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

A teacher asked each of 4 students to describe the *molecular shape* (the geometrical arrangement of the atoms in a molecule) of each of 4 molecules: arsenic trifluoride (AsF_3), arsenic trichloride ($AsCl_3$), arsenic tribromide ($AsBr_3$), and arsenic triiodide (AsI_3).

Student 1

An AsF_3 molecule is *T-shaped*, with the As atom in the center. All the atoms in AsF_3 lie in the same plane, and there are 2 unique angles—90° and 180°—between adjacent As–F bonds (see Figure 1).

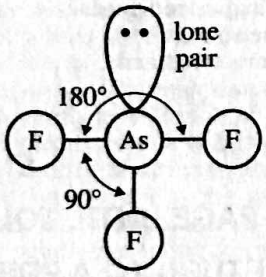


Figure 1

The As atom has a *lone pair* (an outer pair of electrons not involved in chemical bonding) that lies in the same plane as the As and F atoms. These electrons strongly repel the 3 As–F bonds, resulting in the 2 unique bond angles of 90° and 180°.

$AsCl_3$, $AsBr_3$, and AsI_3 are also T-shaped.

Student 2

The shape of an AsF_3 molecule is *trigonal planar*, with the As atom in the center. All the atoms in AsF_3 lie in the same plane, and there is only 1 unique angle—120°—between adjacent As–F bonds (see Figure 2).

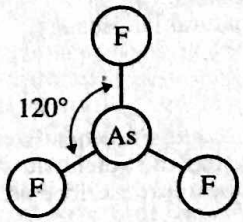


Figure 2

The As atom does not have a lone pair. The 3 As–F bonds repel each other equally, resulting in the 1 unique bond angle of 120°.

$AsCl_3$, $AsBr_3$, and AsI_3 are also trigonal planar.

Student 3

The shape of an AsF_3 molecule is *trigonal pyramidal*, with the As atom in the center. All the atoms in AsF_3 do not lie in the same plane, and there is only 1 unique angle—109°—between adjacent As–F bonds (see Figure 3).

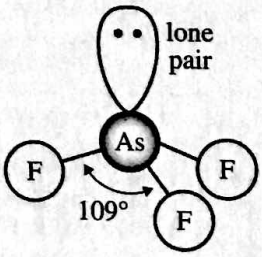


Figure 3

The As atom has a lone pair. The lone pair and the 3 As–F bonds repel each other equally, resulting in the 1 unique bond angle of 109°.

$AsCl_3$, $AsBr_3$, and AsI_3 are also trigonal pyramidal.

Student 4

Student 3 is correct that, due to the lone pair, AsF_3, $AsCl_3$, $AsBr_3$, and AsI_3 molecules are all trigonal pyramidal. AsF_3, $AsCl_3$, $AsBr_3$, and AsI_3 each have only 1 unique bond angle, but that bond angle is different for each of the 4 molecules. The bond angle depends on the size of the atom that is bound to the As atom: the larger the atom that is bound to the As atom, the larger the bond angle. The atoms bound to the As atom, listed by size from smallest to largest, are F, Cl, Br, and I.

After the 4 descriptions were offered, the teacher used a computer program that (1) determined that in each of the 4 molecules, there is only 1 unique bond angle and (2) calculated the bond angle for each molecule (see Table 1).

Table 1

Molecule	Calculated bond angle
AsF_3	100°
$AsCl_3$	101°
$AsBr_3$	103°
AsI_3	111°

Table adapted from Ian J. McNaught, "Testing and Extending VSEPR with WebMO and MOPAC or GAMESS." ©2011 by Division of Chemical Education, Inc., American Chemical Society.

1. The table below gives the atomic mass (in atomic mass units, amu) of the elements F, Cl, Br, and I.

Element	Atomic mass (amu)
F	19.00
Cl	35.45
Br	79.90
I	126.9

Based on Student 4's description, among the elements listed in the table, as atomic mass increases, *atomic radius*:

A. increases only.
B. decreases only.
C. increases, then decreases.
D. decreases, then increases.

2. Which of the students claimed that the As atom in an AsF_3 molecule has a lone pair?

F. Students 1 and 2 only
G. Students 3 and 4 only
H. Students 1, 3, and 4 only
J. Students 2, 3, and 4 only

3. Which of the students would be likely to agree with the statement "All 4 atoms in an AsF_3 molecule lie in the same plane"?

A. Student 1 only
B. Student 3 only
C. Students 1 and 2 only
D. Students 3 and 4 only

4. Consider the claim that there are 3 unique bond angles in an AsF_3 molecule. This claim is consistent with the description(s) given by which student(s), if any?

F. Student 2 only
G. Students 1 and 2 only
H. Students 3 and 4 only
J. None of the students

5. Based on the descriptions given by Students 1, 2, and 3, which of these students would be likely to agree that the sum of the 3 bond angles in an AsI_3 molecule is equal to 360° ?

A. Students 1 and 2 only
B. Students 1 and 3 only
C. Students 2 and 3 only
D. Students 1, 2, and 3

6. A molecule of ammonia (NH_3) has only 1 unique bond angle, and that bond angle is 107°. The N atom also has a lone pair that strongly repels the 3 N–H bonds. Based on the descriptions given by Students 2 and 3, is the molecular shape of NH_3 more likely trigonal planar or trigonal pyramidal?

F. Trigonal planar; the bond angle is more consistent with Student 2's description.
G. Trigonal planar; the bond angle is more consistent with Student 3's description.
H. Trigonal pyramidal; the bond angle is more consistent with Student 2's description.
J. Trigonal pyramidal; the bond angle is more consistent with Student 3's description.

7. The data in Table 1 are most consistent with the description given by which student?

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

Passage II

Each dog in a particular population has a black, brown, or yellow coat. In this population, coat color is determined by 2 unlinked genes: Gene B and Gene E. Gene B has 2 alleles: *B* and *b*. Gene E also has 2 alleles: *E* and *e*. Table 1 shows the possible genotypes for Gene B and Gene E and the resulting coat color phenotypes.

Table 1

Genotype	Coat color
BBEE	black
BBEe	black
BBee	yellow
BbEE	black
BbEe	black
Bbee	yellow
bbEE	brown
bbEe	brown
bbee	yellow

Two of the dogs with black coats were crossed 3 times (Crosses 1–3). The coat colors of the offspring produced in each cross are shown in Table 2.

Table 2

Cross	Number of offspring with a: black coat	brown coat	yellow coat
1	8	0	0
2	6	1	2
3	2	2	2

8. After Cross 1 but before Cross 2, a student hypothesized that each of the parents in Cross 1 had the genotype *BBEE*. Was this hypothesis consistent with the results of Cross 1 ?

   F. Yes, because all the offspring of Cross 1 had black coats.
   G. Yes, because all the offspring of Cross 1 had yellow coats.
   H. No, because all the offspring of Cross 1 had black coats.
   J. No, because all the offspring of Cross 1 had yellow coats.

9. What was the Gene B and Gene E genotype of the offspring of Cross 2 that had a brown coat?

   A. *bbee*
   B. *BBEE*
   C. *BbEE* or *BbEe*
   D. *bbEE* or *bbEe*

10. Based on Tables 1 and 2, what fraction of the offspring of Cross 3 had 1 or more copies of the *E* allele of Gene E ?

    F. $\frac{1}{4}$
    G. $\frac{1}{3}$
    H. $\frac{2}{3}$
    J. $\frac{15}{16}$

11. Consider the offspring of each of the 3 crosses. Based on Tables 1 and 2, some of the offspring of which of the crosses, if any, could have had only recessive alleles of Gene B and Gene E ?

A. Cross 1 only
B. Crosses 2 and 3 only
C. Crosses 1, 2, and 3
D. None of the crosses

12. Suppose 2 of the offspring from Cross 3 with yellow coats are crossed. What percent of the resulting offspring will have yellow coats?

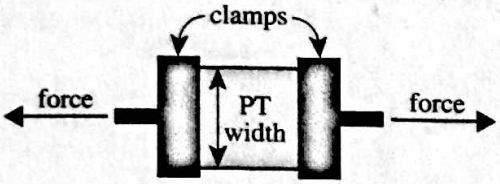
F. 0%
G. 25%
H. 50%
J. 100%

13. Approximately what percent of the normal gametes produced by a dog with the genotype *BbEE* will contain the *B* allele?

A. 0%
B. 25%
C. 50%
D. 100%

Passage III

The *tensile strength* of a paper towel (PT) is the force per unit width required to break the PT when it is clamped and stretched (see diagram).



diagram

Dry strength is the tensile strength of a dry PT, and *wet strength* is the tensile strength of a PT that has been submerged in water. The wet strength can be increased by treating the PT with certain chemicals.

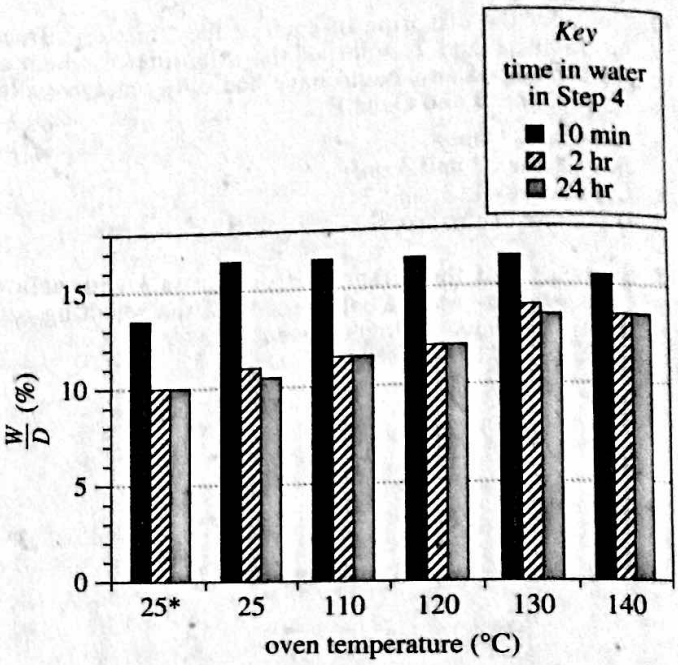
Students conducted 2 experiments to study the wet strengths of identical PTs, each 20 cm × 20 cm, treated with glutaraldehyde (GLA) or with GLA and zinc nitrate.

Experiment 1

First, the dry strengths of 5 PTs were measured, in newtons per meter (N/m), and the average of the measurements, D, was calculated. Then, Steps 1–5 were performed on each of 100 other PTs:

1. A PT was submerged for 30 sec in water (if the PT was to be a control) or in a test solution containing GLA.
2. The PT was dried on a hot plate at 85°C for 4 min.
3. The PT was heated in an oven for 3 min at a certain temperature—25°C for a control PT and 25°C, 110°C, 120°C, 130°C, or 140°C for a treated PT.
4. The PT was submerged in water for 10 min, 2 hr, or 24 hr.
5. The wet strength of the PT was measured in N/m.

The wet strengths of PTs that had been subjected to identical conditions were averaged. Each average wet strength, W, was divided by D and then multiplied by 100. The resulting $\frac{W}{D}$ values are shown in Figure 1.

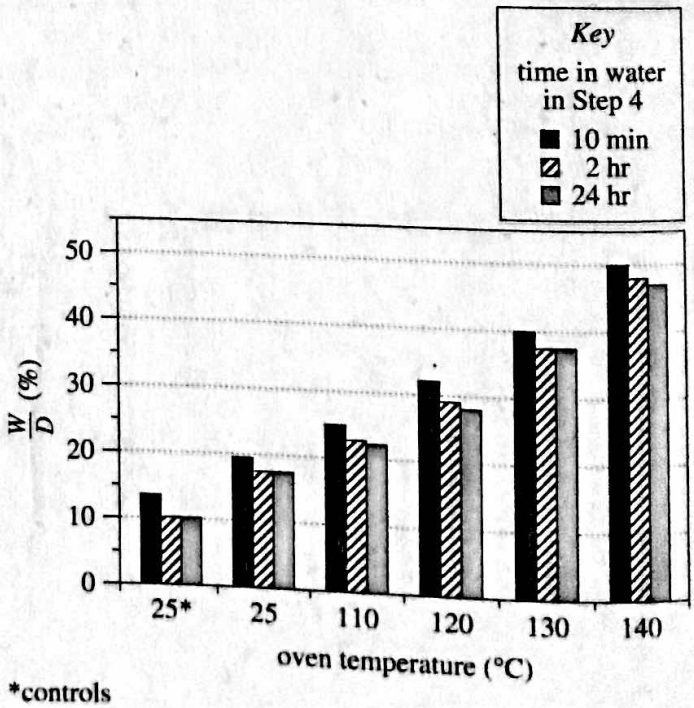


*controls

Figure 1

Experiment 2

Steps 1–5 were repeated with 100 other PTs, except that the test solution contained both GLA and zinc nitrate (see Figure 2).



*controls

Figure 2

Figures 1 and 2 adapted from Gordon Guozhong Xu, Charles Qiuliang Yang, and Yulin Deng, "Applications of Bifunctional Aldehydes to Improve Paper Wet Strength." ©2002 by John Wiley & Sons, Inc.

14. In Experiment 2, the greatest average wet strength was observed for the PTs that were submerged in water for 10 min after having been heated in an oven at what temperature?

F. 110°C
G. 120°C
H. 130°C
J. 140°C

15. In Experiment 2, for PTs that were submerged in water for 2 hr, as the oven temperature increased from 110°C through 140°C, the $\frac{W}{D}$ value:

A. increased only.
B. decreased only.
C. remained the same.
D. varied, but with no general trend.

16. In Step 1 of Experiment 1, the PTs that would become controls were submerged in what liquid, and in Step 3 of Experiment 1, these control PTs were heated in an oven at what temperature?

	liquid	temperature
F.	water	25°C
G.	water	85°C
H.	GLA solution	25°C
J.	GLA solution	85°C

17. In which of Experiments 1 and 2, if either, did the students measure the wet strengths of PTs that had been submerged in water for a total of 18 hr ?

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

18. Which of the following statements comparing the $\frac{W}{D}$ value of the PTs that were submerged in water for 2 hr with the $\frac{W}{D}$ value of the PTs that were submerged in water for 10 min is supported by the results of Experiment 1 ?

F. For all the oven temperatures, the $\frac{W}{D}$ value at 2 hr was greater than the $\frac{W}{D}$ value at 10 min.
G. For all the oven temperatures, the $\frac{W}{D}$ value at 2 hr was less than the $\frac{W}{D}$ value at 10 min.
H. For all the oven temperatures, the $\frac{W}{D}$ value at 2 hr was the same as the $\frac{W}{D}$ value at 10 min.
J. For some of the oven temperatures, the $\frac{W}{D}$ value at 2 hr was greater than the $\frac{W}{D}$ value at 10 min; at the other oven temperatures, the $\frac{W}{D}$ value at 2 hr was less than the $\frac{W}{D}$ value at 10 min.

19. One of the students predicted that the wet strengths of PTs would NOT increase after treating the PTs with a solution containing both GLA and zinc nitrate. The results of which experiment better refute or support this prediction? The results of:

A. Experiment 1 better refute this prediction.
B. Experiment 1 better support this prediction.
C. Experiment 2 better refute this prediction.
D. Experiment 2 better support this prediction.

20. Based on the results of the experiments, is the dry strength of a paper towel greater than or less than the wet strength of the paper towel?

F. Greater; each average wet strength, W, was greater than 100% of D.
G. Greater; each average wet strength, W, was less than 100% of D.
H. Less; each average wet strength, W, was greater than 100% of D.
J. Less; each average wet strength, W, was less than 100% of D.

Passage IV

The tiger frog, *Rana rugulosa*, is a species of frog that is commercially farmed. A farmer conducted 2 experiments to help determine the optimum diet for the growth of *R. rugulosa*.

Prior to the experiments, 10 diets (Diets 1–10) were prepared. The diets differed in the percent by mass of protein, the number of calories per gram (cal/g), or both (see Table 1).

Table 1

Diet	Percent by mass of protein	Calories per gram (cal/g)
1	30.0	5,300
2	32.5	5,300
3	35.0	5,300
4	37.5	5,300
5	40.0	5,300
6	37.0	4,500
7	37.0	4,700
8	37.0	4,900
9	37.0	5,300
10	37.0	5,700

Experiment 1

Each of 5 identical outdoor 1 m^3 tanks was prepared as follows: First, the tank was filled with water to a depth of 20 cm. Next, 30 adult *R. rugulosa*, each with a mass of 3.3 g, were placed into the tank. Then the tank was covered with a fine wire mesh.

Each tank of frogs was assigned a different diet: Diet 1, Diet 2, Diet 3, Diet 4, or Diet 5. Each frog was fed 1,000 mg of its assigned diet, twice per day, for the next 12 weeks. At the end of 12 weeks, the average final mass of the frogs was determined for each diet (see Table 2).

Table 2

Diet	Average final mass (g)
1	54.0
2	69.3
3	80.1
4	86.2
5	90.4

Experiment 2

Five more of the outdoor 1 m^3 tanks were prepared as in Experiment 1, except that each of the *R. rugulosa* had an initial mass of 7.9 g instead of 3.3 g. Each tank of frogs was assigned a different diet: Diet 6, Diet 7, Diet 8, Diet 9, or Diet 10. Each frog was fed 2,000 mg of its assigned diet, once per day, for the next 12 weeks. At the end of 12 weeks, the average final mass of the frogs was determined for each diet (see Table 3).

Table 3

Diet	Average final mass (g)
6	126.9
7	135.1
8	143.0
9	132.0
10	129.5

Tables adapted from P. Somsueb and M. Boonyaratpalin, "Optimum Protein and Energy Levels for the Thai Native Frog, *Rana rugulosa* Weigmann." ©2001 by Blackwell Science Ltd.

21. The values that were averaged to obtain the data in Tables 2 and 3 were most likely read from which of the following instruments?

A. Graduated cylinder
B. Electronic balance
C. Metric ruler
D. Calorimeter

22. In Experiment 1, as the percent by mass of protein increased, the average final mass of the frogs:

F. increased only.
G. decreased only.
H. increased, then decreased.
J. decreased, then increased.

23. The fine wire mesh was most likely intended to function in which of the ways described below?

I. To prevent predators of frogs from entering each tank
II. To place the frogs into each tank
III. To keep the frogs from leaving each tank

A. I and II only
B. I and III only
C. II and III only
D. I, II, and III

24. In Experiment 2, as the number of calories per gram increased, the average final mass of the frogs:

F. increased only.
G. decreased only.
H. increased, then decreased.
J. decreased, then increased.

25. Which of the statements about the frogs involved in the experiments given below, if either, is(are) consistent with the information in the passage?

I. All the frogs belonged to the same genus.
II. All the frogs belonged to the same species.

A. I only
B. II only
C. Both I and II
D. Neither I nor II

26. Experiment 2 differed from Experiment 1 in which of the following ways?

F. The initial mass of each frog was greater in Experiment 1 than in Experiment 2.
G. The initial mass of each frog was greater in Experiment 2 than in Experiment 1.
H. The quantity of food that each frog was fed per day was greater in Experiment 1 than in Experiment 2.
J. The quantity of food that each frog was fed per day was greater in Experiment 2 than in Experiment 1.

27. To determine whether the number of calories per gram in the diet of *R. rugulosa* affects the growth of *R. rugulosa*, would the farmer more likely have compared the results of Diets 1–5 or the results of Diets 6–10 ?

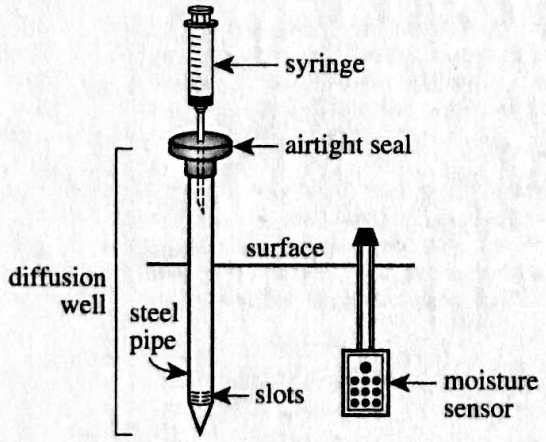
A. Diets 1–5, because those diets varied in the percent by mass of protein but not in the number of calories per gram.
B. Diets 1–5, because those diets varied in the number of calories per gram but not in the percent by mass of protein.
C. Diets 6–10, because those diets varied in the percent by mass of protein but not in the number of calories per gram.
D. Diets 6–10, because those diets varied in the number of calories per gram but not in the percent by mass of protein.

Passage V

In soil, CO_2 is produced through 2 processes—respiration in plant roots and bacterial decomposition of organic matter. A study was done in an oak forest to examine the CO_2 content of soil gas as well as the water content of the soil. The study was done during an 8-week period that began just as the growing season ended.

Study

On October 12, 5 evenly spaced locations in the forest were marked along a 120 m long straight line, starting at one end. At each location, 5 sets of 2 instruments each—a *diffusion well* and a *moisture sensor*—were positioned so that soil gas could be collected and soil water content could be measured at each of 5 soil depths: 10 cm, 30 cm, 60 cm, 100 cm, and 140 cm. The slots near one end of the steel pipe of the diffusion well allowed only soil gas to enter the pipe. The soil gas could be sampled by inserting the needle of a syringe through the airtight seal on the aboveground end of the pipe. See Figure 1.



Note: Drawing is not to scale.

Figure 1

At noon on each of 4 dates—October 26, November 9, November 23, and December 7—a 0.5 mL sample of soil gas was collected from each diffusion well and the water content of the soil was read from each moisture sensor. Each soil gas sample was analyzed to determine its CO_2 content. Figure 2 shows the averaged results for CO_2 content of the soil gas, expressed in percent by volume, and Figure 3 shows the averaged results for water content of the soil, expressed in percent by mass.

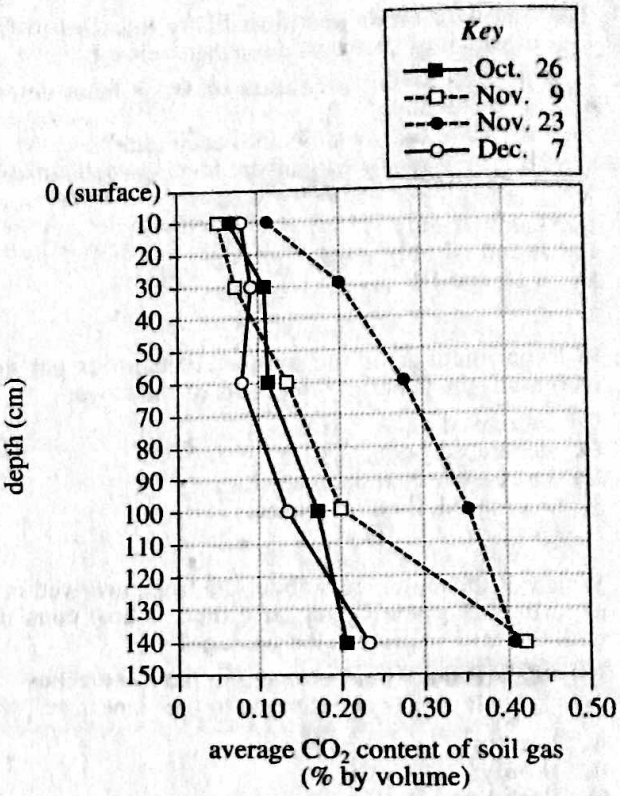


Figure 2

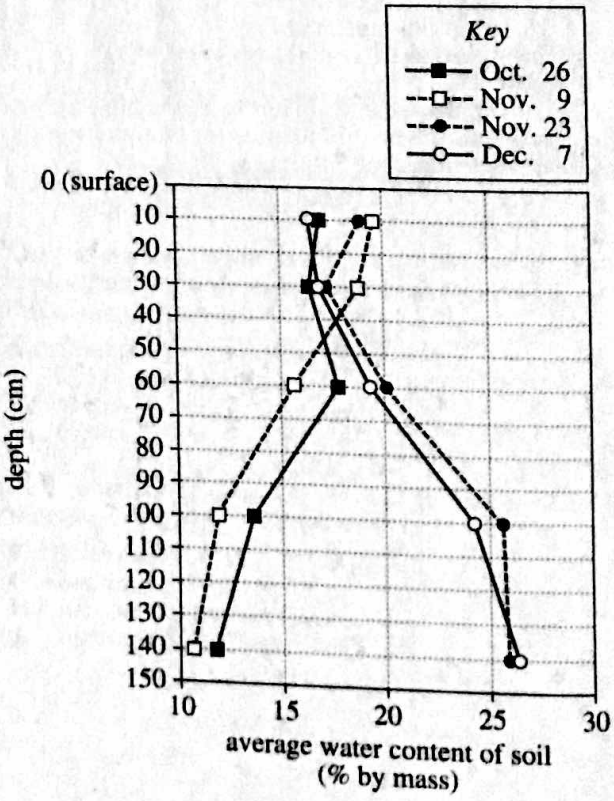


Figure 3

Figures adapted from James M. Dyer and George A. Brook, "Spatial and Temporal Variations in Temperate Forest Soil Carbon Dioxide during the Non-Growing Season." ©1991 by John Wiley & Sons, Ltd.

28. According to Figure 3, at what depth were the average water content values for the 4 dates closest in value?

F. 30 cm
G. 60 cm
H. 100 cm
J. 140 cm

29. The slots at the bottom of a diffusion well's pipe were designed to allow the passage of:

A. soil gas but not soil or water.
B. soil and water but not soil gas.
C. water but not soil or soil gas.
D. soil gas as well as soil and water.

30. What percent of the CO_2 in each soil gas sample was due to bacterial decomposition of organic matter and not due to respiration in plant roots?

F. 10%
G. 25%
H. 50%
J. Cannot be determined from the given information

31. In the study, one step in the determination of CO_2 content was to divide a volume of CO_2 by another volume. That other volume was the volume of a:

A. sample of soil.
B. sample of soil gas.
C. sample of water.
D. steel pipe of a diffusion well.

32. Which of the following statements describing how the average water content generally varied over the 140 cm of soil depth is consistent with Figure 3 ?

F. On each of the 4 dates, the average water content generally increased with depth.
G. On each of the 4 dates, the average water content generally decreased with depth.
H. On October 26 and November 9, the average water content generally increased with depth, whereas on November 23 and December 7, the average water content generally decreased with depth.
J. On October 26 and November 9, the average water content generally decreased with depth, whereas on November 23 and December 7, the average water content generally increased with depth.

33. Suppose that at each of the 5 locations a diffusion well had been positioned at a depth of 145 cm. Based on Figure 2, on November 23, the average CO_2 content of the soil gas at that depth would most likely have been determined to be:

A. less than 0.30% by volume.
B. between 0.30% by volume and 0.35% by volume.
C. between 0.35% by volume and 0.40% by volume.
D. greater than 0.40% by volume.

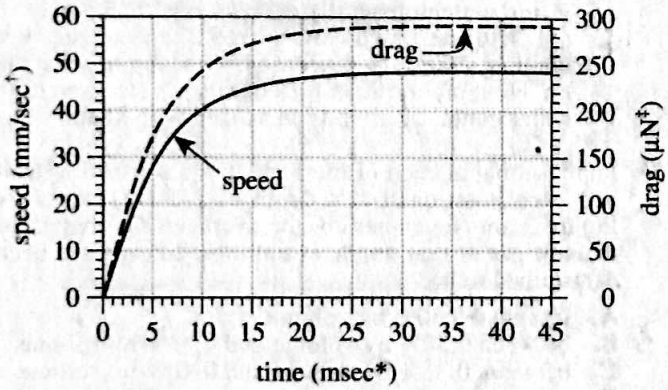
34. Suppose that a 10 g sample of soil had been collected on November 23 at a depth of 60 cm. Based on Figure 3, what mass of water would most likely have been present in the sample?

F. 1 g
G. 2 g
H. 5 g
J. 10 g

Passage VI

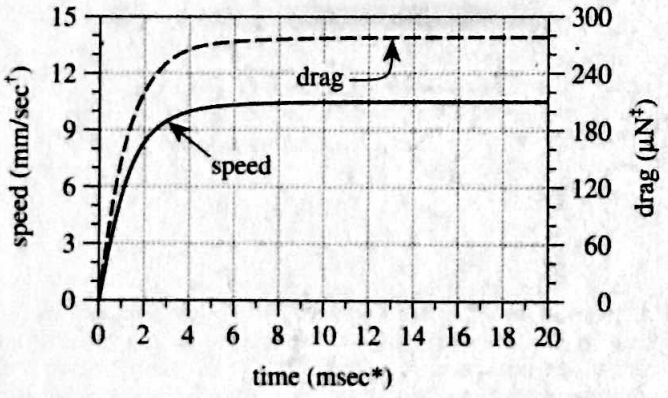
An object falling through a liquid has 3 forces acting on it: gravity, a buoyant force, and *drag* (a force that opposes motion). If the net upward force on the object is equal in magnitude to the net downward force on the object, then the object will fall at *terminal speed*.

A steel ball was dropped from rest into a column of motor oil and into a column of glycerin. Figures 1 and 2 show how the speed of the ball and the drag on the ball varied with time as the ball fell through the oil and through the glycerin, respectively. Figure 3 shows how the depth of the ball varied with time for each case.



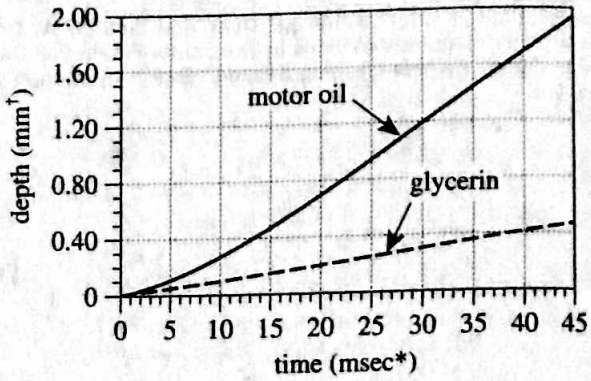
*milliseconds
†millimeters per second
‡micronewtons

Figure 1



*milliseconds
†millimeters per second
‡micronewtons

Figure 2



*milliseconds
†millimeters

Figure 3

35. Based on Figure 3, the depth of the steel ball in the motor oil at time = 50 msec would most likely have been closest to which of the following?

A. 0.50 mm
B. 0.60 mm
C. 1.90 mm
D. 2.10 mm

36. Which of the following diagrams best represents the 3 forces that acted on the steel ball—gravity (*G*), the buoyant force (*B*), and drag (*D*)—as it moved through either liquid?

(Note: Assume that down is toward the bottom of the page.)

F.


H.


G.


J.


37. The steel ball required *less* time to reach terminal speed in which liquid?

A. Motor oil; the ball took less than 10 msec in motor oil but more than 25 msec in glycerin to reach terminal speed.
B. Motor oil; the ball took more than 25 msec in motor oil but less than 10 msec in glycerin to reach terminal speed.
C. Glycerin; the ball took less than 10 msec in glycerin but more than 25 msec in motor oil to reach terminal speed.
D. Glycerin; the ball took more than 25 msec in glycerin but less than 10 msec in motor oil to reach terminal speed.

38. According to Figures 1 and 2, the steel ball's terminal speed was greater in which liquid?

F. Motor oil; the terminal speed was about 48 mm/sec in motor oil and about 10.5 mm/sec in glycerin.
G. Motor oil; the terminal speed was about 240 mm/sec in motor oil and about 210 mm/sec in glycerin.
H. Glycerin; the terminal speed was about 48 mm/sec in glycerin and about 10.5 mm/sec in motor oil.
J. Glycerin; the terminal speed was about 240 mm/sec in glycerin and about 210 mm/sec in motor oil.

39. Based on Figures 1, 2, and 3, is it reasonable to conclude that the drag on the steel ball was directly proportional to the depth of the ball?

A. Yes; both the depth and the drag increased only.
B. Yes; both the depth and the drag increased and then gradually approached a constant value.
C. No; the depth increased only, whereas the drag increased and then approached a constant value.
D. No; the depth increased and then approached a constant value, whereas the drag increased only.

40. Based on Figures 1 and 3, at a depth of 0.50 mm in the motor oil, what was the approximate drag exerted on the steel ball?

F. 230 μN
G. 250 μN
H. 270 μN
J. 290 μN

END OF TEST 4

STOP! DO NOT RETURN TO ANY OTHER TEST.