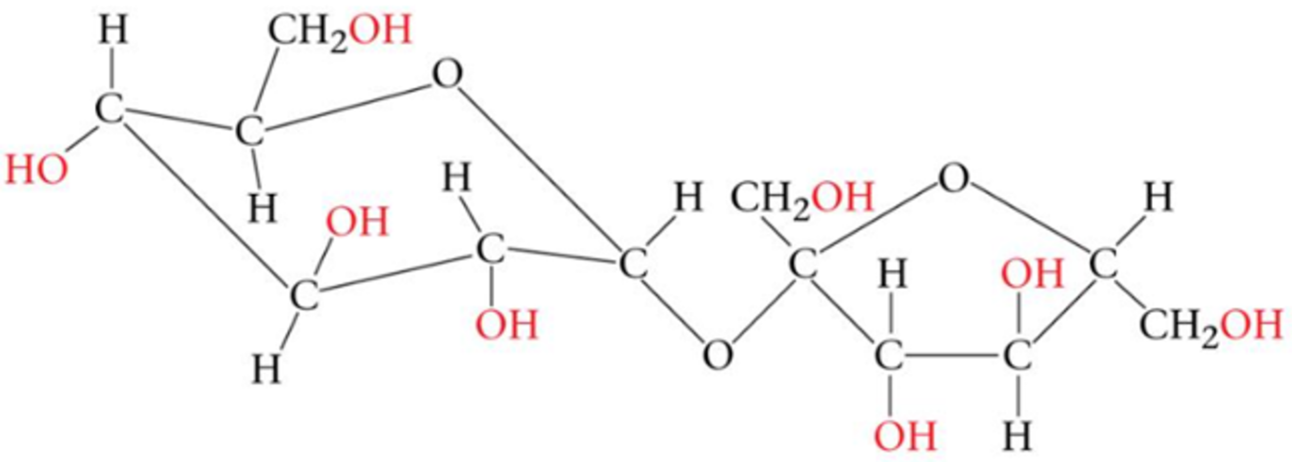
- Vapor pressure
- IMF
- Boiling point
- Melting point

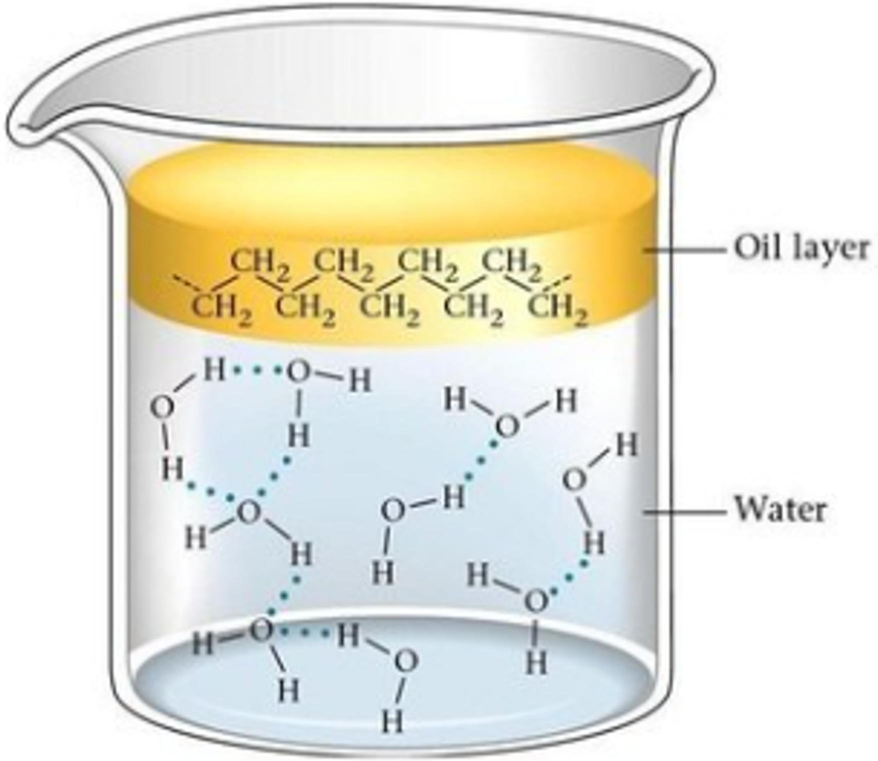
Which compound would have the higher vapor pressure? Explain.



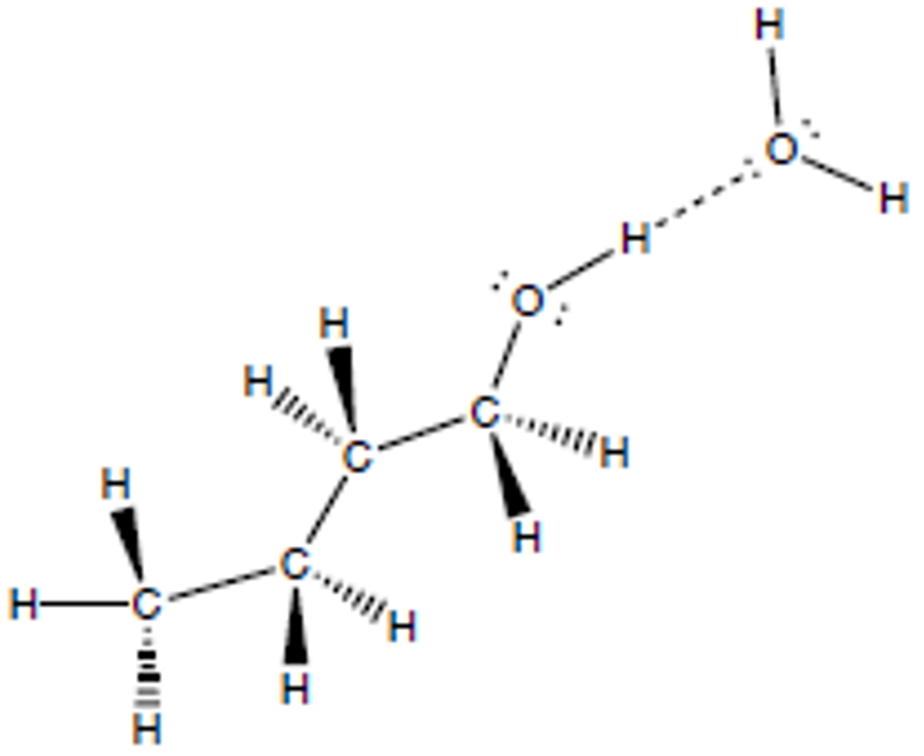


Why is sugar soluble in water, but oil is not?





Where else can another water molecule hydrogen bond?



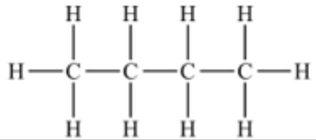
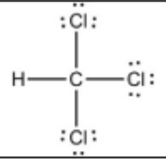
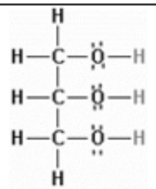
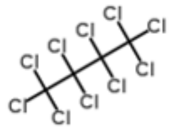
Question 4

Consider the carbon-based compounds shown here.

- In the space provided in the table, list **all** types of intermolecular forces present in each compound.

- Explain the trend in boiling points between each of the following. Be sure to discuss each compound in your response.

    - Butane and chloroform
    - Chloroform and glycerol
    - Glycerol and decachlorobutane

Compound	Structure	Boiling Point	IMF
Butane		0°C	
Chloroform		61°C	
Glycerol		290°C	
Decachlorobutane		367°C	

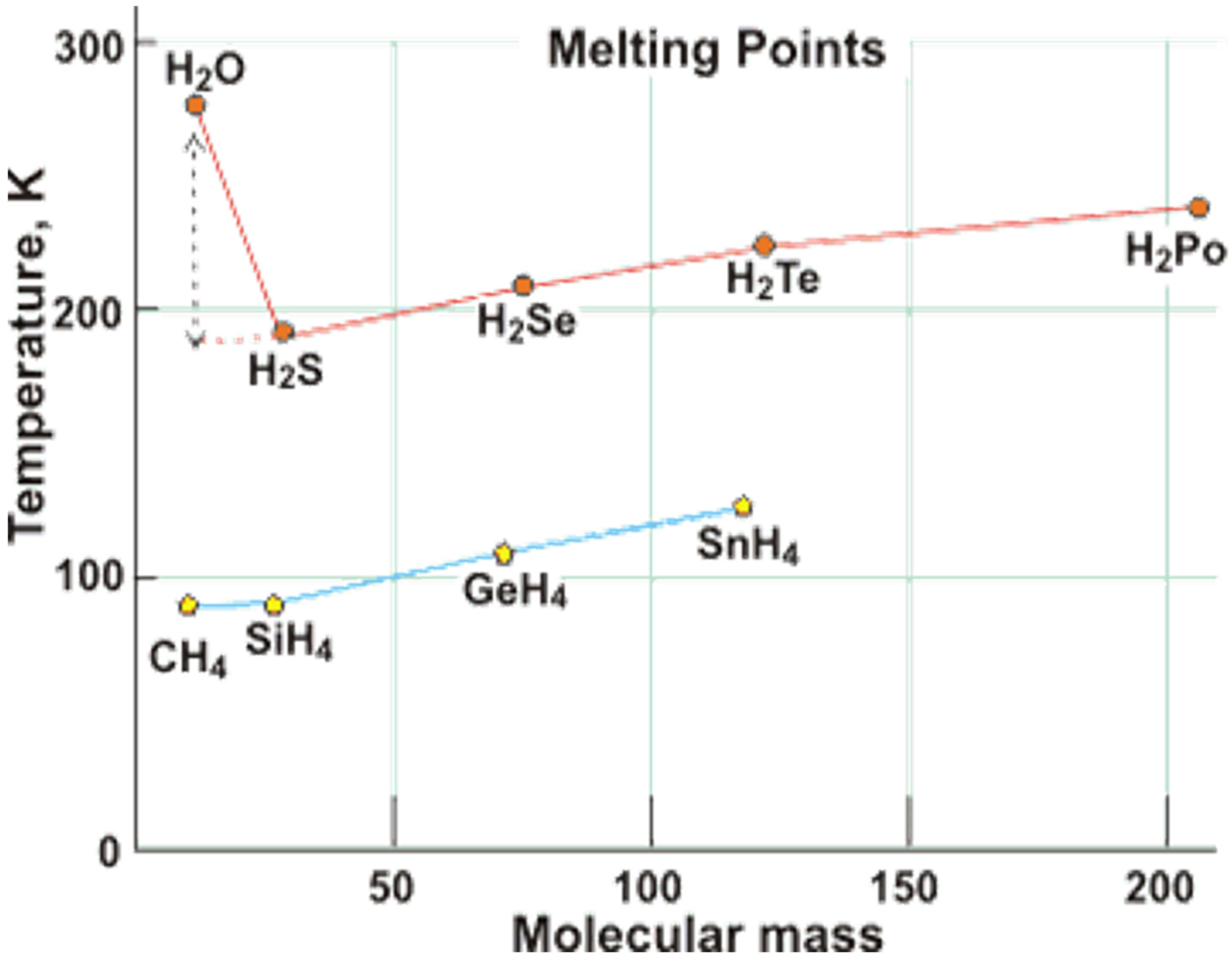
Explain

Formula	Name	Molar Mass	Boiling Point (°C)
CH_4	methane	16	–164
HOH	water	18	100
C_2H_6	ethane	30	–89
CH_3OH	methanol	32	65
C_3H_8	propane	44	–42
CH_3CH_2OH	ethanol	46	78
C_4H_{10}	butane	58	–1
$CH_3CH_2CH_2OH$	1-propanol	60	97

Explain

	Helium	Neon	Argon
Boiling Point	4.4 K	27.3 K	87.4 K
Melting Point	0.95 K	24.7 K	83.6 K
Enthalpy of Vaporization	0.08 kJ/mol	1.74 kJ/mol	5.62 kJ/mol

Explain

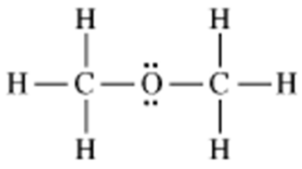


Melting Points
Temperature, K
300
200
100
0
50
100
150
200
Molecular mass
H2O
H2S
H2Se
H2Te
H2Po
CH4
SiH4
GeH4
SnH4

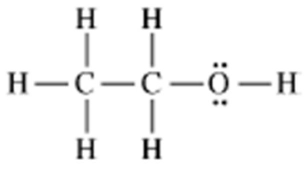
Ideas for warmup/quick quiz

This can be done daily during unit, or once a week after unit is complete to reinforce concepts and save review time at the end of the year.

Show something like this:



Dimethyl Ether



Ethanol

Then ask questions such as:

- What is the bond angle around carbon 1? (This will force students to think about the number of electron domains to arrive at the correct answer of 109.5°, instead of 90°, as represented on the structural diagram.
- What is the shape around the oxygen?
- What is the hybridization around the oxygen?
- Dimethyl ether boils at 250K.
  Ethanol boils at 351K.
  Explain.