SCIENCE TEST

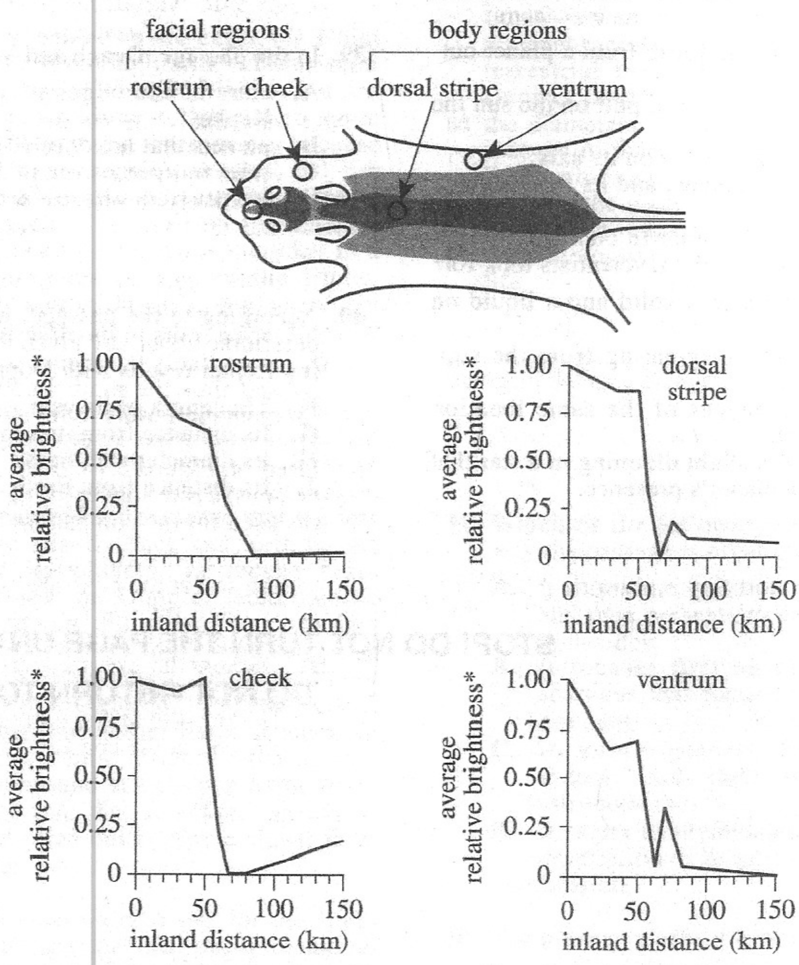
35 Minutes—40 Questions

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

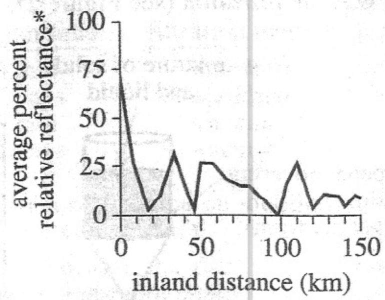
In a study of fur pigmentation in deer mice, *Peromyscus polionotus*, scientists compared the brightness of the fur of mice from populations located different distances directly inland from a coastal site. Figure 1 shows the 2 facial regions and the 2 body regions at which the fur of each mouse was evaluated (on a scale from 0 to 1.00) with respect to its brightness. Figure 1 also shows how, for each of the 4 regions, average relative brightness varied with inland distance.



*For each facial or body region, the darkest fur pigmentation was assigned a brightness value of 0, and the lightest fur pigmentation was assigned a brightness value of 1.00.

Figure 1

Figure 2 shows how the average brightness of surface soil samples, given as the average percent relative reflectance, varied with inland distance.



*compared to a standard that was assigned 100% reflectance

Figure 2

Figures 1 and 2 adapted from Lynne M. Mullen and Hopi E. Hoekstra. "Natural Selection Along an Environmental Gradient: A Classic Cline in Mouse Pigmentation." ©2008 by The Author(s).

1. Based on Figure 2, on average, where was the brightest surface soil found?
   - **A.** At the coastal site
   - **B.** 50 km inland
   - **C.** 100 km inland
   - **D.** 150 km inland

2. According to Figure 1, the average relative brightness of the dorsal stripe was 0.25 at an inland distance that was closest to which of the following?
   - **F.** 20 km
   - **G.** 40 km
   - **H.** 60 km
   - **J.** 80 km

3. According to Figure 1, the greatest change in the average relative brightness of the fur on the rostrum occurred between which of the following inland distances?
   - **A.** 0 km and 25 km
   - **B.** 25 km and 50 km
   - **C.** 50 km and 75 km
   - **D.** 100 km and 125 km

4. Based on Figure 1, on average, was the fur pigmentation on the ventrum of *P. polionotus* lighter or darker 150 km inland than it was at the coastal site?
   - **F.** Lighter, because the average relative brightness 150 km inland was greater.
   - **G.** Lighter, because the average relative brightness 150 km inland was less.
   - **H.** Darker, because the average relative brightness 150 km inland was greater.
   - **J.** Darker, because the average relative brightness 150 km inland was less.

5. Which of the following statements best explains the geographic variation in the fur pigmentation of *P. polionotus* ? At any given inland distance, the more closely the fur pigmentation of a *P. polionotus* mouse matches the soil, the:
   - **A.** less likely the mouse will be found by a predator, and thus the less likely it will pass its fur pigmentation traits to its offspring.
   - **B.** less likely the mouse will be found by a predator, and thus the more likely it will pass its fur pigmentation traits to its offspring.
   - **C.** more likely the mouse will be found by a predator, and thus the less likely it will pass its fur pigmentation traits to its offspring.
   - **D.** more likely the mouse will be found by a predator, and thus the more likely it will pass its fur pigmentation traits to its offspring.

6. Based on Figure 2, on average, was the surface soil at the coastal site lighter or darker than the standard that was used for the comparison?
   - **F.** Lighter; the average percent relative reflectance of the soil at the coastal site was 100%.
   - **G.** Lighter; the average percent relative reflectance of the soil at the coastal site was less than 100%.
   - **H.** Darker; the average percent relative reflectance of the soil at the coastal site was 100%.
   - **J.** Darker; the average percent relative reflectance of the soil at the coastal site was less than 100%.

Passage II

A high concentration of *dissolved nickel* (Ni^{2+}) in wastewater is an environmental concern. Students studied the removal of Ni^{2+} from wastewater, using an aqueous Ni^{2+} solution as a model of wastewater.

In water, hydroxide (OH^-) reacts with Ni^{2+} to form nickel hydroxide monohydrate [$Ni(OH)_2 \cdot H_2O$]. The balanced chemical equation for this reaction is

$$Ni^{2+} + 2OH^- + H_2O \rightarrow Ni(OH)_2 \cdot H_2O$$

Because the monohydrate is a solid, it can be filtered from the solution. Some of the solid will eventually dissolve if it is left in contact with the solution.

The students did 2 experiments to study how reaction time and filtration method affected the removal of Ni^{2+} from the aqueous Ni^{2+} solution.

Experiment 1

In each of Trials 1–3, Steps 1–4 were performed:

1. Thirty-two mL of aqueous 1.0 mole/L OH^- solution and 260 mL of aqueous 0.060 mole/L Ni^{2+} solution were poured into the same flask.
2. The mixture was stirred at 22°C for 10 min, 3 days, or 7 days.
3. Solid monohydrate was recovered by *standard filtration* (see Figure 1).

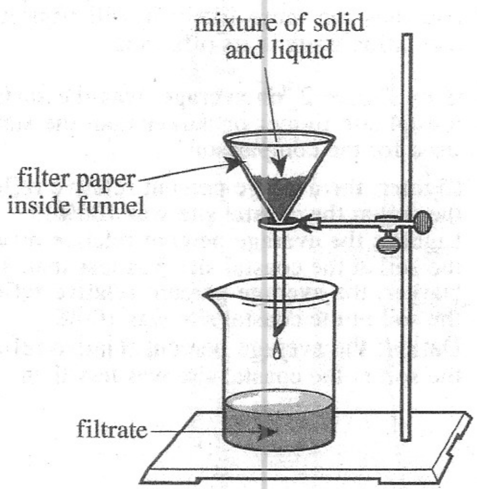


Figure 1

4. The *concentration of Ni^{2+} in the filtrate*, CNF, was determined, in milligrams of Ni^{2+} per kilogram of solution (mg/kg).

Experiment 2

In each of Trials 4–6, Steps 1–4 in Experiment 1 were performed except that in Step 3, solid monohydrate was recovered by *vacuum filtration* (see Figure 2).

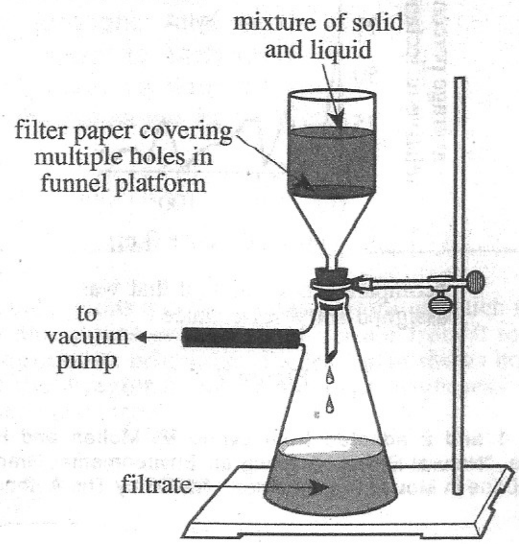


Figure 2

The results of Experiments 1 and 2 are shown in Table 1.

Table 1

Experiment	Trial	Reaction time	CNF (mg/kg)
1	1	10 min	6
	2	3 days	39
	3	7 days	42
2	4	10 min	58
	5	3 days	69
	6	7 days	73

Table 1 adapted from K. Blake Corcoran, Brian E. Rood, and Bridget G. Trogden, "Chemical Remediation of Nickel(II) Waste: A Laboratory Experiment for General Chemistry Students." ©2010 by Division of Chemical Education, Inc., American Chemical Society.

7. If a reaction time of 2 days had been tested in Experiment 1, the CNF would most likely have been:
   A. less than 6 mg/kg.
   B. between 6 mg/kg and 39 mg/kg.
   C. between 39 mg/kg and 42 mg/kg.
   D. greater than 42 mg/kg.

8. Based on the results of Experiments 1 and 2, what combination of reaction time and filtration method resulted in the lowest concentration of dissolved nickel in the filtrate?

	reaction time	filtration method
F.	10 min	standard
G.	7 days	standard
H.	10 min	vacuum
J.	7 days	vacuum

9. Was the net force exerted on the mixture in the funnel more likely greater in Trial 3 or in Trial 6 ?

A. Trial 3, because the filtration apparatus was connected to a vacuum pump.
B. Trial 3, because the filtration apparatus was not connected to a vacuum pump.
C. Trial 6, because the filtration apparatus was connected to a vacuum pump.
D. Trial 6, because the filtration apparatus was not connected to a vacuum pump.

10. In each trial, the students performed which of the following chronological sequences of steps?

F. Measuring the CNF; recovering the solid by filtration; mixing the Ni^{2+} and the OH^- solutions
G. Mixing the Ni^{2+} and the OH^- solutions; recovering the solid by filtration; measuring the CNF
H. Recovering the solid by filtration; measuring the CNF; mixing the Ni^{2+} and the OH^- solutions
J. Recovering the solid by filtration; mixing the Ni^{2+} and the OH^- solutions; measuring the CNF

11. A student predicted that when solid monohydrate is recovered by vacuum filtration, a greater CNF will result for a reaction time of 3 days than for a reaction time of 10 min. Do the data in Table 1 support this prediction?

A. No; Trial 1 had a greater CNF than did Trial 2.
B. No; Trial 5 had a greater CNF than did Trial 4.
C. Yes; Trial 1 had a greater CNF than did Trial 2.
D. Yes; Trial 5 had a greater CNF than did Trial 4.

12. In how many of the 6 trials was nickel hydroxide monohydrate recovered by standard filtration after OH^- and Ni^{2+} had been allowed to react for at least 3 days?

F. 1
G. 2
H. 4
J. 6

13. Based on the balanced chemical equation in the passage, as 6 OH^- ions are consumed, how many formula units of $Ni(OH)_2 \cdot H_2O$ are produced?

A. 3
B. 6
C. 12
D. 18

Passage III

Star formation begins with the gravitational collapse of matter in an interstellar gas cloud. A *protostar* (forming star) affects gas in the surrounding portions of the cloud in 2 ways:

- The protostar's gravitational field attracts gas, causing the gas to *accrete* (accumulate onto the protostar).
- *Radiation pressure* (RP) associated with the protostar's emissions causes gas to be pushed away from the protostar, inhibiting accretion.

Star formation ends when the effect of RP overcomes that of gravity. At that point, the protostar can no longer gain mass by accretion and is considered a fully formed star.

Three scientists debate whether the maximum mass that a protostar can reach by accretion is great enough to account for the most massive stars observed.

Scientist 1

The effect of RP is uniform in all directions around a protostar. As a result, the maximum mass that a protostar can reach by accretion is 20 M_S (1 M_S = mass of the Sun). Any further increase in mass requires at least 1 *stellar merger* (the combination of 2 or more fully formed stars into 1). Because stars tend to form in clusters, stellar mergers are likely.

Scientist 2

Scientist 1 is correct that stellar mergers are likely. However, because a protostar rotates about its axis, a disk of gas forms in the plane of the protostar's equator. This reduces the effect of RP in that plane, allowing gas from the disk to readily accrete. As a result, the maximum mass that a protostar can reach by accretion is 40 M_S. Any further increase in mass requires at least 1 stellar merger.

Scientist 3

Stellar mergers are very unlikely given the vast distances between stars, even within clusters. Scientist 2 is correct about the formation and the effect of the disk. In addition, a protostar produces bubble-like regions of radiation that increase the effect of RP near the protostar's poles, promoting the flow of gas into the disk. As a result, accretion continues until the surrounding portions of the cloud are nearly depleted of gas. Therefore, the maximum mass that a protostar can reach by accretion is limited only by the amount of available gas.

14. Relative to the center of the protostar, does gravity more likely accelerate gas particles inward or outward, and does RP more likely accelerate gas particles inward or outward?

	gravity	RP
F.	inward	inward
G.	inward	outward
H.	outward	inward
J.	outward	outward

15. Based on Scientist 2's argument, do gas particles more likely accrete near the equator or near the poles of a protostar with a disk?

A. Near the equator, because the effect of RP is increased there.
B. Near the equator, because the effect of RP is reduced there.
C. Near the poles, because the effect of RP is increased there.
D. Near the poles, because the effect of RP is reduced there.

16. Detailed surveys of star clusters in and near the Milky Way have yielded no evidence of stellar mergers having occurred at any time during the galaxy's history. These results are *inconsistent* with the argument(s) of which scientist(s)?

F. Scientist 1 only
G. Scientist 3 only
H. Scientists 1 and 2 only
J. Scientists 1 and 3 only

17. One of the most massive stars known is Eta Carinae, which has an approximate mass of 120 M_S. Based on the arguments of Scientists 1, 2, and 3, respectively, what is the *minimum* number of stars, each formed entirely by accretion, that would have been required to form Eta Carinae?

	Scientist 1	Scientist 2	Scientist 3
A.	5	3	1
B.	5	4	2
C.	6	3	1
D.	6	4	2

18. When the effect of RP overcomes that of gravity, a star is said to have "emerged from its envelope," because that is the first time the star is directly observable from outside the cloud. An observation of which of the following stars emerging from its envelope would support Scientist 2's argument but weaken Scientist 1's argument?

F. A 15 M_S star
G. A 20 M_S star
H. A 30 M_S star
J. A 50 M_S star

19. Scientists 2 and 3 agree that a disk forms around a protostar as a result of the protostar's:

A. motion.
B. emission of radiation.
C. location within a star cluster.
D. merger with another star.

20. Which of the scientists, if any, would be likely to agree that the Sun could have formed entirely by accretion?

F. Scientist 1 only
G. Scientist 3 only
H. Scientists 1, 2, and 3
J. None of the scientists

Passage IV

Two studies were done to examine how the proportion of *vermicompost* (feces from earthworms) in a particular potting soil affects the *yield* of each of 2 plant species: *Solanum lycopersicum* (a tomato plant) and *Capsicum annuum* (a pepper plant). The yield of a plant species is the mass of fruit produced per plant of the species.

Six different mixtures (Mixtures 1–6) were prepared according to the percents listed in Table 1.

Table 1

	Percent by volume of:	
Mixture	vermicompost	potting soil
1	0	100
2	20	80
3	40	60
4	60	40
5	80	20
6	100	0

Study 1

Equal amounts of Mixtures 1–6 were distributed among thirty-six 2 L pots in the following manner: 1.5 kg of Mixture 1 was put into each of 6 pots, 1.5 kg of Mixture 2 was put into each of 6 other pots, 1.5 kg of Mixture 3 was put into each of 6 other pots, and so on. Then, 3 *S. lycopersicum* seeds were added to each pot. For the next 158 days, all the pots received equal amounts of water and light. On Day 28 of the 158 days, all the seedlings that had emerged were removed from the pots with the exception of a single seedling in each pot. On Day 158, the yield of the remaining plant in each pot was measured. The average yield of the plants grown in each mixture was then calculated. The results are shown in Figure 1.

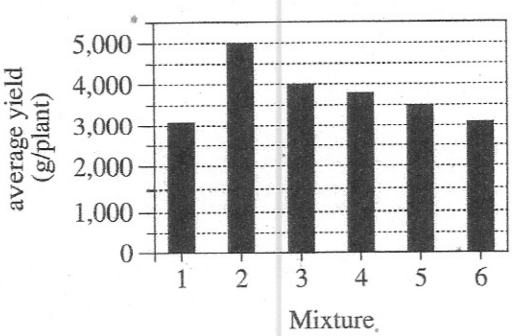


Figure 1

Figure 1 adapted from Rola M. Atiyeh et al., "Influence of Earthworm-Processed Pig Manure on the Growth and Yield of Greenhouse Tomatoes." ©2000 by Elsevier Science Ltd.

Study 2

The procedures of Study 1 were repeated, except that 5 *C. annuum* seeds instead of 3 *S. lycopersicum* seeds were added to each pot, the pots received water and light for 149 days instead of 158 days, seedling removal occurred on Day 42 of the 149 days, and plant yield was measured on Day 149. The results are shown in Figure 2.

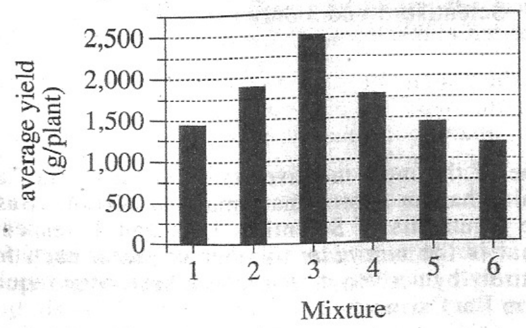


Figure 2

Figure 2 adapted from Norman Q. Arancon et al., "Effects of Vermicomposts Produced from Food Waste on the Growth and Yields of Greenhouse Peppers." ©2004 by Elsevier Science Ltd.

21. In both studies, as the percent by volume of vermicompost increased from 0% through 100%, the average yield:

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

22. In Study 1, which of the following mixtures was most likely intended to serve as a control for the effect of vermicompost on plant yield?

F. Mixture 1
G. Mixture 2
H. Mixture 4
J. Mixture 5

23. Suppose that in Study 1, average yield had been calculated in *kilograms* per plant (kg/plant) instead of g/plant. The average yield for Mixture 5 would have been:

A. 1.45 kg/plant.
B. 3.50 kg/plant.
C. 14.5 kg/plant.
D. 35.0 kg/plant.

24. Which of the factors listed below were the same in Study 2 as they were in Study 1 ?

I. Number of pots used per mixture
II. Length of time needed to perform the study
III. Volume of each pot

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

25. Is the statement "Tomato plants require a *lower* proportion of vermicompost in the potting soil to achieve maximum yield than do pepper plants" consistent with the results of Studies 1 and 2 ?

A. Yes; in Study 1, the greatest average yield was attained with Mixture 2, whereas in Study 2, the greatest average yield was attained with Mixture 3.
B. Yes; in Study 1, the greatest average yield was attained with Mixture 3, whereas in Study 2, the greatest average yield was attained with Mixture 2.
C. No; in Study 1, the greatest average yield was attained with Mixture 2, whereas in Study 2, the greatest average yield was attained with Mixture 3.
D. No; in Study 1, the greatest average yield was attained with Mixture 3, whereas in Study 2, the greatest average yield was attained with Mixture 2.

26. In a 2 L pot, the presence of more than one plant can negatively affect the growth of all the plants in the pot, due to competition among the plants. What action was taken in the studies to prevent competition among the plants?

F. Only one seed was planted per pot.
G. Only one seedling was planted per pot.
H. After an initial period of growth, all but one seed was removed from each pot.
J. After an initial period of growth, all but one seedling was removed from each pot.

27. *S. lycopersicum* and *C. annuum* required water and light for the process represented by which of the following expressions?

A. Water + light → glucose + oxygen + carbon dioxide
B. Glucose + water + light → oxygen + carbon dioxide
C. Oxygen + water + light → glucose + carbon dioxide
D. Carbon dioxide + water + light → glucose + oxygen

Passage V

A *cathode-ray tube* (CRT) is a sealed, evacuated glass tube with a filament at one end and a fluorescent screen at the other end (see Figure 1).

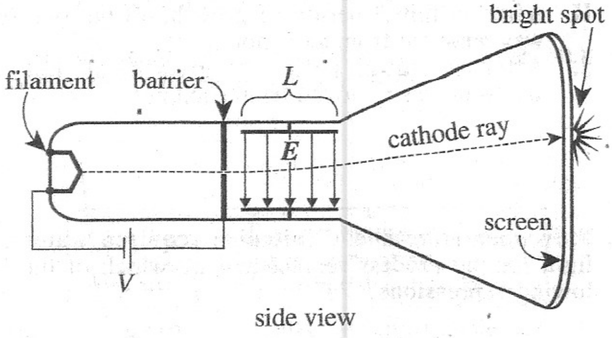


Figure 1

Figure 1 adapted from David Halliday, Robert Resnick, and Jearl Walker, *Fundamentals of Physics*, 9th ed. ©2011 John Wiley & Sons, Inc.

When heated, the filament emits cathode rays that are accelerated by an electric potential, V, toward a barrier having a pinhole. Beyond the barrier are 2 conducting plates, each of length L, that have an electric field, $\boldsymbol{E}$, between them. (The direction of $\boldsymbol{E}$ can be upward or downward; in Figure 1, it is downward.) Any rays that pass through the pinhole travel through the field and strike the screen, producing a bright spot of visible light.

A group of students performed 3 studies on various CRTs, each of which had a ruler taped to the outer surface of the screen (see Figure 2) to measure a spot's vertical location, y (in centimeters, cm).

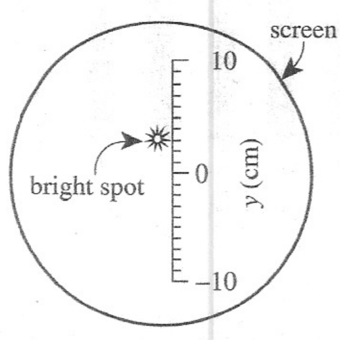


Figure 2

Study 1

The students obtained a CRT having $L = 2.5$ cm. They set V to 1.0 kilovolt (kV), varied both the direction and the magnitude (in newtons per coulomb, N/C) of $\boldsymbol{E}$, and recorded the resulting values of y (see Table 1).

Table 1

Trial	$\boldsymbol{E}$ direction*	$\boldsymbol{E}$ magnitude (N/C)	y (cm)
1	↑	1.0×10^4	−3.2
2	↑	2.0×10^4	−6.3
3	↑	3.0×10^4	−9.5
4	↓	1.0×10^4	3.2
5	↓	2.0×10^4	6.3
6	↓	3.0×10^4	9.5

*↑ = upward
↓ = downward

Study 2

Using the CRT from Study 1, the students set the magnitude of $\boldsymbol{E}$ to 1.0×10^4 N/C, varied V, and recorded the resulting values of y (see Table 2).

Table 2

Trial	V (kV)	y (cm)
7	0.5	6.3
8	1.0	3.2
9	1.5	2.1
10	2.0	1.6
11	2.5	1.3

Study 3

The students obtained various CRTs, each having a different L. For each CRT, they set V to 1.0 kV, set the magnitude of $\boldsymbol{E}$ to 1.0×10^4 N/C, and recorded the resulting value of y (see Table 3).

Table 3

Trial	L (cm)	y (cm)
12	1.5	−2.0
13	2.0	−2.6
14	2.5	−3.2
15	3.0	−3.8
16	3.5	−4.4

28. Studies 1 and 2 differed in which of the following ways? In Study 1, the students determined how the spot's location varied with:

F. electric potential, whereas in Study 2, they determined how the spot's location varied with the magnitude and direction of the electric field.
G. plate length, whereas in Study 2, they determined how the spot's location varied with electric potential.
H. the magnitude and direction of the electric field, whereas in Study 2, they determined how the spot's location varied with electric potential.
J. plate length, whereas in Study 2, they determined how the spot's location varied with the magnitude and direction of the electric field.

29. Suppose that the students had performed a trial in Study 2 in which y was 2.6 cm. The value of V in this trial would most likely have been:

A. less than 1.0 kV.
B. between 1.0 kV and 1.5 kV.
C. between 1.5 kV and 2.0 kV.
D. greater than 2.0 kV.

30. Figure 2 could serve as an illustration of the result(s) of which trial(s)?

F. Trial 1 only
G. Trial 8 only
H. Trials 1 and 4 only
J. Trials 4 and 8 only

31. Based on the results of Study 1, in which direction did $\boldsymbol{E}$ most likely point in Study 2, and in which direction did $\boldsymbol{E}$ most likely point in Study 3 ?

	Study 2	Study 3
A.	↑	↑
B.	↑	↓
C.	↓	↑
D.	↓	↓

32. Once a CRT is sealed, it cannot be reopened. However, because both V and $\boldsymbol{E}$ are controlled from the outside, a CRT can be used repeatedly under varying conditions. Based on the descriptions of Studies 1–3, what is the *minimum* number of different CRTs that the students required to complete the 3 studies?

F. 1
G. 5
H. 11
J. 16

33. Suppose that the students had performed a trial in which the cathode rays traveled all the way from the filament to the screen in a straight-line path, striking the screen at $y = 0$ cm. Based on the results of Studies 1 and 2, which of the following statements about V and the magnitude of $\boldsymbol{E}$ in this trial would have been true?

A. V was zero but the magnitude of $\boldsymbol{E}$ was nonzero.
B. V was nonzero but the magnitude of $\boldsymbol{E}$ was zero.
C. Both V and the magnitude of $\boldsymbol{E}$ were zero.
D. Both V and the magnitude of $\boldsymbol{E}$ were nonzero.

34. In a CRT, $\boldsymbol{E}$ is generated by building up equal and opposite electric charges on the 2 conducting plates. Suppose that cathode rays are negatively charged. If $\boldsymbol{E}$ is directed downward as shown in Figure 1, which conducting plate is more likely the negatively charged plate?

F. The top plate, because charges of like sign are attracted to each other.
G. The top plate, because charges of like sign are repelled from each other.
H. The bottom plate, because charges of like sign are attracted to each other.
J. The bottom plate, because charges of like sign are repelled from each other.

Passage VI

For gas atoms in a state of random motion, the *mean free path*, λ, is the average distance a gas atom will travel between collisions with other gas atoms. This distance depends upon the diameter of the gas atom, d, the volume of the gas, V, and the number of atoms of the gas, N. Table 1 lists the name, symbol, and value of d (in nanometers, nm) for each of 4 gases. Figure 1 shows, for each gas, at 293 kelvins (K), how λ (in nm) varies with V (in liters, L) in a sample with $N = 6 \times 10^{23}$ atoms of the gas. Figure 2 shows, for each gas, at 293 K, how λ varies with N in a sample with $V = 25$ L.

Table 1

Gas	Symbol	d (nm)
Neon	Ne	0.076
Argon	Ar	0.142
Krypton	Kr	0.176
Xenon	Xe	0.216

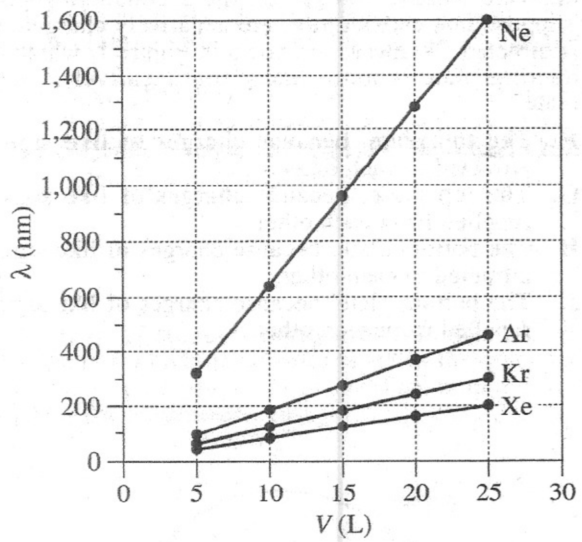


Figure 1

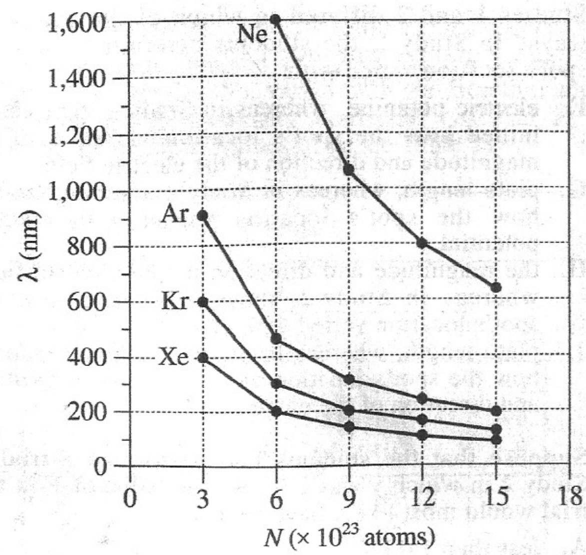


Figure 2

35. According to Figure 2, what is the order of gas samples from shortest λ to longest λ for $N = 15 \times 10^{23}$ atoms?

A. Ne, Ar, Kr, Xe
B. Ne, Kr, Ar, Xe
C. Xe, Ar, Kr, Ne
D. Xe, Kr, Ar, Ne

36. According to Figure 2, doubling the Ne sample size from 6×10^{23} atoms to 12×10^{23} atoms effectively multiplies λ for Ne by a factor of:

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

37. Consider 2 Kr samples at 293 K, each with $N = 6 \times 10^{23}$ atoms, but one with $V = 25$ L and the other with $V = 50$ L. Based on Figure 1, λ for the 50 L sample would most likely be how many times as great as λ for the 25 L sample?

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

38. Based on Figure 1, for the Xe and Ar gas samples with $V = 20$ L, compared to λ for Xe, approximately how much longer is λ for Ar ?

F. 50 nm
G. 100 nm
H. 150 nm
J. 200 nm

39. The *collision frequency* is defined as the number of collisions between gas atoms per second. Consider the 5 L and 25 L Xe samples represented in Figure 1. Assuming the Xe atoms have the same average speed in both samples, in which sample would the collision frequency more likely be higher?

A. In the 5 L sample; Xe atoms in the 5 L sample travel, on average, shorter distances between collisions and therefore collide more often.
B. In the 5 L sample; Xe atoms in the 5 L sample travel, on average, longer distances between collisions and therefore collide more often.
C. In the 25 L sample; Xe atoms in the 25 L sample travel, on average, shorter distances between collisions and therefore collide more often.
D. In the 25 L sample; Xe atoms in the 25 L sample travel, on average, longer distances between collisions and therefore collide more often.

40. For a particular sample of radon (Rn) gas in a 25 L container at 293 K, λ is approximately 320 nm. If *d* for Rn is 0.240 nm, then, based on Table 1 and Figure 2, approximately how many Rn atoms are most likely in this sample?

F. Less than 6×10^{23}
G. Between 6×10^{23} and 9×10^{23}
H. Between 9×10^{23} and 12×10^{23}
J. More than 12×10^{23}

END OF TEST 4

STOP! DO NOT RETURN TO ANY OTHER TEST.