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 reaction is at *equilibrium* when the rate of the forward reaction equals the rate of the reverse reaction. At equilibrium, the ratio of product concentration(s) to reactant concentration(s) is the *equilibrium constant*, K.

Consider the following reaction at equilibrium:

$$X + Y \rightleftharpoons Z$$

For this reaction, K is given by:

$$K = \frac{[Z]}{[X][Y]}$$

The brackets ([ ]) around the symbol for a substance indicate the equilibrium concentration of the substance.

This reaction was studied in 10 trials. Trials 1–5 were conducted at the same temperature (see Table 1), and Trials 6–10 were conducted at different temperatures (see Table 2).

Table 1

Trial	[X] (mol/L*)	[Y] (mol/L)	[Z] (mol/L)	K
1	1.00	1.50	0.15	0.10
2	1.00	2.00	0.20	0.10
3	2.00	1.00	0.20	0.10
4	2.00	1.50	0.30	0.10
5	2.00	2.50	0.50	0.10

*moles per liter

Note: The *initial* concentration of X, of Y, and of Z was varied across Trials 1–5. In no trial was the initial concentration of one substance equal to that of either of the other two substances.

Table 2

Trial	Temperature (°C)	[X] (mol/L*)	[Y] (mol/L)	[Z] (mol/L)	K
6	−15	0.15	0.65	1.00	10.5
7	0	0.68	1.18	0.47	0.59
8	10	1.00	1.50	0.15	0.10
9	25	1.13	1.63	0.016	0.0087
10	40	1.15	1.65	0.002	0.0011

*moles per liter

Note: The *initial* concentration of X, of Y, and of Z was the same in each of Trials 6–10. In no trial was the initial concentration of one substance equal to that of either of the other two substances.

1. According to Table 1, in Trial 5, what was the equilibrium concentration of Z ?
   - **A.** 0.10 mol/L
   - **B.** 0.50 mol/L
   - **C.** 2.00 mol/L
   - **D.** 2.50 mol/L

2. Suppose that Trial 7 had been conducted at −5°C. Based on Table 2, K would most likely have been closest to which of the following?
   - **F.** 0.020
   - **G.** 0.20
   - **H.** 2.0
   - **J.** 20

3. Suppose an additional trial had been conducted at the same temperature at which Trials 1–5 were conducted. If [X] and [Y] had each been 2.00 mol/L, [Z] would most likely have been:

A. 0.15 mol/L.
B. 0.20 mol/L.
C. 0.40 mol/L.
D. 0.60 mol/L.

4. Based on Tables 1 and 2, how many trials were most likely conducted at temperatures above the freezing point of water?

F. 3
G. 5
H. 8
J. 10

5. Consider the temperature data in Table 2. Did the reaction more likely reach equilibrium faster in Trial 6 or Trial 10 ?

A. Trial 6, because the rate of a reaction is generally greater at a lower temperature.
B. Trial 6, because the rate of a reaction is generally greater at a higher temperature.
C. Trial 10, because the rate of a reaction is generally greater at a lower temperature.
D. Trial 10, because the rate of a reaction is generally greater at a higher temperature.

6. Assume that substances X, Y, and Z were gases throughout each trial. The boiling points of X, Y, and Z must each be:

F. below −15°C.
G. between −15°C and 10°C.
H. between 10°C and 40°C.
J. above 40°C.

Passage II

Juvenile *Callinectes sapidus* (a species of crab) typically hide among *Zostera marina* (a species of sea grass) to avoid detection by aquatic predators. Two experiments examined how *Z. marina* population density and *C. sapidus* body size affect the ability of juvenile *C. sapidus* to avoid predation in a particular coastal area.

Experiment 1

Each of 200 small (4.5 mm wide) juvenile *C. sapidus* was prepared for testing as follows: One end of a 1.0 m piece of nylon fishing line was tied around the middle of the *C. sapidus*, and the knot was then securely attached to the *C. sapidus* with *cyanoacrylate* (a strong waterproof glue). The other end of the line was tied to its own metal rod. After being prepared, the 200 *C. sapidus* were equally divided into 4 groups (Groups 1–4).

Each rod associated with a Group 1 *C. sapidus* was randomly placed within a 100 m^2 plot having a *Z. marina* population density of 0 shoots/m^2 (sand only, no plants). Twenty-four hours later, the number of surviving Group 1 *C. sapidus* was determined.

The procedure for Group 1 was repeated for Groups 2–4, except that Group 2, Group 3, and Group 4 were placed in plots having a *Z. marina* population density of 380 shoots/m^2, 760 shoots/m^2, and 1,600 shoots/m^2, respectively.

The results are shown in Table 1.

Table 1

Group	*Z. marina* population density (shoots/m^2)	Number of surviving *C. sapidus*
1	0	26
2	380	31
3	760	24
4	1,600	12

Experiment 2

Each of 200 large (23.3 mm wide) juvenile *C. sapidus* was prepared as in Experiment 1. After being prepared, the *C. sapidus* were equally divided into 4 groups (Groups 5–8). The procedures for Groups 1–4 were repeated for Groups 5–8 (see Table 2).

Table 2

Group	*Z. marina* population density (shoots/m^2)	Number of surviving *C. sapidus*
5	0	0
6	380	5
7	760	19
8	1,600	37

Tables adapted from J. L. Schulman, "Habitat Complexity as a Determinant of Juvenile Blue Crab Survival." ©1996 by The College of William and Mary.

7. According to the results of Experiment 2, as the *Z. marina* population density increased from 0 shoots/m^2 through 1,600 shoots/m^2, the number of surviving large juvenile *C. sapidus*:

A. increased only.
B. decreased only.
C. increased, then decreased.
D. decreased, then increased.

8. Suppose that in Experiment 2 a group of *C. sapidus* had been placed in a *Z. marina* plot having a population density of 562 shoots/m^2. The number of surviving *C. sapidus* in that group would most likely have been:

F. less than 5.
G. between 5 and 19.
H. between 19 and 37.
J. greater than 37.

9. To consider whether the body size of juvenile *C. sapidus* affects their ability to avoid predation, the results for which of the following 2 groups should be compared?

A. Groups 1 and 4
B. Groups 2 and 5
C. Groups 4 and 8
D. Groups 5 and 7

10. Which of the nylon line and the cyanoacrylate, if either, functioned to prevent the *C. sapidus* from escaping?

F. The nylon line only
G. The cyanoacrylate only
H. Both the nylon line and the cyanoacrylate
J. Neither the nylon line nor the cyanoacrylate

11. Which of *C. sapidus* or *Z. marina* would occupy the higher trophic level in a food chain?

A. *C. sapidus*, because *C. sapidus* is a producer and *Z. marina* is a consumer.
B. *C. sapidus*, because *C. sapidus* is a consumer and *Z. marina* is a producer.
C. *Z. marina*, because *Z. marina* is a producer and *C. sapidus* is a consumer.
D. *Z. marina*, because *Z. marina* is a consumer and *C. sapidus* is a producer.

12. Which of the following statements describes a difference between the cells of *C. sapidus* and the cells of *Z. marina* ? The cells of *C. sapidus*:

F. have a nucleus, whereas the cells of *Z. marina* lack a nucleus.
G. lack a nucleus, whereas the cells of *Z. marina* have a nucleus.
H. have a cell wall, whereas the cells of *Z. marina* lack a cell wall.
J. lack a cell wall, whereas the cells of *Z. marina* have a cell wall.

13. Which of the following statements comparing an aspect of the design of the 2 experiments is accurate?

A. The *C. sapidus* in Experiment 2 were exactly 3 times as wide as the *C. sapidus* in Experiment 1.
B. The length of time needed to perform Experiment 1 was less than the length of time needed to perform Experiment 2.
C. The number of surviving *Z. marina* was measured in both Experiments 1 and 2.
D. In both experiments, there were initially 50 *C. sapidus* per group.

Passage III

Two students were each asked to experimentally determine the speed of sound in air, s_a. For the atmospheric conditions in which their experiments were performed, the correct value of s_a was 347.1 m/sec.

Experiment 1

Student 1 placed a horn, which could emit a short pulse of sound waves, at a distance x, in m, from a tall cliff (see Figure 1).

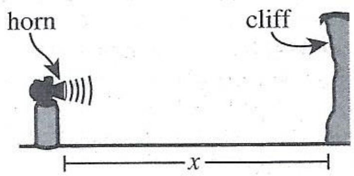


Figure 1

He started a stopwatch when he heard the horn emit a sound pulse and stopped the stopwatch when he heard an echo return from the cliff. He recorded this time interval, Δt_1, in sec, and then calculated s_a using the equation

$$s_a = \frac{2x}{\Delta t_1}$$

Student 1 performed 3 trials at each of 3 values of x, averaging the s_a results at each value of x (see Table 1).

Table 1

Trial	x (m)	Δt_1 (sec)	s_a (m/sec)	Average s_a (m/sec)
1		1.4	290	
2	200	1.5	270	280
3		1.4	290	
4		3.0	330	
5	500	3.1	320	330
6		3.0	330	
7		5.9	340	
8	1,000	5.8	350	340
9		5.9	340	

Experiment 2

Student 2 placed the horn and 2 microphones—M_1 and M_2—in a straight line such that the microphones were separated by a distance y. She then connected a timer to both microphones (see Figure 2).

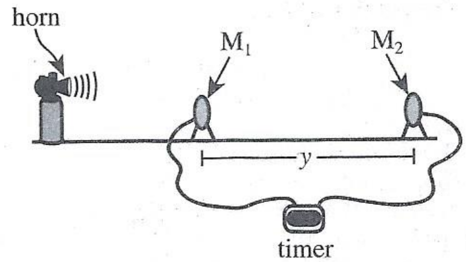


Figure 2

She set the timer to start when the first microphone detected a sound pulse and to stop when the second microphone detected a sound pulse. She recorded this time interval, Δt_2, and then calculated s_a using the equation

$$s_a = \frac{y}{\Delta t_2}$$

Student 2 performed 3 trials at each of 3 values of y, averaging the s_a results at each value of y (see Table 2).

Table 2

Trial	y (m)	Δt_2 (sec)	s_a (m/sec)	Average s_a (m/sec)
10		0.144	347	
11	50	0.143	350	347
12		0.145	345	
13		0.217	346	
14	75	0.216	347	346
15		0.218	344	
16		0.290	345	
17	100	0.289	346	346
18		0.288	347	

14. Suppose Student 2 had conducted a trial in which Δt_2 was 0.191 sec. The value of y in this trial would most likely have been:

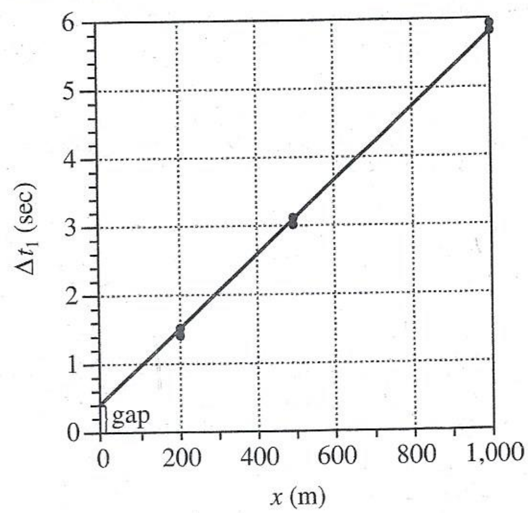
F. less than 50 m.
G. between 50 m and 75 m.
H. between 75 m and 100 m.
J. greater than 100 m.

15. Which of the objects listed below were used in both Experiment 1 and Experiment 2 ?

I. A horn
II. A microphone
III. A timing device

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

16. Student 1 plotted the Δt_1 data versus x and then graphed a line of best fit to the data, as shown below.



The gap shown near the bottom of the vertical axis suggests that even if the value of x had been 0 m, the value of Δt_1 would not have been 0 sec, as one might expect. Based on the description of Experiment 1, this gap was most likely the result of:

F. errors due to human reaction time in starting and/or stopping the stopwatch.
G. the stopwatch itself consistently underestimating the value of Δt_1.
H. the echoes traveling faster than the original sound pulses.
J. the horn being accidentally placed closer to the cliff than intended.

17. In general, the farther a sound wave travels, the more it *attenuates* (reduces in volume), making detection more difficult. In which experiment was attenuation of greater concern?

A. Experiment 1; sound waves had to travel shorter distances in Experiment 1 than in Experiment 2.
B. Experiment 1; sound waves had to travel longer distances in Experiment 1 than in Experiment 2.
C. Experiment 2; sound waves had to travel shorter distances in Experiment 2 than in Experiment 1.
D. Experiment 2; sound waves had to travel longer distances in Experiment 2 than in Experiment 1.

18. Based on the results of both experiments, regardless of the apparatus or procedure used, on average, as a sound pulse's travel distance increased, the recorded time interval:

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

19. In calculating the value of s_a, Student 1 needed to include a factor of 2 in the numerator. However, Student 2 did not include this factor because:

A. in Experiment 1, sound had to travel over the distance x twice, whereas in Experiment 2, sound had to travel over the distance y once.
B. in Experiment 1, sound had to travel over the distance x once, whereas in Experiment 2, sound had to travel over the distance y twice.
C. every value of x was at least 2 times every value of y.
D. every value of x was less than 2 times every value of y.

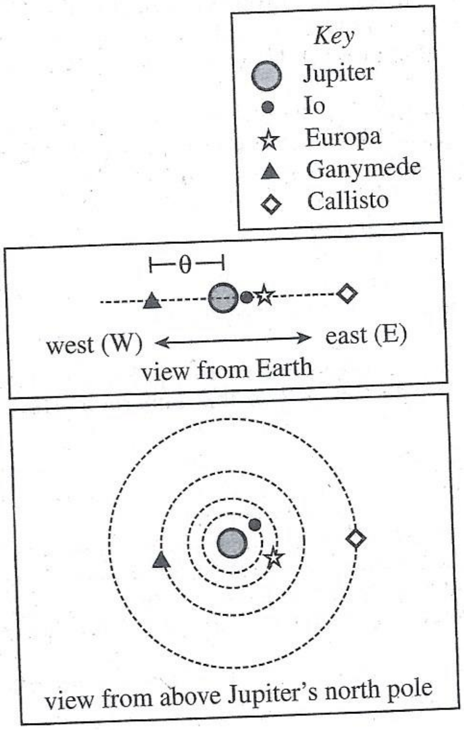
20. Overall, which student obtained the more *accurate* set of s_a data?

(Note: This question is concerned with the *accuracy* of a data set, NOT the *precision* of a data set.)

F. Student 1, because the s_a values in Table 1 are spread over a larger range than are the s_a values in Table 2.
G. Student 1, because the s_a values in Table 1 are closer, on average, to the correct value of s_a than are the values of s_a in Table 2.
H. Student 2, because the s_a values in Table 2 are spread over a smaller range than are the s_a values in Table 1.
J. Student 2, because the s_a values in Table 2 are closer, on average, to the correct value of s_a than are the values of s_a in Table 1.

Passage IV

As viewed from Earth, Jupiter's 4 largest moons—the *Galilean* moons—appear to move relative to Jupiter along an east-west line. The farther from Jupiter a moon appears to be, the greater its *angular separation*, θ. Figure 1 shows these moons' positions at midnight on a certain day in June 2012 as viewed from Earth (top section) and as viewed from above Jupiter's north pole (bottom section).



Note: The figure is not drawn to scale. In the top section, only θ for Ganymede is shown.

Figure 1

Figure 2 shows θ for each moon from midnight on June 20, 2012, to midnight on June 28, 2012. For each moon, 1 *wave cycle* represents 1 orbit around Jupiter. (The time to complete 1 orbit is the time between any 2 consecutive peaks or any 2 consecutive troughs.)

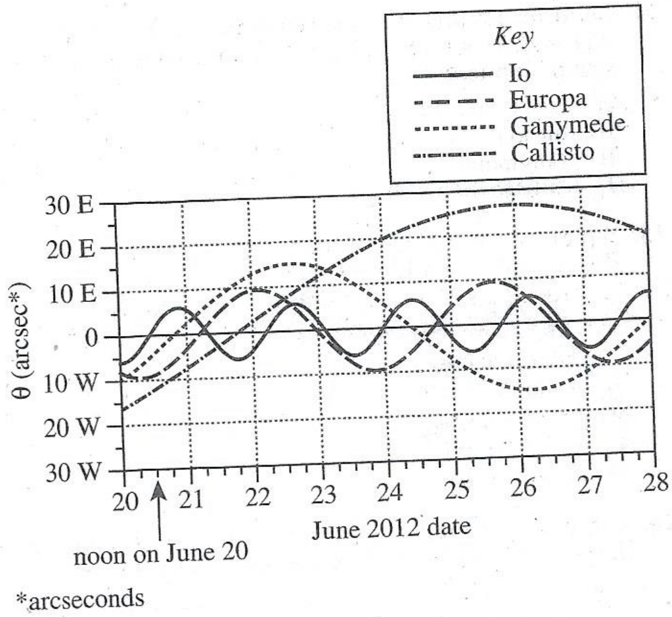


Figure 2

Figure 2 adapted from Sylvain Rondi, *Jupiter Version 2: Programme gratuit de calcul d'éphémérides des satellites galiléens de Jupiter.* ©2009 by Sylvain Rondi.

21. The number of orbits per week is a measure of *orbital frequency*. Based on Figure 2, which Galilean moon has the highest orbital frequency?

A. Io
B. Europa
C. Ganymede
D. Callisto

22. Based on Figure 2, Callisto completes 1 orbit around Jupiter in approximately how many days?

F. Fewer than 4
G. Between 4 and 6
H. Between 6 and 8
J. More than 8

23. Based on Figure 2, as viewed from Earth at midnight on June 27, which Galilean moon appeared farthest west of Jupiter?

A. Io
B. Europa
C. Ganymede
D. Callisto

24. According to Figure 2, at *noon* on June 23, θ for Ganymede was approximately:

F. 10 arcsec east.
G. 10 arcsec west.
H. 14 arcsec east.
J. 14 arcsec west.

25. According to Figure 2, at which of the following times in 2012 was the angular separation for Callisto closest to 20 arcsec east?

A. 6:00 a.m. on June 26
B. 6:00 a.m. on June 27
C. 6:00 p.m. on June 26
D. 6:00 p.m. on June 27

26. *Thebe* is one of Jupiter's smaller moons. Thebe completes 1 orbit of Jupiter in approximately 0.7 days. Based on Figure 2, regardless of direction, the maximum value of θ for Thebe is most likely:

F. less than 7 arcsec.
G. between 7 arcsec and 10 arcsec.
H. between 10 arcsec and 13 arcsec.
J. greater than 13 arcsec.

Passage V

Two scientists discussed the evolution of 3 animal groups: crocodiles, *nonavian dinosaurs* (all dinosaurs except modern birds), and modern birds. The scientists characterized the animals in each group by their *resting metabolic rate*, RMR (the rate at which an animal uses caloric energy when at rest), and according to whether they were *poikilothermic* (had body temperatures that varied significantly) or *homeothermic* (had body temperatures that remained relatively constant).

Scientist 1

Crocodiles and nonavian dinosaurs evolved from a common ancestor that had a low RMR and was poikilothermic. Crocodiles retained these traits. However, nonavian dinosaurs had a high RMR and were homeothermic. Modern birds inherited these traits when the group first evolved from nonavian dinosaurs, and both traits have been retained by all modern birds.

The bones of nonavian dinosaurs had a porous structure, no growth rings, and extensive *vascularization* (channels containing blood vessels). Extensive vascularization, which is also seen in modern birds, is evidence of an efficient circulatory system and a high RMR. Efficient circulation distributes heat evenly throughout the body. Thus, nonavian dinosaurs were homeothermic and could have survived in cold climates.

Scientist 2

Crocodiles and nonavian dinosaurs evolved from a common ancestor that had a low RMR and was poikilothermic. Crocodiles retained these traits. Nonavian dinosaurs also had a low RMR and were poikilothermic. In contrast, modern birds have had a high RMR ever since the group first evolved from nonavian dinosaurs. Modern birds only became homeothermic after nonavian dinosaurs went extinct 65 million years ago.

The bones of nonavian dinosaurs were dense and had growth rings. Each of these features indicates a low RMR, and neither is seen in the bones of modern birds. Nonavian dinosaur bones also lacked extensive vascularization, suggesting an inefficient circulatory system that would not have been able to distribute heat evenly throughout the body. Thus, nonavian dinosaurs were poikilothermic and could not have survived in cold climates.

27. Both scientists would be likely to agree that modern birds:

A. evolved from crocodiles.
B. evolved from nonavian dinosaurs.
C. have always had a low RMR.
D. have always had bones with growth rings.

28. Would Scientist 2 more likely expect to find bones that have growth rings in a crocodile or in a modern bird?

F. Crocodile; Scientist 2 suggested that growth rings indicate a high RMR.
G. Crocodile; Scientist 2 suggested that growth rings indicate a low RMR.
H. Modern bird; Scientist 2 suggested that growth rings indicate a high RMR.
J. Modern bird; Scientist 2 suggested that growth rings indicate a low RMR.

29. In which of the 3 animal groups would Scientist 1 most likely expect to find animals having bones with extensive vascularization?

A. Crocodiles only
B. Nonavian dinosaurs only
C. Crocodiles and modern birds only
D. Nonavian dinosaurs and modern birds only

30. Consider a crocodile and a modern bird, each having the same body mass. Based on Scientist 2's discussion, which animal would more likely produce CO_2 at a faster rate: the crocodile or the modern bird?

F. Crocodile; Scientist 2 argues that modern birds have a high RMR and that crocodiles have a low RMR.
G. Crocodile; Scientist 2 argues that modern birds have a low RMR and that crocodiles have a high RMR.
H. Modern bird; Scientist 2 argues that modern birds have a high RMR and that crocodiles have a low RMR.
J. Modern bird; Scientist 2 argues that modern birds have a low RMR and that crocodiles have a high RMR.

31. Consider a rock formation containing many bones and nesting sites from nonavian dinosaurs as well as indicators of a stable but cold climate. Suppose it were discovered that both the nonavian dinosaur fossils and climate indicators have been present together throughout the entire 50-million-year history of the formation. This discovery would support the viewpoint(s) of which of the scientists, if either?

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

32. Scientist 1 characterized the animals in which of the 3 groups as poikilothermic?

F. Crocodiles only
G. Modern birds only
H. Crocodiles and nonavian dinosaurs
J. Modern birds and nonavian dinosaurs

33. Suppose it were confirmed that the common ancestor of nonavian dinosaurs and crocodiles had a low RMR. This finding would be consistent with the viewpoint(s) of which of the scientists, if either?

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

GO ON TO THE NEXT PAGE.

Passage VI

Biosorption is a process that uses certain biological materials (*biomass*) to remove metal ions from a solution. Three experiments were done to study the removal of the chromium ion Cr^{6+} from aqueous solutions using a biomass composed of crushed shells of the fruit *Litchi chinensis*. In each trial in each experiment, the following steps were performed:

1. In a flask, 1.0 g of fresh biomass was added to 100 mL of an aqueous solution having a particular pH and Cr^{6+} concentration.
2. The flask was capped, and the contents were shaken for a particular time at a particular temperature.
3. Periodically, shaking was stopped so that a 0.01 mL sample could be removed from the flask. This sample was analyzed to determine the percentage of Cr^{6+} remaining in the solution.

Experiment 1

In each of Trials 1–4, an aqueous solution with an initial Cr^{6+} concentration of 100 mg/L was tested at a temperature of 30°C. The pH was varied from trial to trial. The results are shown in Figure 1.

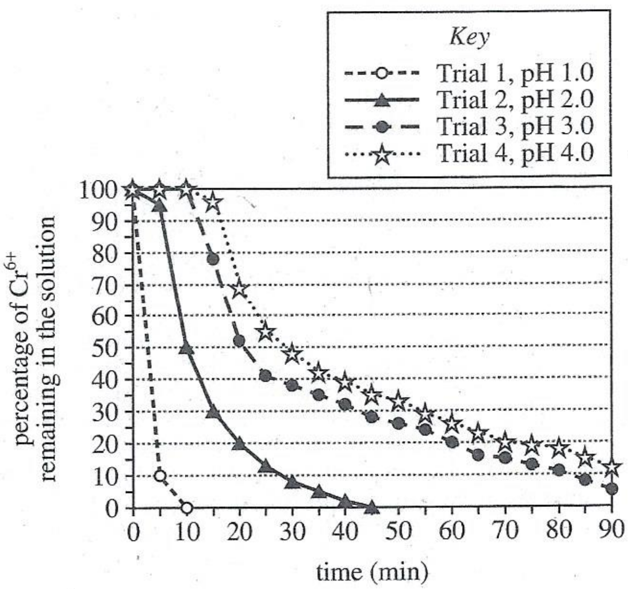


Figure 1

Experiment 2

In each of Trials 5–7, an aqueous solution with an initial Cr^{6+} concentration of 100 mg/L was tested at a pH of 1.0. The temperature was varied from trial to trial. The results are shown in Figure 2.

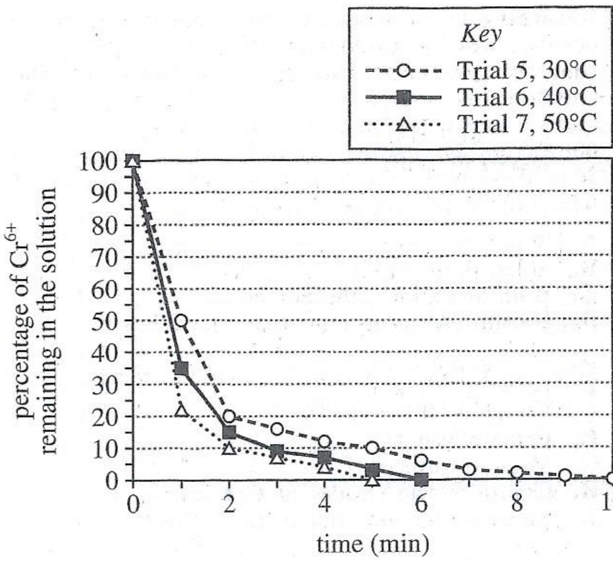


Figure 2

Experiment 3

In each of Trials 8–11, an aqueous solution at a pH of 1.0 was tested at a temperature of 30°C. The initial Cr^{6+} concentration was varied from trial to trial. The results are shown in Figure 3.

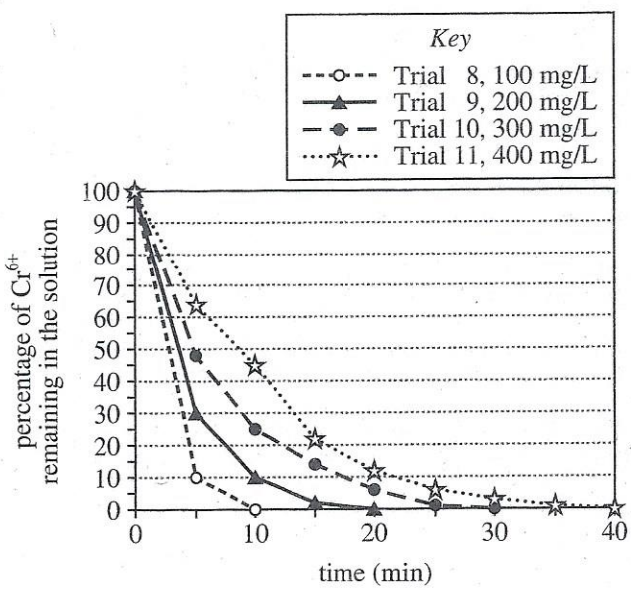


Figure 3

Figures adapted from Ismael Acosta-Rodríguez et al., "Removal of Hexavalent Chromium from Solutions and Contaminated Sites by Different Natural Biomasses." ©2013 by Ismael Acosta-Rodríguez et al.

34. According to the results of Experiment 2, as the temperature was increased from 30°C to 50°C from trial to trial, the time needed to remove all the Cr^{6+} from the solution:

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

35. Based on Figure 1, if a sample from Trial 3 had been analyzed at 95 min, the percentage of Cr^{6+} remaining in the solution would most likely have been:

A. less than 5%.
B. between 5% and 10%.
C. between 10% and 15%.
D. greater than 15%.

36. According to the results of Experiment 1, as the pH was increased from trial to trial, the time needed to remove 90% of the Cr^{6+} from the solution:

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

37. In how many trials in Experiments 1–3 did the percentage of Cr^{6+} remaining in solution reach 0% in less than 1 hr ?

A. 0
B. 2
C. 9
D. 11

38. Biosorption using *L. chinensis* involves the one-time transfer of 3 electrons from the biomass to each chromium ion. Based on information in the passage, the resulting charge on each chromium ion after it gains 3 electrons is:

F. 3+, because electrons have negative charge.
G. 3+, because electrons have positive charge.
H. 9+, because electrons have negative charge.
J. 9+, because electrons have positive charge.

39. How many of the trials performed in Experiment 1 were done at an acidic pH ?

A. Zero, because any pH less than 7.0 is basic.
B. Zero, because any pH less than 7.0 is acidic.
C. Four, because any pH less than 7.0 is basic.
D. Four, because any pH less than 7.0 is acidic.

40. Based on Figure 3, which of the following expressions best approximates the *mass* of Cr^{6+} remaining in the 200 mg/L solution at 5 min ?

F. $100 \text{ mL} \times \frac{1{,}000 \text{ mL}}{1 \text{ L}} \times \frac{200 \text{ mg}}{1 \text{ L}} \times 5\%$

G. $100 \text{ mL} \times \frac{1 \text{ L}}{1{,}000 \text{ mL}} \times \frac{200 \text{ mg}}{1 \text{ L}} \times 5\%$

H. $100 \text{ mL} \times \frac{1{,}000 \text{ mL}}{1 \text{ L}} \times \frac{200 \text{ mg}}{1 \text{ L}} \times 30\%$

J. $100 \text{ mL} \times \frac{1 \text{ L}}{1{,}000 \text{ mL}} \times \frac{200 \text{ mg}}{1 \text{ L}} \times 30\%$

END OF TEST 4

STOP! DO NOT RETURN TO ANY OTHER TEST.