SCIENCE TEST

35 Minutes—40 Questions

DIRECTIONS: There are seven 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

Deicers (mixtures of salt and water that are used on roads to melt ice) can over time cause concrete pavement to deteriorate.

Two studies examined how 4 different deicers affected the length, mass, and compressive strength (CS) of identical cylinders made of hardened concrete. (CS is the maximum lengthwise pressure that can be applied to the ends of a cylinder without crushing it.) Each deicer was 15% by mass of $Ca(OH)_2$, NaCl, $MgCl_2$, or $CaCl_2$ kept at 4°C.

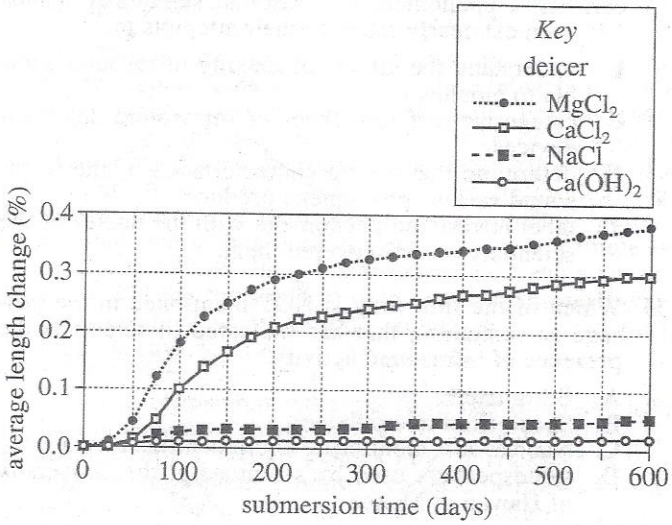


Figure 1

Study 1

Five of the cylinders were submerged in 4 L of the $Ca(OH)_2$ deicer. Every 25 days over the next 600 days, the following was done:

1. The 5 cylinders were removed from the deicer and wiped dry.
2. Each cylinder's length and mass were measured.
3. Two average values were calculated for the 5 cylinders: the average percent change in length relative to the original length and the average percent change in mass relative to the original mass.
4. The cylinders were resubmerged.

All of the above procedures were repeated for the other deicers (see Figures 1 and 2).

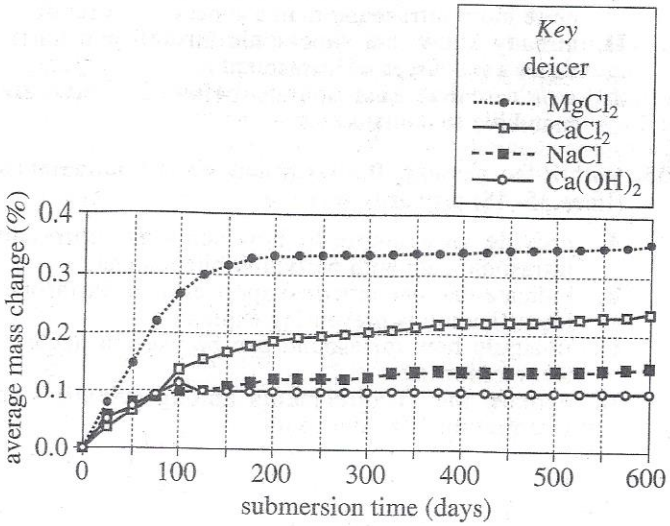


Figure 2

Study 2

Sixty more of the cylinders were submerged in 20 L of the $Ca(OH)_2$ deicer. Every 50 days over the next 600 days, the following was done:

1. Five cylinders were removed from the deicer and wiped dry.
2. Each cylinder's CS, in megapascals (MPa), was determined.
3. The average CS was calculated for the 5 cylinders.

All of the above procedures were repeated for the other deicers. Finally, the CS of 5 more of the cylinders—cylinders that had not been submerged in any deicer—was determined, and their average CS was calculated (see Figure 3).

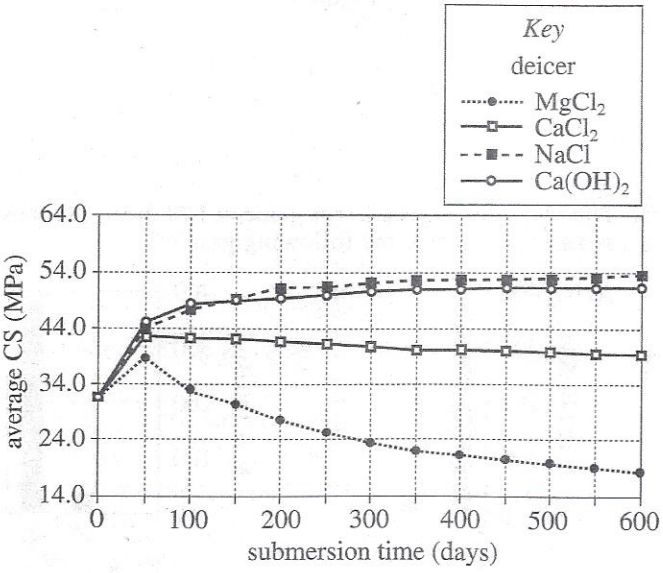


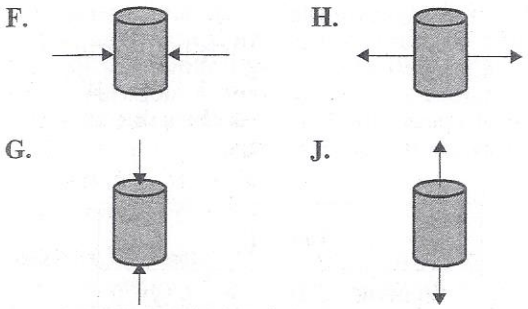
Figure 3

Figures adapted from Lawrence Sutter et al., "The Deleterious Chemical Effects of Concentrated Deicing Solutions on Portland Cement Concrete," South Dakota Department of Transportation Study SD2002-01. 2008.

1. According to Figure 1, for any submersion time after 0 days, what is the order of the 4 deicers, from the deicer that produced the greatest average percent change in cylinder length to the deicer that produced the least average percent change in cylinder length?

   A. $MgCl_2$, $CaCl_2$, NaCl, $Ca(OH)_2$
   B. $MgCl_2$, NaCl, $CaCl_2$, $Ca(OH)_2$
   C. $Ca(OH)_2$, NaCl, $CaCl_2$, $MgCl_2$
   D. $Ca(OH)_2$, NaCl, $MgCl_2$, $CaCl_2$

2. Which of the following diagrams best shows how pressure was applied to a cylinder to determine its CS ?



3. The change in the mass of the cylinders was caused by the absorption of the deicer into the concrete. Based on Figure 2, the cylinders submerged in which deicer had absorbed, on average, the greatest mass of deicer at 250 days?

   A. $MgCl_2$
   B. $CaCl_2$
   C. NaCl
   D. $Ca(OH)_2$

4. Based on the information provided, how many grams of solid NaCl would have had to be dissolved in water to prepare 1,000 grams of the NaCl deicer?

   F. 15 g
   G. 30 g
   H. 150 g
   J. 300 g

5. In the studies, it is most likely that the cylinders were submerged in deicers at 4°C because that temperature is:

   A. the freezing point of all 4 deicers.
   B. the freezing point of water.
   C. a typical summer temperature in areas where deicers are used.
   D. a typical winter temperature in areas where deicers are used.

6. For pavement made of the same concrete as the cylinders, the minimum CS that is required to maintain a smooth, uncracked road surface is 25 MPa. Based on the results of Study 2, which deicer(s) could most likely be kept in contact with this concrete continuously for 600 days without lowering the average CS of the concrete below 25 MPa ?

   F. NaCl only
   G. $MgCl_2$ and $CaCl_2$ only
   H. $MgCl_2$, NaCl, and $Ca(OH)_2$ only
   J. $CaCl_2$, NaCl, and $Ca(OH)_2$ only

Passage II

When the nucleus of an atom of a radioactive isotope undergoes certain types of decay, the atom transforms into an atom of a different isotope. An isotope's *half-life* is the time it takes for half of any given number of its nuclei to decay. An isotope's *decay constant*, λ, depends on the isotope's rate of decay. Table 1 gives the value of λ (in yr^{-1}) for 8 isotopes of different elements.

Table 1

Element	Isotope	λ (yr^{-1})
Nickel	Ni-63	0.0069
Titanium	Ti-44	0.010
Strontium	Sr-90	0.024
Hydrogen	H-3	0.056
Sulfur	S-35	2.9
Iron	Fe-59	5.7
Phosphorus	P-32	18
Iodine	I-131	32

Figures 1 and 2 show, for each of 6 of the isotopes listed in Table 1, the change over time in the number of the nuclei remaining, N_t, in a sample initially containing 1,000 of the nuclei.

(Note: In Figure 1, the unit of time is *years*; in Figure 2, the unit of time is *days*.)

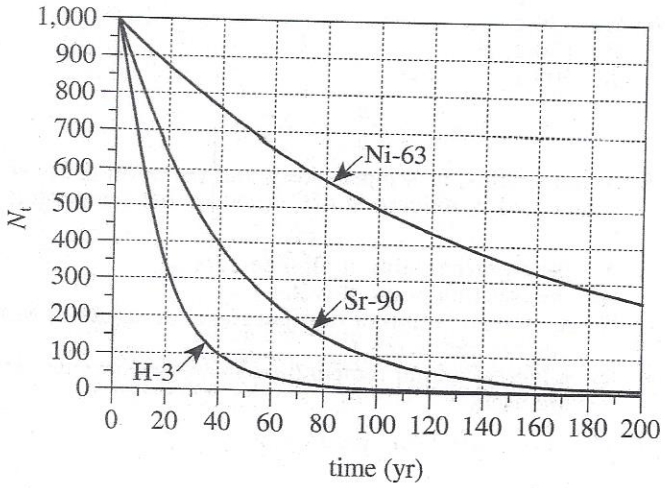


Figure 1

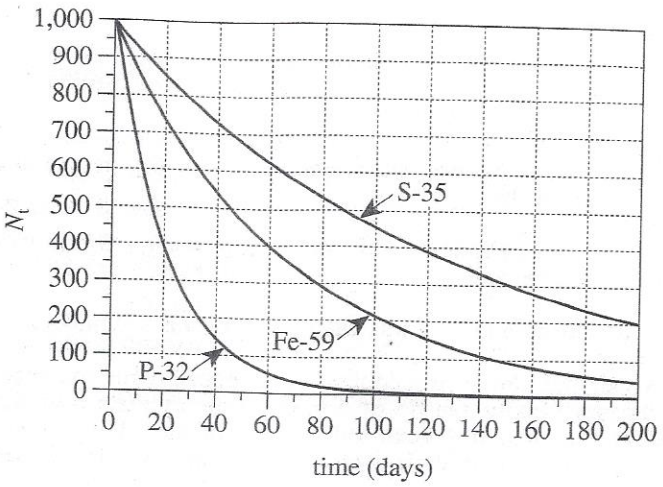
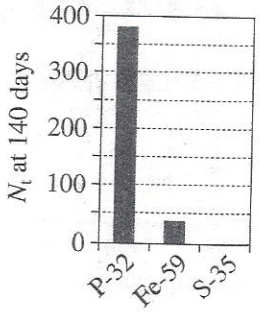


Figure 2

7. The data in Figure 2 for time = 140 days are best shown by which of the following graphs?

A.



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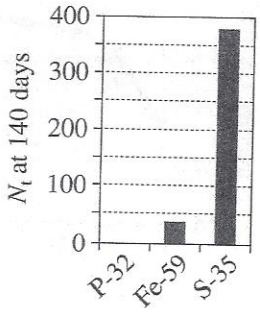
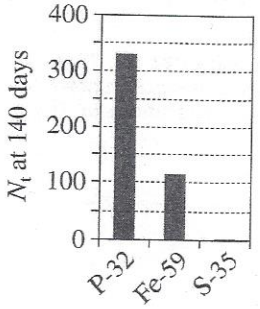
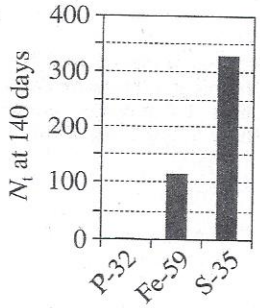


B.



D.



8. According to Figure 2, for which isotope, S-35 or P-32, will the average rate of decay be greater over the first 200 days?

   F. S-35, because at any given time after zero, S-35 will have the lower N_t.
   G. S-35, because at any given time after zero, S-35 will have the higher N_t.
   H. P-32, because at any given time after zero, P-32 will have the lower N_t.
   J. P-32, because at any given time after zero, P-32 will have the higher N_t.

9. Based on Table 1 and Figure 1, if a sample initially contains 1,000 Ti-44 atoms, the number of Ti-44 atoms in the sample 20 yr later will most likely be:

   A. less than 300.
   B. between 300 and 600.
   C. between 600 and 900.
   D. greater than 900.

10. According to Figure 1, the half-life of Sr-90 is approximately:

    F. 30 yr.
    G. 90 yr.
    H. 160 yr.
    J. 200 yr.

11. Based on Figure 2, if a sample contained 2,000 atoms of Fe-59 at time = 0, at approximately what time will the N_t of the sample be 400 ?

    A. 40 days
    B. 60 days
    C. 80 days
    D. 100 days

Passage III

Transferrin is a blood protein. When in the presence of iron ions (Fe^{3+}), each transferrin molecule will bind with 2 Fe^{3+}. *Iron chelators* are used to remove excess iron in the blood because they can bind with and thereby remove Fe^{3+} from transferrin.

Transferrin bound to Fe^{3+} strongly absorbs light at a wavelength of 466 nanometers (nm), but unbound transferrin and unbound Fe^{3+} do not. Three experiments were done using a *colorimeter* (a device that measures a solution's absorbance of light) to study the removal of Fe^{3+} from transferrin by iron chelators.

Experiment 1

Seven solutions (Solutions 1–7) were made, all with an initial unbound transferrin concentration of 100.0 micromoles per liter (μM), but each with a different initial unbound Fe^{3+} concentration. The solutions were incubated at 37°C for 30 min. A test tube containing a sample of Solution 1 was placed in the colorimeter. The colorimeter was adjusted such that the absorbance reading measured at 466 nm for Solution 1 at 37°C was 0.00. The absorbance at 466 nm of each of Solutions 2–7 at 37°C was then measured (see Table 1).

Table 1

Solution	Initial unbound Fe^{3+} concentration (μM)	Absorbance
1	0.0	0.00
2	50.0	0.35
3	100.0	0.64
4	150.0	0.76
5	200.0	0.80
6	250.0	0.80
7	300.0	0.80

Experiment 2

For each of 4 trials, 0.0010 mL of solution that contained 10 millimoles of 1 of 4 iron chelators was added to 3 mL of Solution 5. The absorbance at 466 nm was then monitored at 37°C over the next 4,000 sec (see Figure 1).

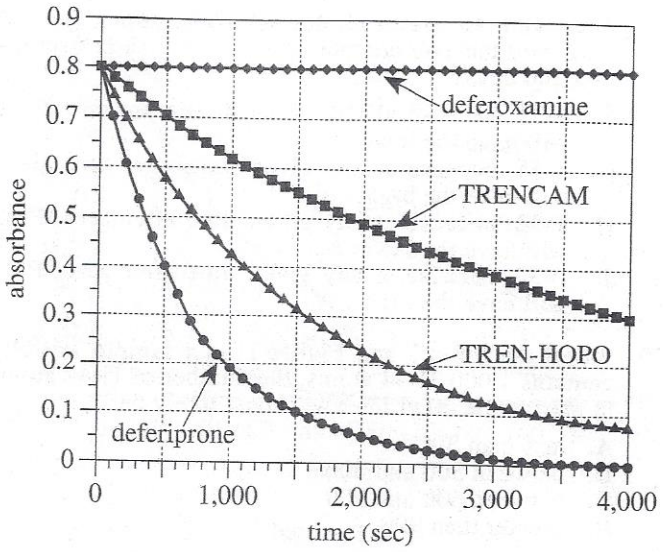


Figure 1

Figure 1 adapted from Isabelle Turcot et al., "Fast Biological Iron Chelators: Kinetics of Iron Removal from Human Diferric Transferrin by Multidentate Hydroxypyrodonates." ©2000 by Society of Biological Inorganic Chemistry.

Experiment 3

The deferiprone trial in Experiment 2 was repeated twice, except that one trial was carried out at 25°C and the other trial was carried out at 32°C (see Figure 2).

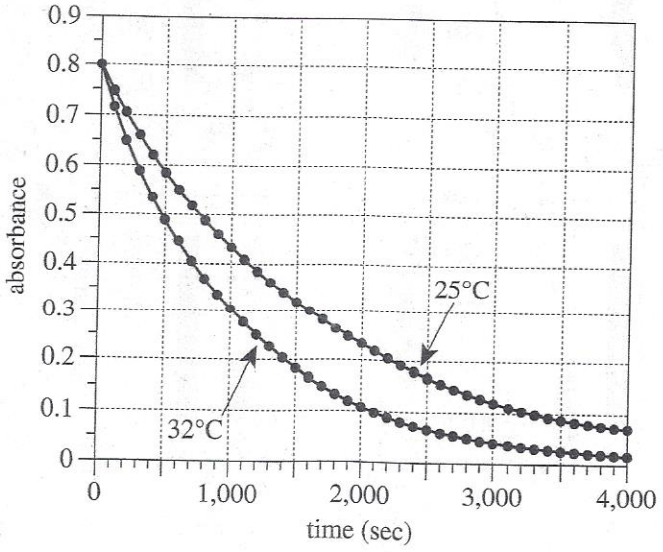


Figure 2

Figure 2 adapted from Erin E. Battin et al., "Using Proteins in a Bioinorganic Laboratory Experiment: Iron Loading and Removal from Transferrin." ©2009 by Division of Chemical Education, Inc., American Chemical Society.

12. When a colorimeter is used, a solution called a *blank* is first placed in the colorimeter to establish a baseline value against which other solutions will be measured. Which of the solutions served as the blank?

F. Solution 1
G. Solution 3
H. Solution 5
J. Solution 7

13. In each trial of Experiments 2 and 3, how often was an absorbance measurement recorded?

A. Every 10 sec
B. Every 50 sec
C. Every 100 sec
D. Every 500 sec

14. Based on the experiments, as the concentration of Fe^{3+} bound to transferrin in a solution *decreases*, the absorbance:

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

15. Based on the results of Experiments 2 and 3, the average rate of change in the absorbance during the TREN-HOPO trial was closest to that observed during the trial with what other iron chelator and at what temperature?

A. TRENCAM at 25°C
B. TRENCAM at 37°C
C. Deferiprone at 25°C
D. Deferiprone at 32°C

16. Suppose that in Experiment 1, 10 mL of Solution 2 had been mixed with 10 mL of Solution 4 after the solutions were incubated. If the absorbance of a sample of the resulting solution had been measured at 37°C, it would most likely have been closest to which of the following?

F. 0.35
G. 0.64
H. 0.76
J. 0.80

17. Based on the description of Experiment 1 and of a colorimeter, the material making up the test tube that was placed in the colorimeter most likely:

A. absorbed little or no light at 466 nm.
B. strongly absorbed light at 466 nm.
C. reflected all light that was less than 466 nm.
D. reflected all light that was greater than 466 nm.

Passage IV

In 2 studies, students recorded the temperature changes that occurred in different liquids when the liquids were heated for 10 min each by various metal coils through which selected amounts of electrical current, I, flowed.

For each trial in the studies, the students carried out the following procedure: First, they poured 400 mL of a liquid into an insulated container fitted with a thermometer and a metal coil and sealed the container (see diagram).

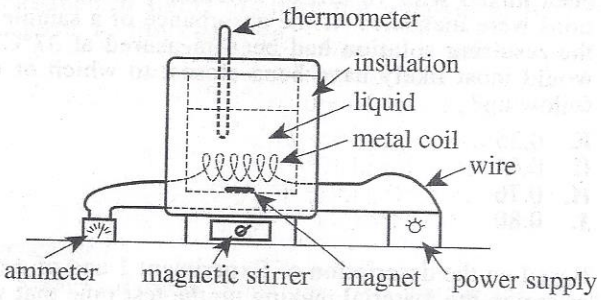


diagram of apparatus

With the liquid, the container, and the coil at room temperature, 25°C, the students began to stir the liquid with a magnetic stirrer. Next, they adjusted the voltage across the ends of the coil until I reached the desired value, in amps (A). For the next 10 min, they continued to stir the liquid. After 10 min of heating, they recorded T, the liquid's temperature, in °C, and computed ΔT, the difference between T and the liquid's initial temperature of 25°C.

Study 1

The students computed water's ΔT after 10 min of heating at each of several selected values of I, first with a copper coil, then with an aluminum coil, and finally with a tungsten coil. Plots of water's ΔT versus I for each metal coil are shown in Figure 1.

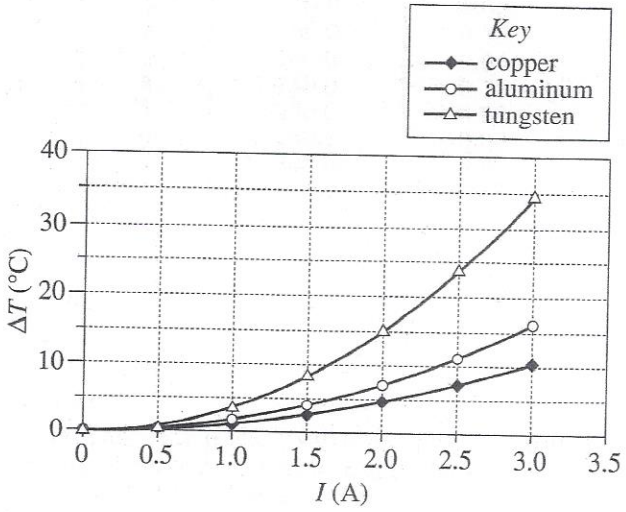


Figure 1

Study 2

With the aluminum coil, the students heated ethylene glycol for 10 min at each of the values of I selected in Study 1. For each value of I, they computed ΔT. They did likewise with vegetable oil, substituting it for the ethylene glycol. Plots of ΔT versus I for water (from Figure 1), the ethylene glycol, and the vegetable oil are shown in Figure 2.

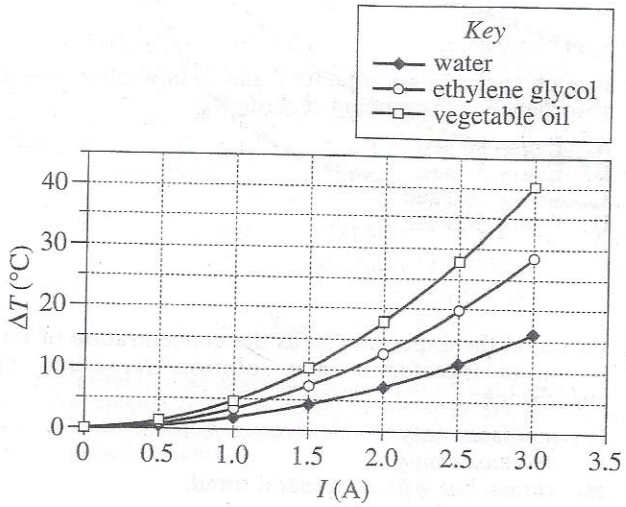


Figure 2

18. According to the results of the studies, for a given coil and a given liquid, as the current that passed through the coil was increased, ΔT:

F. increased only.
G. decreased only.
H. varied, but with no general trend.
J. remained the same.

19. Based on the results of the studies, to obtain the *lowest* ΔT after 10 min of heating at a given I using the apparatus diagrammed in the passage, the students should select which liquid and which metal coil?

	liquid	metal coil
A.	water	copper
B.	water	aluminum
C.	ethylene glycol	tungsten
D.	vegetable oil	aluminum

20. The students stirred each liquid for which of the following reasons?

- **F.** To provide additional heat to the liquid
- **G.** To ensure that the temperature was uniform throughout the liquid
- **H.** To prevent the liquid from settling to the bottom of the container
- **J.** To prevent the liquid from contacting the metal coil

21. Suppose that, in Study 1, the students had also tested a coil made of a fourth metal, Metal X, at $I = 1.5$ A, and determined that after 10 min of heating, ΔT was 6°C. Based on Figure 1, if the students had next tested the Metal X coil at $I = 2.0$ A, ΔT after 10 min of heating would most likely have been:

- **A.** less than 5°C.
- **B.** between 5°C and 7°C.
- **C.** between 7°C and 15°C.
- **D.** greater than 15°C.

22. Based on the results of Study 2, when vegetable oil was heated with $I = 1.5$ A, T at the end of 10 min was closest to which of the following?

- **F.** 30°C
- **G.** 35°C
- **H.** 40°C
- **J.** 45°C

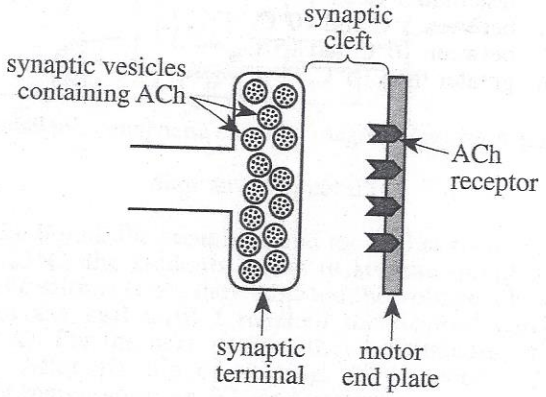
23. Suppose that, in a new study, the tungsten coil with $I = 2.0$ A is used to heat 200 mL of water. After the water is heated for 10 min, ΔT will most likely be:

- **A.** less than 5°C.
- **B.** between 5°C and 10°C.
- **C.** between 10°C and 15°C.
- **D.** greater than 15°C.

Passage V

Introduction

A skeletal *neuromuscular junction* (NMJ; see the figure) is composed of a *synaptic terminal* (a tip of an axon of a neuron), a *motor end plate* (a depression in the plasma membrane of a muscle fiber), and a *synaptic cleft* (the region between these 2 structures). The synaptic terminal contains *synaptic vesicles*: structures that contain the neurotransmitter *acetylcholine* (ACh). When the neuron fires, synaptic vesicles fuse with the neuron's plasma membrane and release ACh into the synaptic cleft. ACh then diffuses across the synaptic cleft and binds to *ACh receptors* (membrane proteins produced by the muscle fiber) in the motor end plate. If this binding does not occur, the muscle fiber cannot contract.



If a person ingests *botulin* (a toxin), it enters the bloodstream, diffuses into NMJ synaptic clefts, and disrupts the contraction of the muscle fibers associated with these NMJs. Four hypotheses propose mechanisms for the disruption of function at an NMJ.

Hypothesis 1

Botulin is absorbed from the synaptic cleft by the synaptic terminal. Botulin then binds to and breaks down the neuron's *docking proteins* (proteins required for the fusion of synaptic vesicles with the neuron's plasma membrane). Because the vesicles cannot fuse with the plasma membrane, they cannot release ACh into the synaptic cleft. Thus, ACh does not bind to the ACh receptors. Therefore, the muscle fiber cannot contract.

Hypothesis 2

Botulin remains in the synaptic cleft, where it binds to and breaks down ACh before the ACh can diffuse across the synaptic cleft and bind to the ACh receptors. Therefore, the muscle fiber cannot contract.

Hypothesis 3

Botulin remains in the synaptic cleft, where it binds to and irreversibly blocks the ACh receptors. As a result, ACh cannot bind to the ACh receptors. Therefore, the muscle fiber cannot contract.

Hypothesis 4

Botulin is absorbed from the synaptic cleft by the muscle fiber. Botulin then binds to and breaks down *myosin*, a protein that is an essential component of the contractile apparatus of a muscle fiber. As a result of this breakdown, the muscle fiber cannot contract.

24. Both Hypothesis 1 and Hypothesis 4 indicate that, in the human body, botulin is:

- **F.** absorbed by a human cell.
- **G.** synthesized by a human cell.
- **H.** destroyed before it leaves the bloodstream.
- **J.** excreted before it enters the digestive tract.

25. Which of the following statements best characterizes ACh as it is described in the introduction?

- **A.** It is a hormone because it carries information from a muscle fiber to a synaptic terminal.
- **B.** It is a hormone because it carries information from a synaptic terminal to a muscle fiber.
- **C.** It is a neurotransmitter because it carries information from a muscle fiber to a synaptic terminal.
- **D.** It is a neurotransmitter because it carries information from a synaptic terminal to a muscle fiber.

26. An *acetylcholinesterase* is a molecule that binds to and breaks down ACh. Which hypothesis indicates that botulin functions like an acetylcholinesterase?

- **F.** Hypothesis 1
- **G.** Hypothesis 2
- **H.** Hypothesis 3
- **J.** Hypothesis 4

27. In which of the following ways do Hypotheses 3 and 4 differ with regard to how botulin disrupts muscle contraction? Hypothesis 3 asserts that botulin:

- **A.** breaks down a protein that partially composes the plasma membrane of a neuron; Hypothesis 4 asserts that botulin blocks ACh binding sites.
- **B.** breaks down a protein that partially composes the contractile apparatus of a muscle fiber; Hypothesis 4 asserts that botulin blocks ACh binding sites.
- **C.** blocks ACh binding sites; Hypothesis 4 asserts that botulin breaks down a protein that partially composes the plasma membrane of a neuron.
- **D.** blocks ACh binding sites; Hypothesis 4 asserts that botulin breaks down a protein that partially composes the contractile apparatus of a muscle fiber.

28. In which of the following ways does Hypothesis 1 differ from the other 3 hypotheses with regard to the location in the body where botulin is likely to be found after it is consumed? Only Hypothesis 1 asserts that botulin enters:

F. NMJs.
G. neurons.
H. the bloodstream.
J. muscle fibers.

29. According to Hypotheses 3 and 4, which of the following statements best describes a step in the mechanism that results in the disruption of function at an NMJ by botulin?

A. Botulin binds to a protein that is part of a muscle fiber.
B. Botulin binds to a protein that is part of a neuron.
C. Botulin synthesizes a type of protein that is also synthesized by a muscle fiber.
D. Botulin synthesizes a type of protein that is also synthesized by a neuron.

30. Which hypothesis would be best supported by the finding that botulin has a high affinity for the ACh receptors in a motor end plate?

F. Hypothesis 1
G. Hypothesis 2
H. Hypothesis 3
J. Hypothesis 4

Passage VI

Tasters are people who can taste Chemical P. *Nontasters* are people who cannot taste Chemical P. The ability to taste Chemical P is determined by Gene T, which has 2 alleles: T and t. In a population that is not evolving—a population in *Hardy-Weinberg equilibrium* (HWE)—the frequency of allele T is p and the frequency of allele t is q. Table 1 shows the Gene T genotype(s) of tasters and of nontasters and the expression that predicts the frequency of each genotype in a population in HWE. Table 2 shows p, q, and the frequency of each Gene T genotype for 4 populations in HWE.

Table 1

Phenotype	Genotype	Frequency
Taster	TT	p^2
Taster	Tt	$2pq$
Nontaster	tt	q^2

Table 2

Population	p	q	Frequency of: TT	Tt	tt
1	0.5	0.5	0.25	0.50	0.25
2	0.4	0.6	N.P.	0.48	0.36
3	0.8	N.P.	0.64	0.32	0.04
4	N.P.	N.P.	0.09	0.42	0.49

Note: N.P. indicates that the value has not been provided.

31. Based on Table 2, in which population would the number of people with the genotype TT and the number of people with the genotype tt be closest to the same?

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

32. The frequency of nontasters is greatest in which population?

F. Population 1
G. Population 2
H. Population 3
J. Population 4

33. A student concluded that for Population 3, p is greater than q. Is this conclusion consistent with Table 2 ?

A. Yes; $p = 0.8$ and $q = 0.64$.
B. Yes; $p = 0.8$ and $q = 0.2$.
C. No; $p = 0.8$ and $q = 0.8$.
D. No; $p = 0.8$ and $q = 0.9$.

34. For Population 2, what is the frequency of the genotype TT ?

F. 0.16
G. 0.4
H. 0.6
J. 1

35. People that are heterozygous for Gene T are most common in the population for which p is:

A. greater than q.
B. less than q.
C. equal to q.
D. not provided.

Passage VII

When an object floats in a liquid, a fraction of the object extends above the surface of the liquid.

Seven objects with different densities were placed in containers of 4 different liquids. Table 1 lists the objects and their densities, in grams per cubic centimeter (g/cm^3), at 15°C.

Table 1

Object	Density (g/cm^3)
1	0.100
2	0.200
3	0.300
4	0.400
5	0.500
6	0.600
7	0.700

Table 2 lists the 4 liquids and their densities, in g/cm^3, at 15°C.

Table 2

Liquid	Density (g/cm^3)
Crude oil	0.87
Gasoline	0.74
Mercury	13.6
Water	0.99

Figure 1 shows, for each liquid, a graph of the fraction of each object extending above the liquid's surface versus the object's density, in g/cm^3.

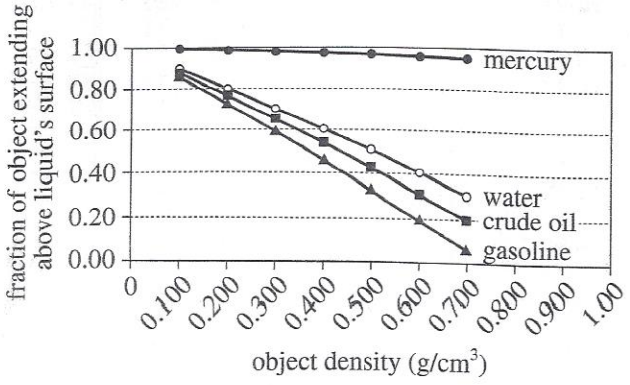


Figure 1

36. Based on Figure 1, for each liquid, as object density increased, the fraction of the object extending above the liquid's surface:

F. increased only.
G. decreased only.
H. varied, but with no general trend.
J. remained the same.

37. Based on Table 1 and Figure 1, the fraction of Object 6 extending above the surface of the crude oil was closest to which of the following values?

A. 0.10
B. 0.20
C. 0.30
D. 0.40

38. A material composing a cube has a density of 0.200 g/cm^3 at 15°C. Each side of the cube is 10 cm long. The cube floats in a container of water. Based on Figure 1, what *volume* of the cube, in cm^3, will extend above the surface of the water?

F. 200 cm^3
G. 600 cm^3
H. 800 cm^3
J. 1,000 cm^3

39. Suppose an object with a density of 0.99 g/cm^3 floats in a container of water, and both the object and the water are at 15°C. If the temperatures of both the object and the water are raised to 90°C, and if the object neither expands nor contracts with the change in temperature, will the object more likely sink or remain afloat?

A. Sink, because the water will become more dense than the object.
B. Sink, because the water will become less dense than the object.
C. Remain afloat, because the water will become more dense than the object.
D. Remain afloat, because the water will become less dense than the object.

40. What is the meaning of the value for the density of mercury that is given in Table 2 ?

F. One g of mercury has a volume of 13.6 cm^3.
G. One g of mercury has a mass of 13.6 cm^3.
H. One cm^3 of mercury has a volume of 13.6 g.
J. One cm^3 of mercury has a mass of 13.6 g.

END OF TEST 4

STOP! DO NOT RETURN TO ANY OTHER TEST.