The Particulate Nature of Matter Assessment (ParNoMA) Version 1

We constructed an early version of the Particulate Nature of Matter Assessment (ParNoMA) using Treagust's steps for developing and using diagnostic tests to evaluate students' misconceptions (*1*) including the following topics.

Size of particles	Composition of particles
Weight of particles	Energy of particles
Phases and phase change	

The literature and interview responses from an unpublished pilot study conducted by Yezierski in 2000 provided distractors. This early version of the ParNoMA consists of 12 multiple-choice items constructed such that the correct answer described the currently accepted scientific conception and each distractor was a documented misconception. The items are based solely on published misconceptions (*2*-*5*). Four of the items are based on the work of Cosgrove and Osborne (*2*) and relate to the composition of bubbles in boiling water and particulate descriptions of evaporation and condensation. The item about gas molecules under different pressures relates to the findings of Benson, Whittrock, and Baur (*3*) and incorporates a misconception about pressure changing the size of molecules. The items relating to energy, shape, arrangement, structure, and weight of atoms/molecules and phases are based on the findings summarized by Griffiths and Preston (*4*) and Garnett, Garnett, and Hackling (*5*).

The questions that include particulate drawings differ from examples in the literature in that scales are not mixed. That is to say, pictures of atoms and molecules are shown in call outs from macroscopic views of containers. The call outs show groups of atoms and molecules drawn inside circles representing particulate views, rather than directly into containers such as beakers or flasks. Lines serving as arrows connect the circles to a point inside the container to indicate that the circle represents an enlarged view of a tiny portion of the container's contents.

Version 1 of the ParNoMA was reviewed by three college chemistry instructors and deemed valid based on their 100% agreement upon the correct answers. We piloted the new instrument in a summer 2002 first semester general chemistry class ($N = 72$, Cronbach $\alpha = 0.78$). We conducted the pilot with college students, since it was likely that they would have the fewest PNM misconceptions of all the grade levels planned for the study. We expected that college students would score the highest and likely reveal a ceiling effect if one was inherent in the test. Since the mean of the ParNoMA was 5.78 out a possible score of 12 (48.2%), the instrument did not have a ceiling effect in the pilot sample.

Literature Cited

1. Treagust, D. *International J. Sci. Educ.* **1988,** 10, 159-169.
2. Osborne, R.; Cosgrove, M. *J. Res. in Sci. Teaching* **1993,** *20,* 313-319.
3. Benson, D.; Whittrock, M.; Baur, M. *J. Res. in Sci. Teaching* **1993,** 29, 687-699.
4. Griffiths, A.; Preston, K. *J. Res. in Sci. Teaching* **1992,** 29, 611-628.
5. Garnett, P.; Garnett, P.; Hackling, M. *Studies in Sci. Educ.* **1995,** 25, 69-95.

Particulate Nature of Matter Assessment (ParNoMA)

Version 1

May 2002

Instructions:
Carefully read each question. Choose the best answer for each one and bubble in your response. Be sure to make erasures complete. Please do not make any marks on this test.

1. Which determines the speed of a molecule?
   A. its size
   B. its energy
   C. the amount of space it has to move in
   D. all of the above
   E. none of the above

2. A water molecule in the gas phase is _____ a water molecule in the solid phase.
   A. smaller than
   B. lighter than
   C. heavier than
   D. larger than
   E. the same weight as

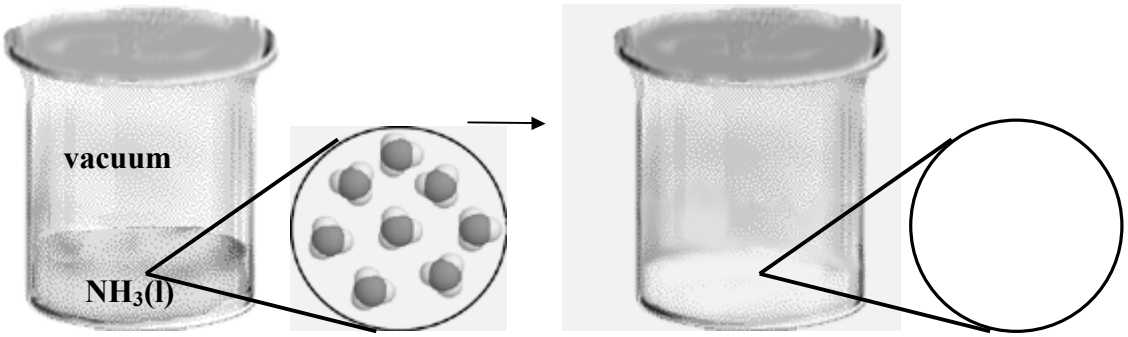
3. What affects the shape of a water molecule?
   A. nothing
   B. pressure
   C. temperature
   D. the phase it's in
   E. the shape of its container

4. A pot of water is placed on a hot stove. Small bubbles begin to appear at the bottom of the pot. The bubbles rise to the surface of the water and seem to pop or disappear. What are the bubbles made of?
   A. heat
   B. oxygen or hydrogen
   C. air
   D. oxygen and hydrogen
   E. steam

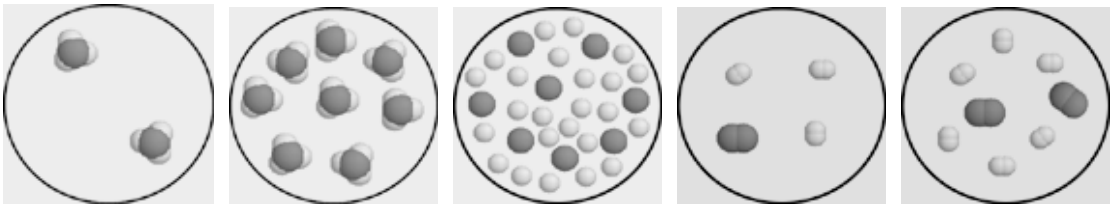
5. The same pot of water described above in #4 begins to boil rapidly. A glass lid is placed on the pot and water droplets begin forming on the inside of the lid. What happened?
   A. The lid became sweaty.
   B. Hydrogen and oxygen combined to form water.
   C. Water from outside leaked into the pot.
   D. Steam cools and water molecules moved closer together.
   E. Steam combined with the air to wet the inside of the lid.

6. A wet dinner plate is left on the counter after it has been washed. After awhile it is dry. What happened to the water that didn't drip onto the counter?
   A. It goes into the air as very small bits of water.
   B. It just dries up and no longer exists as anything.
   C. It changes to carbon dioxide.
   D. It goes into the plate.
   E. It changes to oxygen and hydrogen in the air.

7. A sample of liquid ammonia (NH_3) is completely evaporated (changed to a gas) in a closed container as shown:



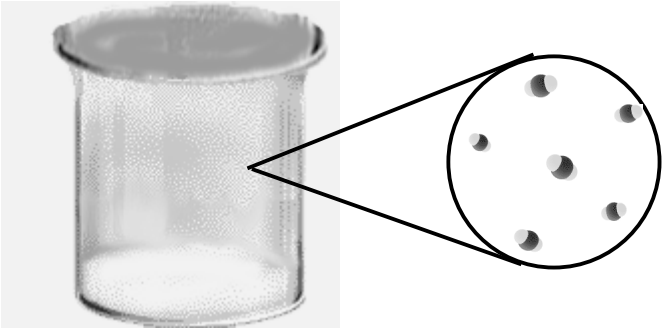
Which of the following diagrams best represents what you would "see" in the same area of the magnified view of the vapor?



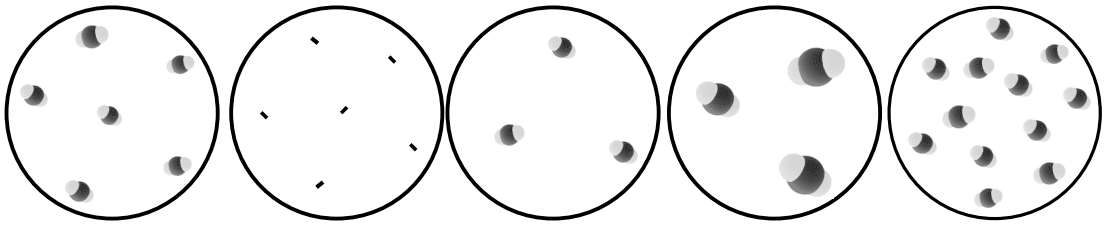
A. B. C. D. E.

8. In a pure sample of oxygen gas, what exists between the oxygen molecules?
   A. matter
   B. air
   C. water vapor
   D. nothing
   E. atmosphere

9. A magnified view of a sample of carbon dioxide (CO2) gas at a pressure of 1.0 atm is shown below.



Which of the following diagrams best describes what you would "see" in the same area at a reduced pressure of 0.5 atm?



A. B. C. D. E.

10. What is the approximate number of water (H_2O) molecules found in a single drop of water?

   A. 20 (2×10^1)
   B. 2000 (2×10^3)
   C. 2,000,000 (2×10^6 or 2 million)
   D. 200,000,000,000 (2×10^{11} or 200 billion)
   E. 2,000,000,000,000,000,000,000 (2×10^{21})

11. Which of the following statements is incorrect?
    A. Water molecules move at the same speed in the solid, liquid, and gaseous phases.
    B. Water molecules move the fastest when they are in the gaseous phase.
    C. Water molecules in the solid phase vibrate.
    D. Water molecules in the liquid phase move faster than molecules in the solid phase.
    E. Water molecules in solid phase are in the form of ice.

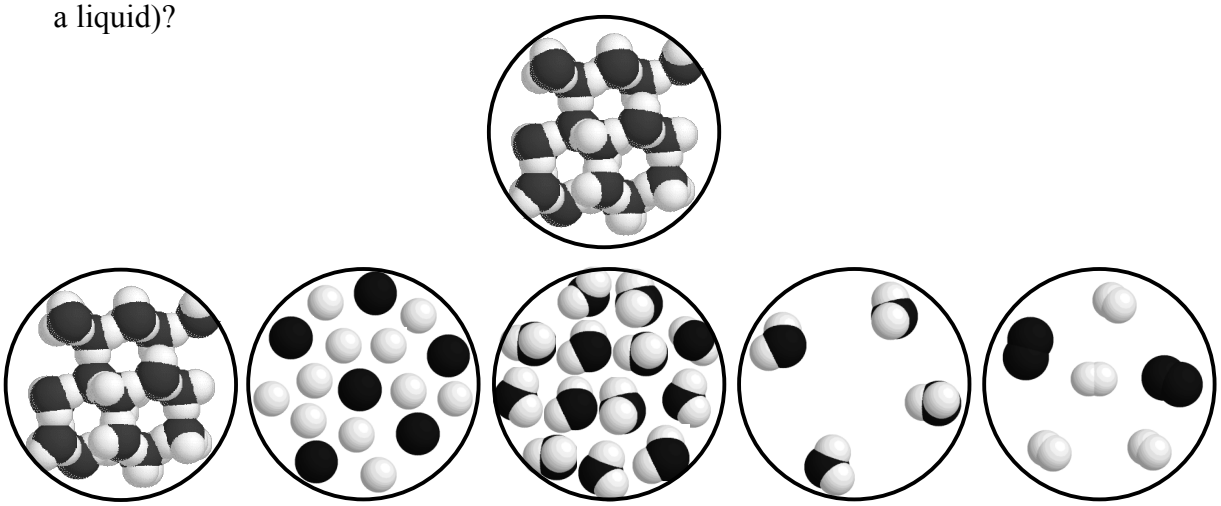
12. Which of the following statements is correct?
    A. Heat causes molecules to expand.
    B. Molecular size depends on temperature.
    C. Gases have mass and volume.
    D. When a liquid changes to a gas, there is a decrease in mass.
    E. Bonds within molecules are broken during melting.

Particulate Nature of Matter Assessment (ParNoMA)
Version 2

Instructions:
Carefully read each question and choose the best answer.

1. A diagram representing water molecules in the solid phase (ice) is shown below.

   Which of these diagrams best shows what water would look like after it melts (changes to a liquid)?

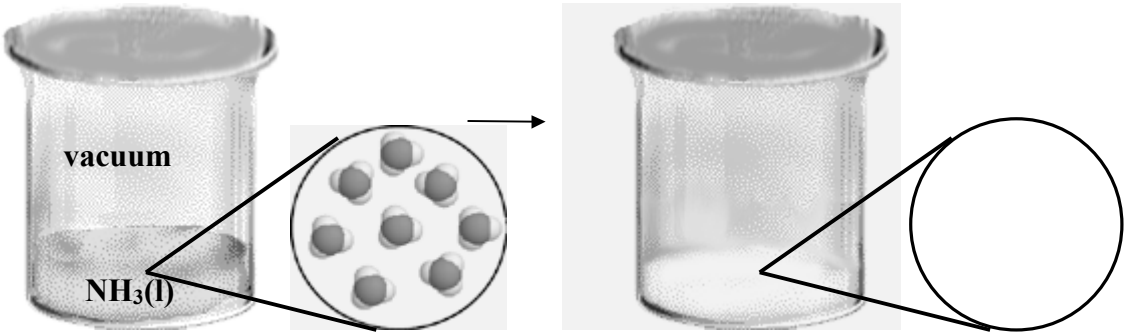


A. B. C. D. E.

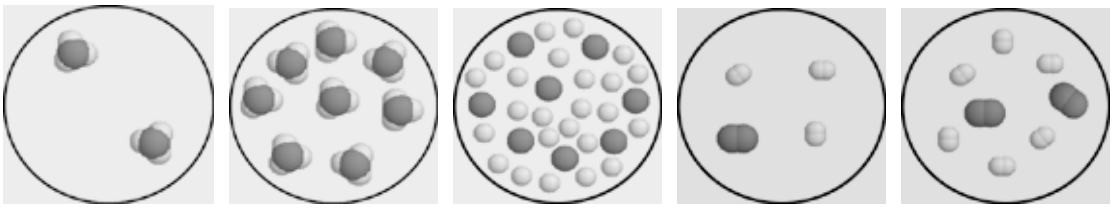
2. Consider three samples of water in three phases. The first is solid water (ice) at 0 C, the second is liquid water at 24 C, and the third is gaseous water at 100 C. The water molecules in the liquid phase _____ the water molecules in the gaseous phase.
   A. move faster than
   B. move slower than
   C. move at the same speed as
   D. move more randomly than
   E. travel in the same direction as

3. Which of the following processes will make water molecules larger?
   A. freezing
   B. melting
   C. evaporation
   D. condensation
   E. none of the above

4. A sample of liquid ammonia (NH_3) is completely evaporated (changed to a gas) in a closed container as shown:



Which of the following diagrams best represents what you would "see" in the same area of the magnified view of the vapor?



A. B. C. D. E.

5. When water changes from a liquid to a gas through evaporation or vaporization, energy is required to
   A. break the bonds between the hydrogen atoms.
   B. form new bonds between the atoms.
   C. break the bonds between the oxygen and hydrogen atoms in the molecules.
   D. break the water molecules away from other water molecules.
   E. form new bonds between the molecules.

6. A water molecule in the gas phase is _____ a water molecule in the solid phase.
   A. smaller than
   B. lighter than
   C. heavier than
   D. larger than
   E. the same weight as

7. When water is vaporized, it is changed to
   A. hydrogen and oxygen
   B. hydrogen only
   C. gaseous water
   D. air, hydrogen, and oxygen
   E. oxygen only

8. A pot of water is placed on a hot stove. Small bubbles begin to appear at the bottom of the pot. The bubbles rise to the surface of the water and seem to pop or disappear. What are the bubbles made of?
   A. heat
   B. air
   C. gaseous oxygen and hydrogen
   D. gaseous water
   E. none of the above

9. A pot of water on a hot stove begins to boil rapidly. A glass lid is placed on the pot and water droplets begin forming on the inside of the lid. What happened?
   A. The lid became sweaty.
   B. Steam cools and water molecules moved closer together.
   C. Water from outside leaked into the pot.
   D. Hydrogen and oxygen combined to form water.
   E. Steam combined with the air to wet the inside of the lid.

10. Consider three samples of water in three phases. The first is solid water (ice) at 0 C, the second is liquid water at 24 C, and the third is gaseous water at 100 C. The water molecules in the <u>liquid</u> phase _____ the water molecules in the <u>solid</u> phase.
   A. move faster than
   B. move slower than
   C. move at the same speed as
   D. move less randomly than
   E. travel in the same direction as

11. A wet dinner plate is left on the counter after it has been washed. After awhile it is dry. What happened to the water that didn't drip onto the counter?
   A. It changes to carbon dioxide.
   B. It just dries up and no longer exists as anything.
   C. It goes into the air as molecules of water.
   D. It goes into the plate.
   E. It changes to oxygen and hydrogen in the air.

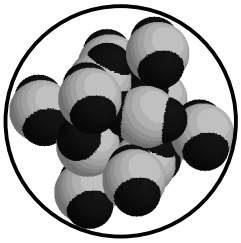
12. Which of the following processes does **<u>NOT</u>** require heat energy?
   A. evaporating water
   B. melting ice
   C. boiling water
   D. vaporizing water
   E. condensing water

13. When water molecules in the gas phase are heated, the molecules themselves
    A. expand.
    B. move faster.
    C. become less massive.
    D. change to a liquid.
    E. release air.

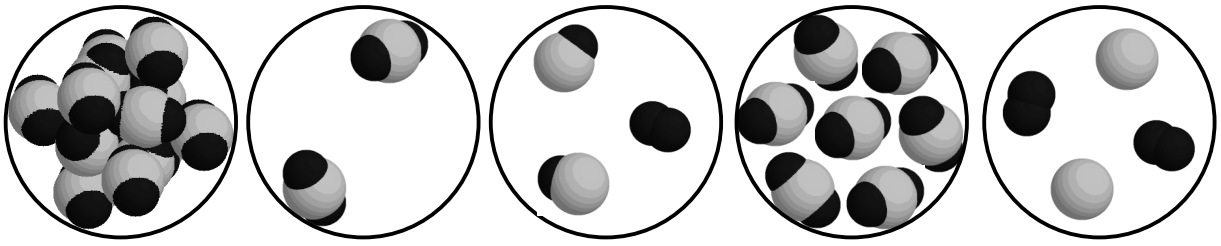
14. Which of the following processes will make molecules smaller?
    A. freezing
    B. melting
    C. evaporation
    D. condensation
    E. none of the above

15. Oxygen and hydrogen gases may be formed from liquid water through the process of
    A. vaporization.
    B. evaporation.
    C. decomposition.
    D. freezing.
    E. boiling.

16. A diagram representing carbon dioxide molecules in the solid phase, also known as dry ice, is shown below.



Which of these molecular diagrams best shows what dry ice would look like after it melts (changes to a liquid)?



A. B. C. D. E.

17. When water at 25ºC is heated and changes to a gas at 110ºC, the water molecules
    A. become more organized.
    B. move farther apart.
    C. stop moving.
    D. move closer together.
    E. move more slowly.

18. Which of the following processes requires heat energy?
    A. condensation
    B. freezing
    C. evaporation
    D. cooling
    E. none of the above

19. A water molecule in the liquid phase is _____ a water molecule in the solid phase.
    A. smaller than
    B. lighter than
    C. heavier than
    D. larger than
    E. the same weight as

20. When water at 24ºC is cooled to 0ºC and freezes, the water molecules
    A. become less organized.
    B. move much faster.
    C. stop moving.
    D. break apart.
    E. move much more slowly.