SCIENCE TEST

35 Minutes—40 Questions

DIRECTIONS: There are several passages in this test. Each passage is followed by several questions. After reading a passage, choose the best answer to each question and fill in the corresponding oval on your answer document. You may refer to the passages as often as necessary.

You are NOT permitted to use a calculator on this test.

Passage I

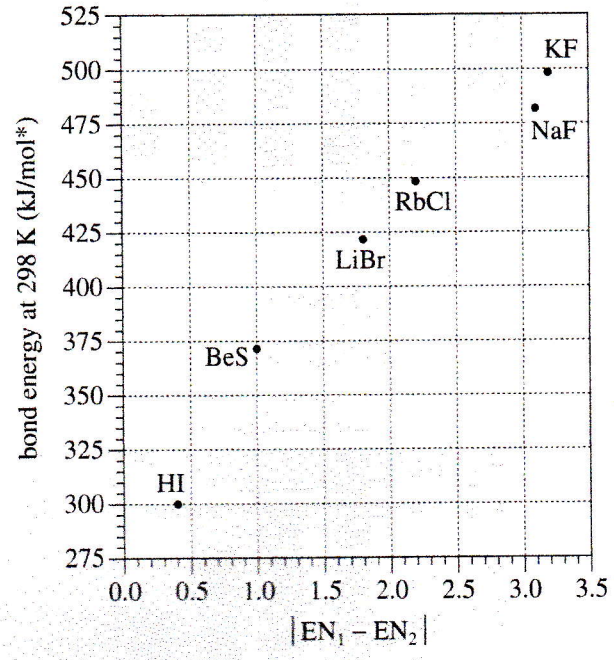
Figure 1 is a simplified periodic table that gives the *atomic number*, symbol, name, and *electronegativity* (EN) of 21 elements. Rows of elements are called *periods*. Columns of elements are called *groups*.

Period	Group						
	1A	2A	3A	4A	5A	6A	7A
1	1 ← atomic number H hydrogen 2.1 ← EN						
2	3 Li lithium 1.0	4 Be beryllium 1.5	5 B boron 2.0	6 C carbon 2.5	7 N nitrogen 3.0	8 O oxygen 3.5	9 F fluorine 4.0
3	11 Na sodium 0.9	12 Mg magnesium 1.2	13 Al aluminum 1.5	14 Si silicon 1.8	15 P phosphorus 2.1	16 S sulfur 2.5	17 Cl chlorine 3.0
4	19 K potassium 0.8	20 Ca calcium 1.0					35 Br bromine 2.8
5	37 Rb rubidium 0.8	38 Sr strontium 1.0					53 I iodine 2.5

Figure 1

Figure 1 adapted from Nivaldo J. Tro, *Chemistry: A Molecular Approach*, 2nd ed. ©2011 by Pearson Education, Inc.

The greater the EN of an element, the more strongly an atom of that element attracts electrons to itself in a chemical bond. The greater the absolute value of the difference between the ENs of 2 elements, $|EN_1 - EN_2|$, the more polar is the bond between atoms of the elements. Figure 2 gives, for each of 6 compounds, $|EN_1 - EN_2|$ and the *bond energy at 298 K* (the energy needed to break all the bonds in 1 mole of a compound at 298 K).



*kilojoules per mole;
1 mole = 6×10^{23} molecules or formula units

Figure 2

Figure 2 adapted from James G. Speight, *Lange's Handbook of Chemistry*, 16th ed. ©2005 by McGraw-Hill, Inc.

1. According to Figure 1, the element in Period 2 that is also a member of Group 3A has an EN of:

   A. 1.2.
   B. 2.0.
   C. 2.5.
   D. 3.0.

2. According to Figure 1, all 3 elements in which of the following lists belong to the same period?

   F. H, Li, Na
   G. Cl, Br, I
   H. Mg, P, S
   J. S, N, Br

3. The atomic number of an element is the number of protons in the nucleus of an atom of that element. According to Figure 1, the nucleus of an atom of which of the following elements contains more protons than does an atom of sulfur?

   A. Fluorine
   B. Oxygen
   C. Phosphorus
   D. Potassium

4. Among the 6 compounds represented in Figure 2, as $|EN_1 - EN_2|$ increases, the bond energy at 298 K:

   F. decreases only.
   G. increases only.
   H. remains the same.
   J. varies, but with no general trend.

5. Consider $|EN_1 - EN_2|$ in Figure 2 for BeS. Based on Figure 1, is the bond in HBr less polar or more polar than the bond in BeS ?

   A. Less polar; $|EN_1 - EN_2|$ for HBr is less than $|EN_1 - EN_2|$ for BeS.
   B. Less polar; $|EN_1 - EN_2|$ for HBr is greater than $|EN_1 - EN_2|$ for BeS.
   C. More polar; $|EN_1 - EN_2|$ for HBr is less than $|EN_1 - EN_2|$ for BeS.
   D. More polar; $|EN_1 - EN_2|$ for HBr is greater than $|EN_1 - EN_2|$ for BeS.

6. Consider a sample composed of 3×10^{23} molecules of HI. Based on Figure 2, at 298 K, would the amount of energy required to break all the bonds in this sample be greater than 300 kJ or less than 300 kJ ?

   F. Greater, because the sample contains more than 1 mole of HI.
   G. Greater, because the sample contains less than 1 mole of HI.
   H. Less, because the sample contains more than 1 mole of HI.
   J. Less, because the sample contains less than 1 mole of HI.

Passage II

Triticum aestivum wheat plants grown in a particular soil are affected by salt (NaCl) in the soil, overwatering of the soil, or both. A study examined the effects.

The following 5 steps were performed:

1. Forty identical pots were divided equally into 4 groups (Groups 1–4).

2. Five kilograms (kg) of the soil was put into each Group 1 pot and each Group 3 pot. A mixture of 4.98 kg of the soil and 20 g of NaCl was put into each Group 2 pot and each Group 4 pot.

3. Ten wheat seeds were planted in each pot and watered daily until all the seeds sprouted. Then 7 of the 10 seedlings were removed from each pot.

4. Over the next 4 months, all the pots received the same amount of sunlight and the same amounts of nutrients daily. Each Group 1 pot and each Group 2 pot received 500 mL of water daily. Each Group 3 pot and each Group 4 pot received 500 mL of water daily, except for 3 consecutive weeks during the third month. Over that 3-week period, each Group 3 pot and each Group 4 pot was overwatered by keeping the water level 1 cm above the top of the soil.

Table 1 describes the differences among the groups.

Table 1

Group	NaCl mixed with soil?	Plants overwatered?
1	no	no
2	yes	no
3	no	yes
4	yes	yes

5. At 4 months, 2 averages were calculated for the plants in each group of pots: the average plant mass (roots included), in g per plant, and the average *grain yield* (mass of grain produced), in g of grain per plant.

The average plant mass results are shown in Figure 1, and the average grain yield results are shown in Figure 2.

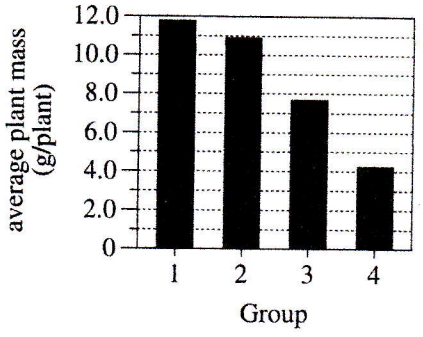


Figure 1

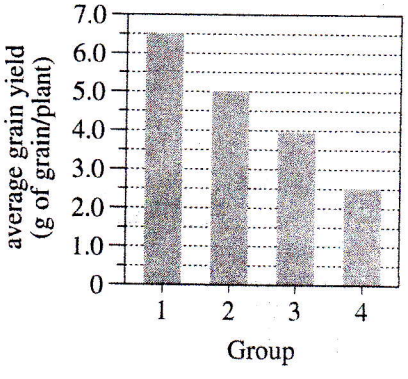


Figure 2

Figures adapted from Muhammad Saqib, Javaid Akhtar, and Riaz Hussain Qureshi, "Pot Study of Wheat Growth in Saline and Waterlogged Compacted Soil: [Part] I. Grain Yield and Yield Components." ©2004 by Elsevier B. V.

7. Assume that wheat plants with a greater mass also have a greater height. Based on Figure 1, the average height of the wheat plants in which group of pots was greatest?

   A. Group 1
   B. Group 2
   C. Group 3
   D. Group 4

8. What is the most likely reason that 7 seedlings were removed from each pot in Step 3 ?

   F. To prevent the plants from producing grain
   G. To avoid overcrowding as the plants grew
   H. To reduce the amount of NaCl in the soil
   J. To decrease the total mass of the pot's contents

9. According to Table 1, the Group 1 pots differed from the Group 3 pots with respect to which of the following factors?

   A. Mass of soil put into a pot
   B. Number of wheat seeds planted in a pot
   C. Total amount of nutrients received by a pot
   D. Total amount of water received by a pot

10. According to the results of the study, for the Group 3 pots, what was the average plant mass in g/plant, and what was the average grain yield in g of grain/plant?

	average plant mass	average grain yield
F.	3.9	4.2
G.	3.9	7.8
H.	7.8	3.9
J.	7.8	4.2

11. Based on Figure 2, did NaCl alone or did overwatering alone cause a greater decrease in the average grain yield?

    A. NaCl; the average grain yield was less for the Group 2 pots than for the Group 3 pots.
    B. NaCl; the average grain yield was less for the Group 3 pots than for the Group 2 pots.
    C. Overwatering; the average grain yield was less for the Group 2 pots than for the Group 3 pots.
    D. Overwatering; the average grain yield was less for the Group 3 pots than for the Group 2 pots.

12. According to Figure 2, at 4 months, the plants in the Group 4 pots had produced, on average, 2.5 g of grain per plant. To calculate the total mass of grain produced, on average, by the plants in a *single* Group 4 pot, should 2.5 g be multiplied by 3 or by 10 ?

    F. Three, because at 4 months, there were three Group 4 pots.
    G. Three, because at 4 months, there were 3 plants in each Group 4 pot.
    H. Ten, because at 4 months, there were ten Group 4 pots.
    J. Ten, because at 4 months, there were 10 plants in each Group 4 pot.

13. The researchers who performed the study most likely compared the results shown in Figure 1 for the Group 1 pots and the Group 2 pots to answer which of the following questions?

    A. What effect did NaCl alone have on average plant mass?
    B. What effect did NaCl alone have on average grain yield?
    C. What effect did overwatering alone have on average plant mass?
    D. What effect did overwatering alone have on average grain yield?

Passage III

Both bats and birds have wings used for flight. Two students present opposing views about whether the presence of the wings is an indication that bats and birds are more closely related to each other than either is to other vertebrates without wings, such as humans. Included in each student's presentation is a *cladogram*, a diagram that shows the evolutionary history of several species. A cladogram organizes species into clades based on descent from a common ancestor. A *clade* is a set of related species and their *most recent common ancestor* (MRCA).

Student 1

Although both have wings, bats and birds are not more closely related to each other than either is to other vertebrates without wings. Although the wings of bats and birds evolved in response to similar selective forces, they evolved independently of one another, as shown in Figure 1. The wings of birds evolved at Point A, whereas the wings of bats evolved at Point B.

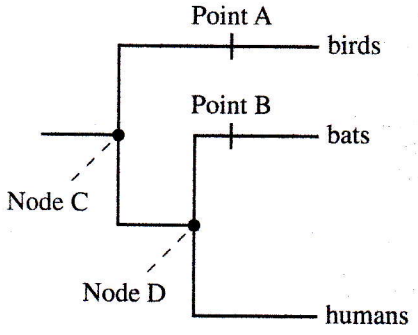


Figure 1

A bat can move individual wing bones, much like the fingers can be moved in a human hand. The bones in a bird wing are fused and inflexible. Thus, the bone structure of a bat wing is more similar to the bone structure of a human hand than to the bone structure of a bird wing. Furthermore, the fact that both bats and humans share mammalian characteristics provides additional evidence that bats are more closely related to humans than to birds.

Student 2

Their both having wings is a good indication that bats and birds are more closely related to each other than either is to other vertebrates without wings. The MRCA of all vertebrates with wings must have had wings. As shown in Figure 2, the MRCA of bats and birds, represented at Node Z, evolved to give rise to all winged vertebrates.

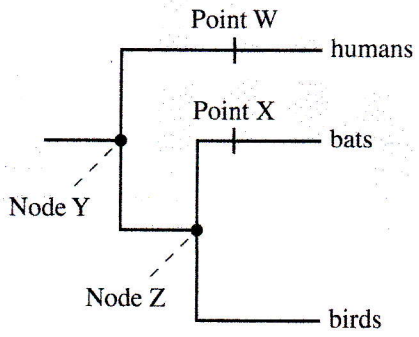


Figure 2

Evidence that the bone structure of a bat wing is similar to that of a human hand does not indicate that bats and humans are closely related because bats, birds, and humans all have a similar forelimb bone structure. Humans and bats are both mammals, but the mammalian characteristics of humans and of bats evolved at Points W and X, respectively.

14. Student 2's cladogram indicates that which of the vertebrates listed below belong to the clade that originates at Node Z ?

I. Humans
II. Bats
III. Birds

F. I only
G. I and II only
H. II and III only
J. I, II, and III

15. Consider the statement "Bats have a small claw that sticks out of the wing and functions like a human thumb, allowing the bat to hang onto and climb on trees." This statement supports the view of which student?

A. Student 1, because Student 1 claims that any descendant of an ancestor with forelimbs will have a nonfunctional structure that resembles a human thumb.
B. Student 1, because Student 1 claims that the similarity of bone structure between a bat wing and a human hand provides evidence that bats and humans are closely related.
C. Student 2, because Student 2 claims that any descendant of an ancestor with forelimbs will have a nonfunctional structure that resembles a human thumb.
D. Student 2, because Student 2 claims that the similarity of bone structure between a bat wing and a human hand provides evidence that bats and humans are closely related.

16. In Student 1's cladogram, is the MRCA of bats and humans represented at Node C or at Node D ?

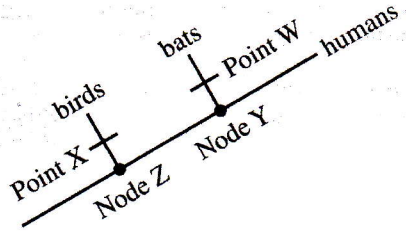
F. Node C, because the clade that begins with the ancestor represented at Node C includes bats and humans, as well as birds, as descendants.
G. Node C, because the clade that begins with the ancestor represented at Node C includes bats and humans, but not birds, as descendants.
H. Node D, because the clade that begins with the ancestor represented at Node D includes bats and humans, as well as birds, as descendants.
J. Node D, because the clade that begins with the ancestor represented at Node D includes bats and humans, but not birds, as descendants.

17. Which of the students, if either, present(s) a cladogram that is consistent with the statement "Birds and humans, but not bats, share a common ancestor that had forelimbs"?

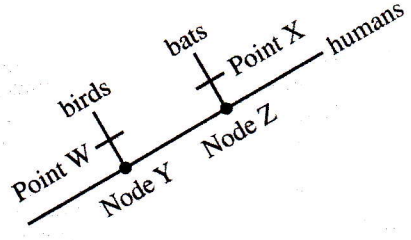
A. Student 1 only
B. Student 2 only
C. Both Student 1 and Student 2
D. Neither Student 1 nor Student 2

18. Which of the following cladograms is consistent with the cladogram constructed by Student 2 ?

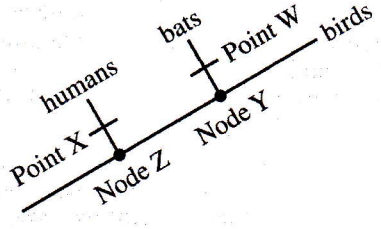
F.



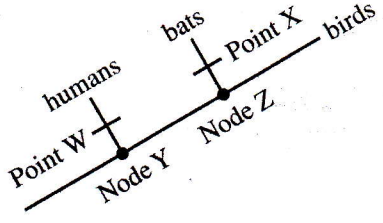
G.



H.



J.



19. Which of the students, if either, would be likely to claim that the MRCA of bats and birds did *not* have wings?

A. Student 1 only
B. Student 2 only
C. Both Student 1 and Student 2
D. Neither Student 1 nor Student 2

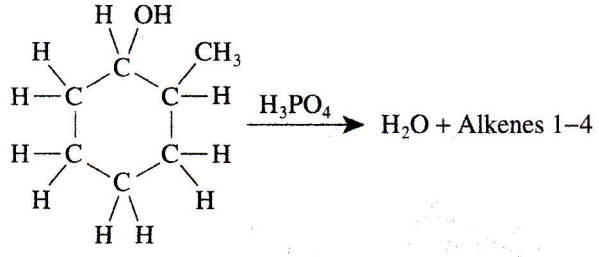
20. Student 2 implies that which of the following morphological traits evolved at Points W and X ?

F. Wings for flight
G. Forelimbs
H. Hands
J. Mammary glands

Passage IV

Alcohols are carbon compounds containing a *hydroxyl* (OH) group. *Alkenes* are carbon compounds containing at least 1 carbon-carbon double bond (C=C).

Dehydration (removal of H_2O) of Alcohol W in the presence of phosphoric acid (H_3PO_4) produces H_2O and a mixture of 4 alkenes (Alkenes 1–4) that each contain only 1 C=C bond:



Alcohol W

Dehydration of each of 3 other alcohols (Alcohols X, Y, and Z) produces H_2O and 2 or more of Alkenes 1–4. Students studied the dehydration of each of these 4 alcohols, which are all liquids at 25°C.

Experiment

In each of 4 trials, the students performed Steps 1–5:

1. A 2.30 g sample of Alcohol W, X, Y, or Z was placed in a flask.
2. A 0.5 mL portion of H_3PO_4 was added to the flask, and an apparatus for *distillation* (evaporation of one or more components of a liquid mixture in one vessel and condensation of the vapors in another vessel) was assembled (see Figure 1).

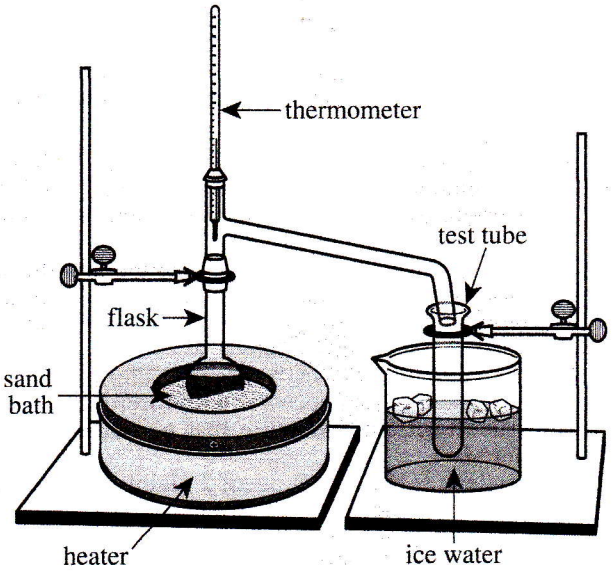


Figure 1

3. The contents of the flask were boiled at 1 atmosphere (atm) of pressure in a heated sand bath. All the components of the product mixture that distilled before the vapor temperature reached 115°C were collected in a test tube that was cooled in ice water.
4. Two mL of saturated salt solution was added to the test tube. The test tube was covered and shaken, and its contents were allowed to settle into 2 layers.
5. The percent composition of the top layer (the mixture of alkene products only) was determined (see Table 1).

Table 1

Trial	Alcohol	Percent composition of the mixture of alkene products:			
		Alkene 1	Alkene 2	Alkene 3	Alkene 4
1	W	6	67	18	9
2	X	2	98	0	0
3	Y	0	15	31	54
4	Z	0	9	12	79

21. Based on the results of the experiment, the mixture of alkene products resulting from the dehydration of which of the alcohols contained the greatest percent of Alkene 3 ?

A. Alcohol W
B. Alcohol X
C. Alcohol Y
D. Alcohol Z

22. Trials 1 and 4 differed with respect to which of the following?

F. The number of alkenes produced
G. The number of alcohols dehydrated
H. The mass of alcohol placed in the flask
J. The volume of H_3PO_4 placed in the flask

23. What was the most likely purpose of the sand bath shown in Figure 1 ?

A. To partially cool the test tube
B. To evenly distribute heat to the flask
C. To provide sand as a reactant in the dehydration reaction
D. To provide sand as a surface onto which the vapors would condense

24. What is the most likely reason that, upon the completion of Step 4, the mixture of alkene products was the top layer in the test tube?

F. The density of the mixture of alkene products was greater than the density of the saturated salt solution.
G. The density of the mixture of alkene products was less than the density of the saturated salt solution.
H. The volume of the mixture of alkene products was greater than the volume of the saturated salt solution.
J. The volume of the mixture of alkene products was less than the volume of the saturated salt solution.

25. When the students dehydrated a different alcohol, Alcohol R, the alkene products that were produced were the same as those resulting from the dehydration of Alcohol W. Based on the results of the experiment, the alkene products resulting from the dehydration of Alcohol R were:

A. Alkenes 1 and 2 only.
B. Alkenes 1, 2, and 3 only.
C. Alkenes 2, 3, and 4 only.
D. Alkenes 1, 2, 3, and 4.

26. Which of the following statements gives the most likely reason that the test tube was cooled in ice water, as shown in Figure 1 ? The test tube was most likely cooled in ice water to more readily:

F. condense the liquid produced.
G. condense the vapor produced.
H. evaporate the liquid produced.
J. evaporate the vapor produced.

27. One of the students predicted that in Step 3, H_2O would be one of the substances collected in the test tube. Based on the boiling point of H_2O at 1 atm of pressure and the description of Step 3, was the student's prediction correct?

A. Yes, because the boiling point of H_2O is greater than 115°C.
B. Yes, because the boiling point of H_2O is less than 115°C.
C. No, because the boiling point of H_2O is greater than 115°C.
D. No, because the boiling point of H_2O is less than 115°C.

Passage V

The processing of sulfur-rich *ore* (rock containing valuable metals) from mines produces liquid waste, which is often stored in a pond. Some of the liquid in the pond seeps down to the groundwater table, where it contaminates the groundwater beneath with sulfate (SO_4^{2-}). A barrier called a *reactive wall* can be installed in the ground near the pond to lessen SO_4^{2-} contamination. As polluted water flows through the wall, SO_4^{2-} is removed from the water (see Figure 1). The material that forms the wall—the *reactive material* (RM)—is composed of one or more organic substances.

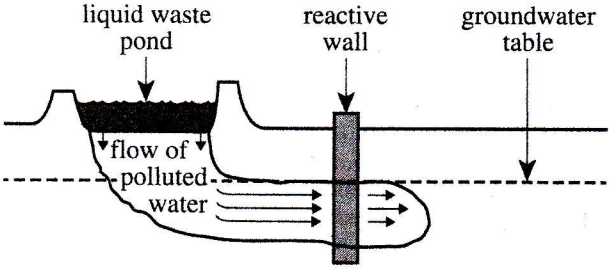


Figure 1

A study evaluated the effectiveness of several reactive materials.

Study

Six reactive materials (RMs 1–6) were prepared from samples of 4 organic substances—sewage sludge, leaf mulch, sheep manure, and sawdust—that had been completely dried. Table 1 shows the composition of each RM.

Table 1

RM	Percent dry mass of substance in material			
	sewage sludge	leaf mulch	sheep manure	sawdust
1	100	0	0	0
2	0	100	0	0
3	0	10	65	25
4	20	10	20	50
5	0	60	0	40
6	15	60	0	25

The following procedures were performed for each RM: First, a 500 mL volume of the RM was placed in a 1 L flask. Next, 500 mL of a simulated liquid mine waste with an SO_4^{2-} concentration of 3,600 mg/L was added to the flask. The flask opening was then covered with an airtight cap. Every 5 days, a 10 mL sample of the liquid in the flask was collected through a seal in the cap. Each sample was analyzed for SO_4^{2-}. Once a sample was found to have an SO_4^{2-} concentration of zero, no additional samples were collected from the flask.

Figure 2 shows the results for each RM.

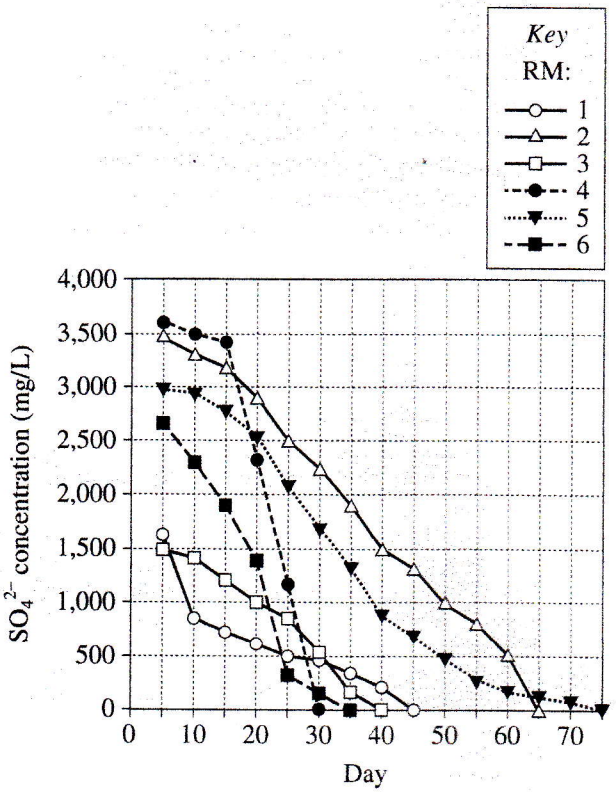


Figure 2

Table and figures adapted from K. R. Waybrant, D. W. Blowes, and C. J. Ptacek, "Selection of Reactive Mixtures for Use in Permeable Reactive Walls for Treatment of Mine Drainage." ©1998 by the American Chemical Society.

28. The movement of liquid waste from a storage pond to the groundwater table is an example of which of the following processes?

F. Infiltration
G. Evaporation
H. Condensation
J. Weathering

29. If a sample of the liquid in the flask containing RM 1 had been collected on Day 22, the SO_4^{2-} concentration of that sample would most likely have been closest to which of the following?

A. 350 mg/L
B. 550 mg/L
C. 750 mg/L
D. 950 mg/L

30. Over the 75 days that samples were collected, how many samples were collected from the flask containing RM 3, and how many samples were collected from the flask containing RM 6 ?

	RM 3	RM 6
F.	8	7
G.	8	8
H.	10	10
J.	10	15

31. Consider the reactive materials for which the percent dry mass of leaf mulch was greater than 50%. Did each of those reactive materials remove all the SO_4^{2-} from the liquid mine waste in their flasks in less than 50 days?

A. Yes, it took only 30 days for RM 2, RM 5, and RM 6 to remove all the SO_4^{2-} from the waste in their flasks.
B. Yes, it took only 45 days for RM 3, RM 4, and RM 5 to remove all the SO_4^{2-} from the waste in their flasks.
C. No, it took more than 60 days for RM 2 and RM 5 to remove all the SO_4^{2-} from the waste in their flasks.
D. No, it took more than 60 days for RM 5 and RM 6 to remove all the SO_4^{2-} from the waste in their flasks.

32. Suppose an environmental engineer wants to ensure that a reactive wall as depicted in Figure 1 will remove as much SO_4^{2-} from the polluted water as possible. Based on Figure 1, would the engineer more likely achieve this goal by increasing the thickness of the wall or the height of the wall?

F. The thickness, because the polluted water will flow horizontally through the wall.
G. The thickness, because the polluted water will flow vertically through the wall.
H. The height, because the polluted water will flow horizontally through the wall.
J. The height, because the polluted water will flow vertically through the wall.

33. Consider the concentration of SO_4^{2-} in the liquid mine waste that was added to the flask containing RM 4 on Day 0. Also consider the concentration of SO_4^{2-} in the sample collected from that flask on Day 25. The concentration on Day 25 was approximately what fraction of the concentration on Day 0 ?

A. $\frac{1}{10}$
B. $\frac{1}{4}$
C. $\frac{1}{3}$
D. $\frac{1}{2}$

34. Suppose that a reactive material with a composition of 50 percent by dry mass of the sewage sludge and 50 percent by dry mass of the leaf mulch had been tested in the study. The SO_4^{2-} concentration of the sample collected on Day 5 from the flask containing that reactive material would most likely have been:

F. less than 500 mg/L.
G. between 500 mg/L and 1,500 mg/L.
H. between 1,500 mg/L and 3,500 mg/L.
J. greater than 3,500 mg/L.

Passage VI

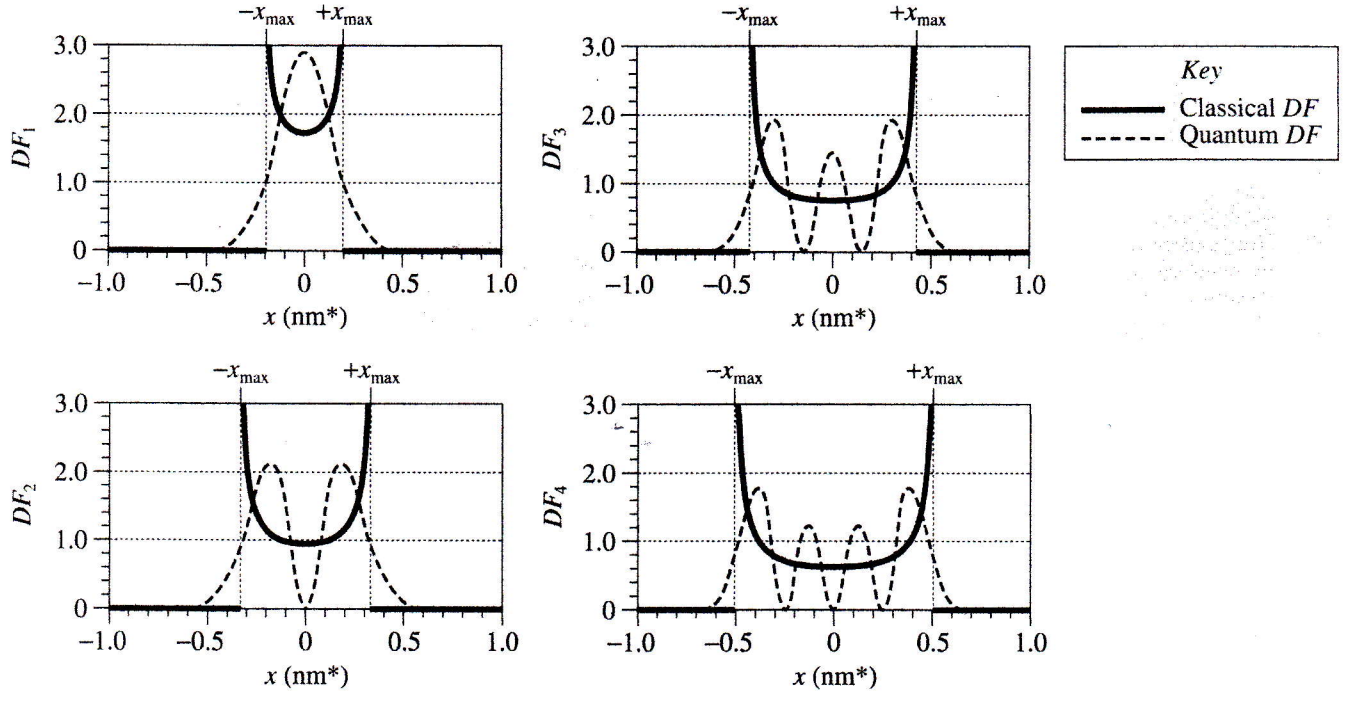
Consider an electron that is constrained to move along the x-axis. The probability of finding the electron at any given location, x, along the axis is obtained from a distribution function, DF, which is related to the electron's energy. The greater the value of DF at a given x, the greater the probability of finding the electron at that x. Classical theory and quantum theory can be used to derive 2 forms of DF: a classical form and a quantum form.

Table 1 lists the electron energy corresponding to each of 4 DFs. Figure 1 shows the classical and quantum forms of each DF.

Table 1

DF	Corresponding electron energy (eV*)
DF_1	1
DF_2	3
DF_3	5
DF_4	7

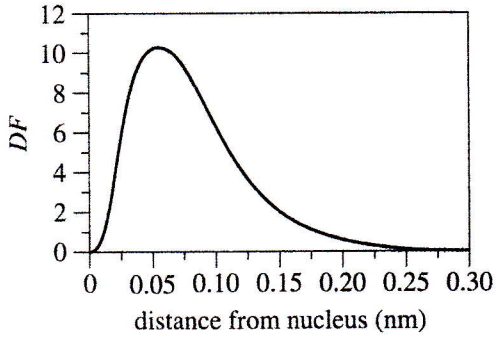
*electron volts



*nanometer; 1 nm = 10^{-9} m

Figure 1

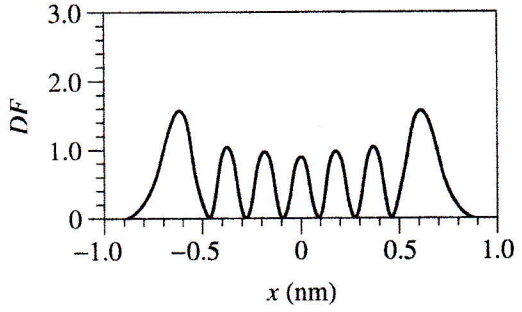
35. The figure below shows the Quantum *DF* for an electron bound within a hydrogen atom.



At approximately what distance from the nucleus is this electron most likely to be found?

A. 0 nm
B. 0.05 nm
C. 0.15 nm
D. 0.30 nm

36. The figure below most likely shows which *DF* ?



F. Classical DF_7
G. Classical DF_8
H. Quantum DF_7
J. Quantum DF_8

37. Based on Table 1 and Figure 1, at which electron energy are *both* the value of Classical *DF* and the value of Quantum *DF* greater than zero at every x between the locations $-x_{max}$ and $+x_{max}$?

A. 1 eV
B. 3 eV
C. 5 eV
D. 7 eV

38. What is the approximate maximum value of Quantum DF_4, and at what approximate locations does Quantum DF_4 have this value?

	maximum value	locations
F.	1.3	$x = \pm 0.1$ nm
G.	1.3	$x = \pm 0.4$ nm
H.	1.8	$x = \pm 0.1$ nm
J.	1.8	$x = \pm 0.4$ nm

39. Each Quantum *DF* represents a unique physical state of the electron. The electron may make a transition from one state to another by either absorbing or emitting energy. Based on Table 1, if the electron were initially in the state represented by DF_3 and then made a transition to the state represented by DF_1, would the electron more likely absorb energy or emit energy, and how much? The electron would:

A. absorb 4 eV.
B. absorb 6 eV.
C. emit 4 eV.
D. emit 6 eV.

40. At locations between $-x_{max}$ and $+x_{max}$, the value of Classical *DF* is inversely proportional to the electron's speed. Based on Table 1 and Figure 1, at which of the following locations is a 5 eV electron most likely moving fastest?

F. $x = -0.3$ nm
G. $x = 0$ nm
H. $x = 0.2$ nm
J. $x = 0.4$ nm

END OF TEST 4

STOP! DO NOT RETURN TO ANY OTHER TEST.