



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

Negative cloud-to-ground (–CG) and positive cloud-to-ground (+CG) lightning strokes move negative charges and positive charges, respectively, from a cloud to the ground during a thunderstorm. Typically, +CG strokes are less numerous than –CG strokes. Figure 1 shows the number of –CG strokes and the number of +CG strokes during each 5 min of a 3 hr period during a thunderstorm that produced a tornado. Also shown are the time of tornado formation (TF) and the time of tornado dissipation (TD). Table 1 shows the average current and the average duration of the strokes during each 30 min period of the 3 hr.

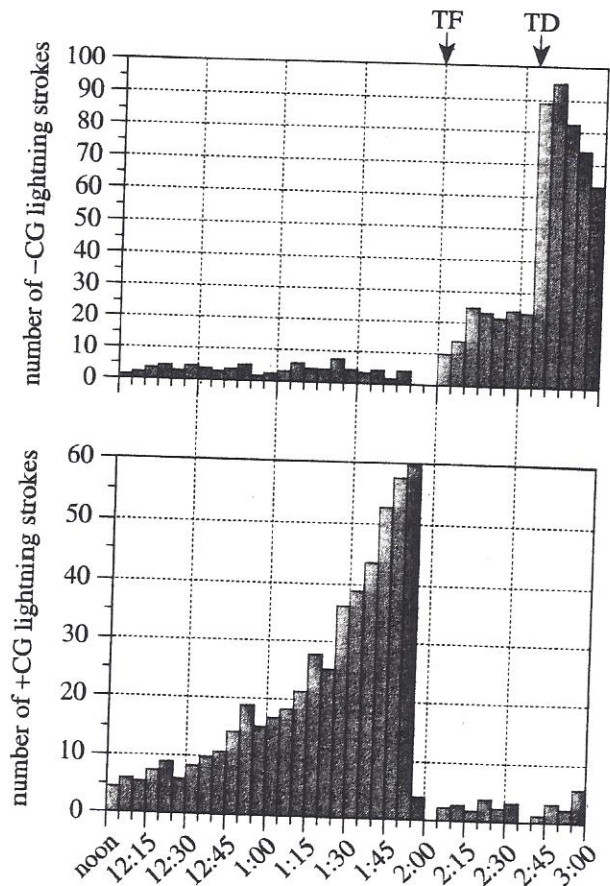


Figure 1

Figure 1 adapted from Donald MacGorman and Donald Burgess, "Positive Cloud-to-Ground Lightning in Tornadic Storms and Hailstorms." ©1994 by the American Meteorological Society.

Table 1

Time period	Average current (kA*)		Average duration (msec†)	
	+CG strokes	-CG strokes	+CG strokes	-CG strokes
noon-12:30 p.m.	+75.2	-11.6	280	26
12:30 p.m.-1:00 p.m.	+79.4	-14.8	250	24
1:00 p.m.-1:30 p.m.	+83.7	-16.6	233	22
1:30 p.m.-2:00 p.m.	+89.5	-18.1	260	25
2:00 p.m.-2:30 p.m.	+42.2	-32.0	246	22
2:30 p.m.-3:00 p.m.	+37.1	-33.7	259	28

*kA = kiloamperes
†msec = milliseconds

1. According to Figure 1, from 1:25 p.m. to 1:55 p.m., the number of +CG strokes in a 5 min period:

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

2. According to Table 1, the average duration of +CG strokes was at least 10 times greater than the average duration of -CG strokes for all the time periods EXCEPT:

F. noon-12:30 p.m.
G. 1:00 p.m.-1:30 p.m.
H. 1:30 p.m.-2:00 p.m.
J. 2:30 p.m.-3:00 p.m.

3. Assume that the storm data in Figure 1 are typical of thunderstorms that produce tornadoes. For such thunderstorms, which type of lightning stroke, -CG or +CG, is predominant before TF and which type of lightning stroke is predominant after TF?

before TF after TF

A. -CG -CG
B. +CG +CG
C. -CG +CG
D. +CG -CG

4. Is the statement "The number of -CG strokes in the 5 min period just after TD will be less than the number of -CG strokes in the 5 min period just before TD" supported by Figure 1?

F. Yes; the number of -CG strokes in the 5 min period just after TD was less than half the number of -CG strokes in the 5 min period just before TD.
G. Yes; the number of -CG strokes in the 5 min period just after TD was the same as the number of -CG strokes in the 5 min period just before TD.
H. No; the number of -CG strokes in the 5 min period just after TD was more than twice the number of -CG strokes in the 5 min period just before TD.
J. No; the number of -CG strokes in the 5 min period just after TD was the same as the number of -CG strokes in the 5 min period just before TD.

5. According to Table 1, from noon until 2:00 p.m., did the *magnitude* (absolute value) of the average current of the +CG strokes increase or decrease, and did the magnitude of the average current of the -CG strokes increase or decrease?

+CG strokes -CG strokes

A. increase increase
B. decrease decrease
C. increase decrease
D. decrease increase

Passage II

Meerkats (*Suricata suricatta*) are mammals that typically live in groups of 2 to 30 individuals. Some group members, called *helpers*, help parents care for their pups. Figure 1 shows how the percent contribution to babysitting and to pupfeeding by helpers varied with the age of the helpers, as categorized in Table 1.

A helper's food intake, as measured by *daily weight gain* (average number of grams gained by a helper per hour during a 24 hr day), can affect its contribution to pup care. Figure 2 shows how the percent contribution to babysitting and to pupfeeding by helpers older than 1 yr varied with daily weight gain.

Age category	Age range
Juveniles	≥ 3 mo and < 6 mo
Subadults	≥ 6 mo and < 12 mo
Yearlings	≥ 12 mo and < 24 mo
Adults	≥ 24 mo

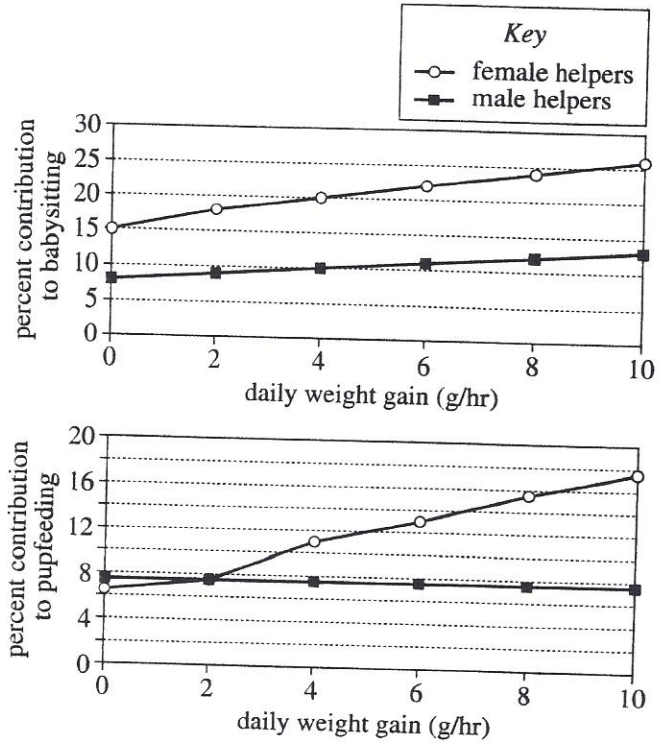


Figure 2

Figures 1 and 2 adapted from T. H. Clutton-Brock et al., "Evolution and Development of Sex Differences in Cooperative Behavior in Meerkats." ©2002 by the American Association for the Advancement of Science.

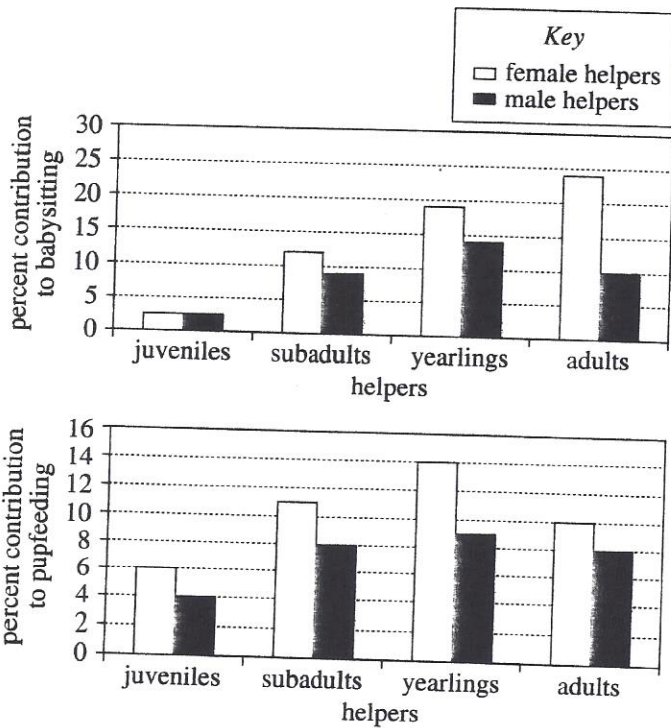


Figure 1

- According to Table 1 and Figure 1, across the 4 age categories, as the age of the helpers increased, the percent contribution to pupfeeding:
 - increased only.
 - decreased only.
 - increased, then decreased.
 - decreased, then increased.
- When food is scarce, meerkats may lose weight, causing them to have a negative daily weight gain. Based on Figure 2, if the percent contribution to babysitting by female helpers older than 1 yr with a daily weight gain of -2 g/hr had been calculated, it would most likely have been:
 - less than 15%.
 - between 15% and 20%.
 - between 20% and 25%.
 - greater than 25%.



8. Based on Table 1 and Figure 1, the greatest difference between the percent contribution by male helpers and the percent contribution by female helpers was observed for which pup care activity and which helper age range?
- F. Babysitting; ≥ 6 mo and < 12 mo
 - G. Babysitting; ≥ 24 mo
 - H. Pupfeeding; ≥ 6 mo and < 12 mo
 - J. Pupfeeding; ≥ 24 mo
9. A student claimed that for male helpers and also for female helpers, the percent contribution to pupfeeding varies with daily weight gain. Are the results shown in Figure 2 consistent with this claim?
- A. Yes; for male helpers and also for female helpers, as daily weight gain increased, the percent contribution to pupfeeding increased.
 - B. Yes; for male helpers and also for female helpers, as daily weight gain increased, the percent contribution to pupfeeding decreased.
 - C. No; for male helpers, the percent contribution to pupfeeding did not vary with weight gain.
 - D. No; for female helpers, the percent contribution to pupfeeding did not vary with weight gain.
10. The helpers whose contributions are recorded in Figure 2 belonged to which of the age categories listed in Table 1 ?
- F. Juveniles only
 - G. Adults only
 - H. Subadults and yearlings only
 - J. Yearlings and adults only



Passage III

Birds have existed since at least 120 million years ago (mya), when *Jeholornis* was alive. *Jeholornis*, one of the earliest birds known from fossils, had reptilian characteristics (including teeth, a long bony tail, and claws) and bird-like characteristics (including feathers, 3 digits on each foot, hollow bones, and a beak). Two scientists discuss the origin of the first birds.

Scientist 1

The first birds appeared 150 mya. They evolved from a group of ground-dwelling, 3-toed dinosaurs known as *theropods*. Like the more recent *Jeholornis*, theropods had long bony tails, teeth, and claws. Theropods had 23 skeletal features that were identical to the corresponding skeletal features of the first birds.

Although theropods could not fly, a 225-million-year-old fossil of a feather-covered theropod has shoulder joints that show the theropod could fold its forelimbs close to its body the way a bird folds its wings. The first birds had a nearly identical shoulder joint and could fly. Fossils of other feather-covered, nonflying theropods that predated *Jeholornis* have also been discovered.

Scientist 2

The first birds appeared 220 mya. They evolved from a group of tree-dwelling reptiles known as *archosaurs* instead of from dinosaurs. Some archosaurs could glide to the ground; others could also fly. The 230-million-year-old fossil of an archosaur indicates that the archosaur had numerous elongated scales along its front limbs. Those scales had some characteristics identical to those of feathers. This archosaur could have glided from trees to the ground, as could *Jeholornis*. Theropods could not be the ancestors of birds, because theropods lived only on the ground.

The fact that some skeletal features of theropods were identical to those of the first birds is not evidence that theropods were the most recent ancestors of birds. Instead, these features are independent adaptations to similar habitats. A study matched each of the 3 digits on the feet of theropods and on the feet of the first birds to one of the 5 digits on the feet of various earlier reptiles. Theropods had the 1st, 2nd, and 3rd digits of the original 5 digits, whereas the first birds had the 2nd, 3rd, and 4th digits.

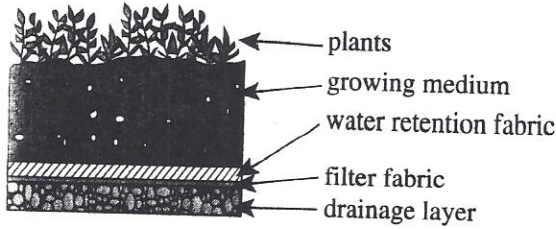
11. Consider Scientist 2's statement about why theropods could not be the ancestors of birds. That statement would be most strongly *contradicted* if it were discovered that theropods typically:
 - A. ate plants.
 - B. tended to their young.
 - C. climbed trees.
 - D. burrowed in the ground.
12. Both scientists would *disagree* with the statement that birds existed how many million years ago?
 - F. 75 mya
 - G. 150 mya
 - H. 175 mya
 - J. 250 mya
13. Scientist 1, but not Scientist 2, describes a fossil that provides evidence of a possible bird ancestor that:
 - A. was covered with elongated scales.
 - B. was covered with feathers.
 - C. could fly.
 - D. could glide.
14. Fossils of *Jeholornis* are considered very unusual because they show a characteristic of early birds that is rarely fossilized. This characteristic is most likely which of the following?
 - F. Claws
 - G. Beak
 - H. Leg bones
 - J. Feathers
15. By discussing the elongated scales indicated by the 230-million-year-old archosaur fossil, Scientist 2 is most likely implying which of the following? The elongated scales possessed by members of that group of archosaurs:
 - A. were used by those archosaurs to grasp prey.
 - B. were used by those archosaurs to climb trees.
 - C. evolved into the feathers of a descendant of those archosaurs.
 - D. evolved from the feathers of the most recent ancestor of those archosaurs.



16. Suppose further fossil evidence reveals that the digits on the feet of theropods actually corresponded to the 2nd, 3rd, and 4th digits, instead of the 1st, 2nd, and 3rd digits, on the feet of earlier reptiles. This discovery would better support the viewpoint of which scientist?
- F. Scientist 1, because this discovery would provide more evidence that the first birds and theropods are not closely related.
 - G. Scientist 1, because this discovery would provide more evidence that the first birds and theropods are closely related.
 - H. Scientist 2, because this discovery would provide more evidence that the first birds and archosaurs are not closely related.
 - J. Scientist 2, because this discovery would provide more evidence that the first birds and archosaurs are closely related.
17. Theropods are thought to have been *endothermic* (controlling body temperature by internal means), whereas archosaurs are thought to have been *ectothermic* (controlling body temperature by external means). This information supports the viewpoint of which scientist?
- A. Scientist 1, because birds are endothermic.
 - B. Scientist 1, because birds are ectothermic.
 - C. Scientist 2, because birds are endothermic.
 - D. Scientist 2, because birds are ectothermic.

Passage IV

A *green roof* on a building is a cover of living plants growing on several other layers of various materials (see typical green roof cross section below). Green roofs help control runoff during rain events.



cross section of a typical green roof

Five 2.5 m × 2.5 m platforms (1 *gravel* platform, 1 *media* platform, and 3 *vegetated* platforms) were constructed at a location on a building's roof. The gravel platform had a 2 cm layer of gravel over a waterproof fabric (a typical roof covering) and was unsloped. The media platform had all the layers as shown in the cross section except for the plants and was unsloped. The vegetated platforms had all the green roof layers as shown. One vegetated platform had a slope of 2.0%, another had a slope of 6.5%, and the third was unsloped (0% slope).

A runoff collection device was attached to each platform and a rain gauge was mounted on the roof. Two studies over a 2-month period measured the runoff from the platforms after each of 21 rain events, all lasting 60 min or more.

Study 1

For each of the 3 unsloped platforms, the amount of runoff in the collection device was recorded every 10 min for 180 min following the start of each rain event. Figure 1 shows the *cumulative* runoff from the platforms for a selected representative light, moderate, and heavy rain event. The 3 rain events produced a total rainfall of 0.5 mm, 4 mm, and 10 mm, respectively, over the 180 min.

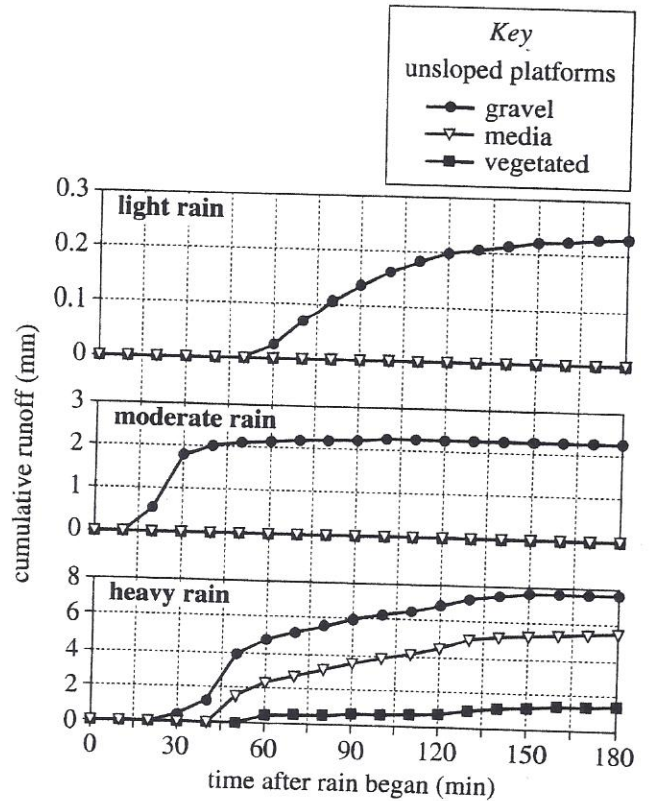


Figure 1

Study 2

For the 2 sloped vegetated platforms, the amount of runoff in the collection device was recorded every 10 min for 180 min following the start of each rain event. Figure 2 shows the cumulative runoff from the platforms for the same 3 representative rain events selected in Study 1.

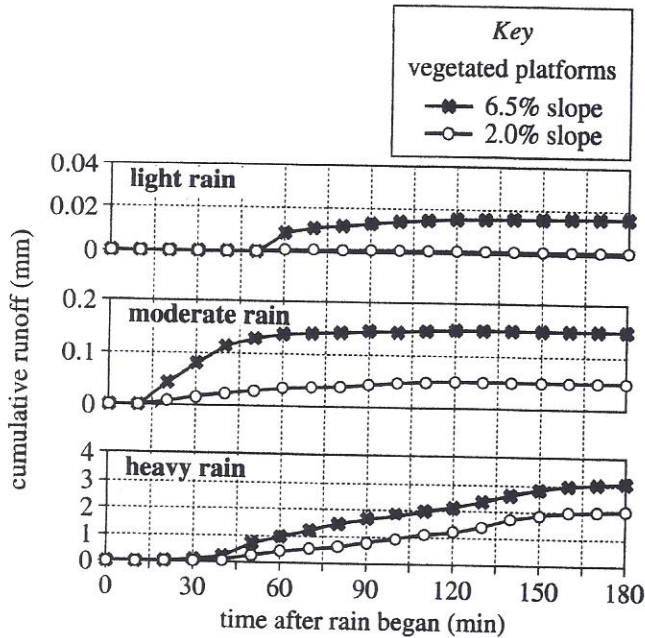


Figure 2

Figures adapted from Nicholas D. VanWoert et al., "Green Roof Stormwater Retention: Effects of Roof Surface, Slope, and Media Depth." ©2005 by the American Society of Agronomy, Crop Science Society of America, and Soil Science Society of America.

18. According to the results of Study 1, for the heavy rain event, the cumulative runoff from the gravel platform stopped increasing at a time closest to which of the following?
- F. 60 min
G. 90 min
H. 120 min
J. 150 min

19. In Study 2, as total rainfall increased, how did the cumulative runoff for the 6.5% slope platform at 180 min and for the 2.0% slope platform at 180 min, respectively, change?

	6.5% slope platform	2.0% slope platform
A.	increased	increased
B.	increased	decreased
C.	decreased	increased
D.	decreased	decreased

- A. increased
B. increased
C. decreased
D. decreased

20. According to the results of Study 1, for the heavy rain event, what is the order of the 3 platforms, from the platform having the least cumulative runoff at 180 min to the platform having the greatest cumulative runoff at 180 min?

- F. Gravel, vegetated, media
G. Gravel, media, vegetated
H. Vegetated, gravel, media
J. Vegetated, media, gravel

21. Consider the results of the studies for the vegetated platforms during the heavy rain event. If a vegetated platform having a slope of 4.0% had been included in Study 2, the cumulative runoff at 150 min would most likely have been:

- A. less than 1.0 mm.
B. between 1.0 mm and 1.5 mm.
C. between 1.5 mm and 3.0 mm.
D. greater than 3.0 mm.

22. In Study 1, which of the following factors was intentionally varied in order to determine the effect on the runoff?

- F. Amount of runoff
G. Rate of runoff
H. Materials on the platform
J. Area of the platform

23. The top layer of the green roof performs which of the processes or functions listed below?

- I. Taking up water
II. Taking in CO₂
III. Holding growing medium in place

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

Passage V

A store sign is to be suspended from a 1-meter-long horizontal rod. The rod is supported by a cable at one end and a bracket at the other (see Figure 1).

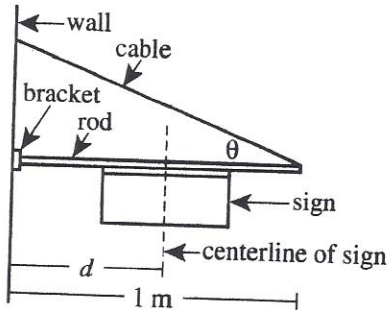


Figure 1

The sign's weight, W ; the angle, θ , between the cable and the rod; and the distance, d , between the centerline of the sign and the wall will each affect the tension, T , in the cable. The cable will break if T exceeds the cable's breaking force, F .

Table 1 lists F , in newtons (N), for stainless steel cable of various diameters. Figure 2 contains graphs of T (in N) versus θ for various W (in N), where $d = 0.50$ m. Figure 3 contains graphs of T versus θ for various d , where $W = 100$ N.

Cable diameter (mm)	F (N)
0.500	59
1.000	235
1.500	531
2.000	942

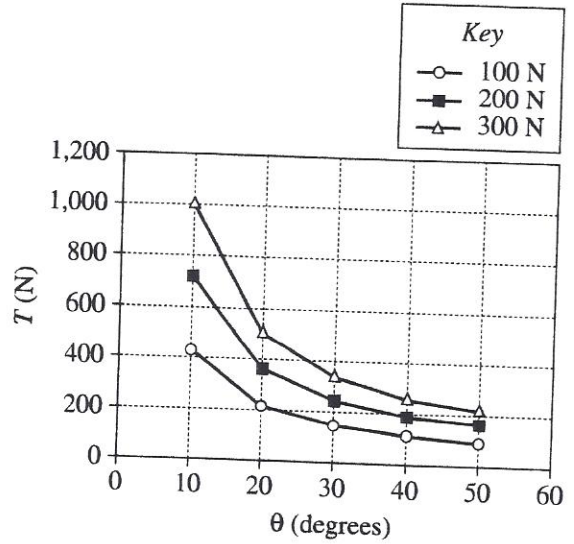


Figure 2

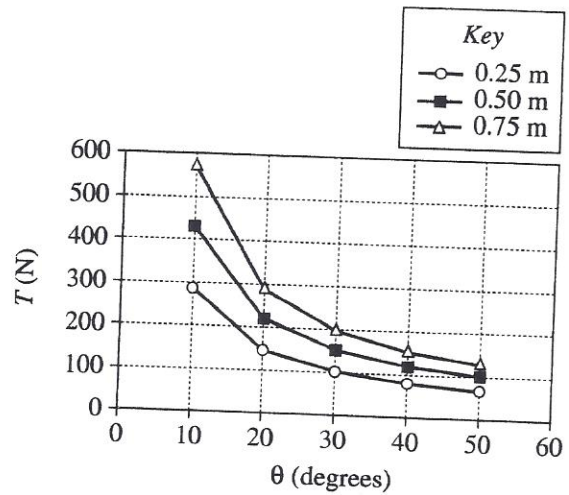


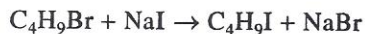
Figure 3



24. According to Figure 3, if $d = 0.75$ m and $W = 100$ N, the greatest change in T occurs when θ increases from:
- F. 10° to 20° .
 - G. 20° to 30° .
 - H. 30° to 40° .
 - J. 40° to 50° .
25. Based on Figure 2, for $d = 0.50$ m and any given θ , what is the order of the sign weights, from the weight that produces the greatest cable tension to the weight that produces the least cable tension?
- A. 100 N, 200 N, 300 N
 - B. 100 N, 300 N, 200 N
 - C. 300 N, 100 N, 200 N
 - D. 300 N, 200 N, 100 N
26. Consider the data in Figure 3 for $d = 0.25$ m and $d = 0.50$ m. For each value of d , what value of θ results in $T = 100$ N?
- | | $d = 0.25$ m | $d = 0.50$ m |
|----|--------------|--------------|
| F. | 30° | 30° |
| G. | 30° | 50° |
| H. | 50° | 30° |
| J. | 50° | 50° |
27. Based on Figure 2, for $d = 0.50$ m and $\theta = 10^\circ$, the W at which $T = 600$ N would most likely be:
- A. less than 100 N.
 - B. between 100 N and 200 N.
 - C. between 200 N and 300 N.
 - D. greater than 300 N.
28. Based on Table 1 and Figure 2, for $d = 0.50$ m and $\theta = 10^\circ$, can the 1.500 mm diameter stainless steel cable support a sign with $W = 300$ N without breaking?
- F. Yes, because T will be greater than F .
 - G. Yes, because T will be less than F .
 - H. No, because T will be greater than F .
 - J. No, because T will be less than F .

**Passage VI**

When 1-bromobutane (C_4H_9Br) and sodium iodide (NaI) are dissolved together in a solvent—acetone or acetonitrile—they react to form 1-iodobutane (C_4H_9I) and sodium bromide ($NaBr$):



$NaBr$ is not very soluble in either solvent, so as $NaBr$ forms, it alone precipitates from the reaction solution. The reaction can be monitored by measuring the *conductivity* (ability to conduct electrical current) of the reaction solution because NaI is the only component that significantly contributes to the solution's conductivity.

Students did 3 experiments to study the rate of this reaction.

Experiment 1

A probe was used to measure (in millisiemens per centimeter, mS/cm) the conductivities of solutions with different NaI concentrations (in millimoles per liter, $mmol/L$) in acetone or in acetonitrile at $40^\circ C$ (see Figure 1). This trial was repeated twice, once at $30^\circ C$ and once at $20^\circ C$. The results did not significantly differ from those at $40^\circ C$.

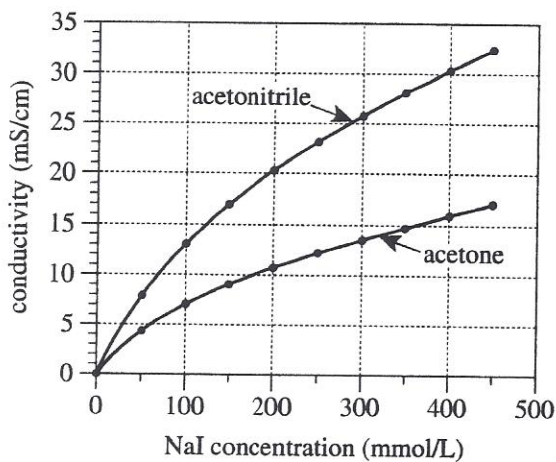


Figure 1

Experiment 2

A capped test tube containing an 800.0 mmol/L C_4H_9Br -acetone solution was mostly submerged in a water bath maintained at $40^\circ C$. Another capped test tube—containing an 800.0 mmol/L NaI -acetone solution, a magnetic stir bar, and the conductivity probe—was mostly submerged in the bath. After 10 min, the tubes were uncapped

and the C_4H_9Br solution was added to the NaI solution. The tube was capped and the solution was stirred in the bath. Conductivity readings were recorded at regular intervals. This trial was repeated twice, once at $30^\circ C$ and once at $20^\circ C$ (see Figure 2).

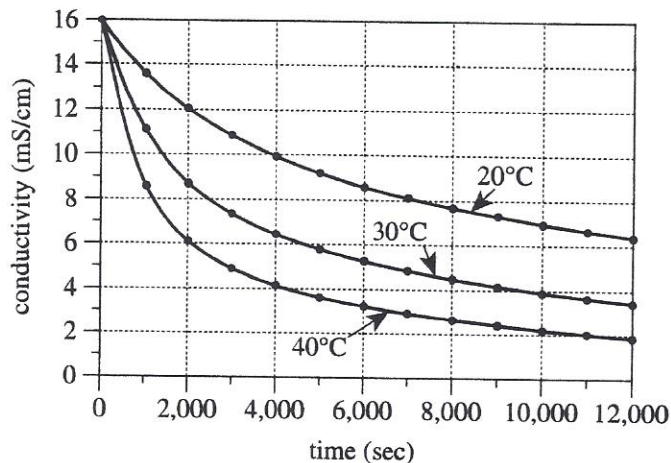


Figure 2

Experiment 3

The trials of Experiment 2 at $40^\circ C$ and at $20^\circ C$ were repeated except that the solvent was acetonitrile (see Figure 3).

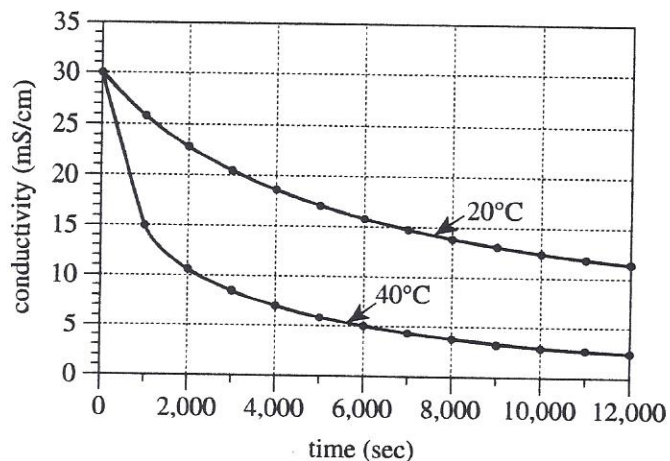


Figure 3

Figures adapted from R. David Pace and Yagya Regmi, "The Finkelstein Reaction: Quantitative Reaction Kinetics of an S_N2 Reaction Using Nonaqueous Conductivity." ©2006 by Division of Chemical Education, Inc., American Chemical Society.



29. A difference between Experiments 2 and 3 was that:
- a different solvent was used in Experiment 2 than was used in Experiment 3.
 - a different initial concentration of reactants was used in Experiment 2 than was used in Experiment 3.
 - in Experiment 2 all trials were done at the same temperature, whereas in Experiment 3 each trial was done at a different temperature.
 - in Experiment 2 each trial was done at a different temperature, whereas in Experiment 3 all trials were done at the same temperature.
30. Based on Experiment 2, if a trial had been done in Experiment 3 at 30°C, the conductivity at 6,000 sec would most likely have been:
- less than 5 mS/cm.
 - between 5 mS/cm and 15 mS/cm.
 - between 15 mS/cm and 25 mS/cm.
 - greater than 25 mS/cm.
31. In Experiments 2 and 3, when the students were measuring the conductivity, they were directly monitoring the:
- increase in the NaI concentration.
 - decrease in the NaI concentration.
 - increase in the NaBr concentration.
 - decrease in the NaBr concentration.
32. What is the most likely reason that in Experiments 2 and 3 the test tubes were left in the bath for 10 min before their contents were mixed?
- To increase the conductivity of the solution in each tube to a level that would allow the reaction to occur
 - To decrease the conductivity of the solution in each tube to a level that would allow the reaction to occur
 - To ensure that the bath and the solution in each tube had reached room temperature
 - To ensure that the solution in each tube had reached the temperature of the bath
33. During each of the trials in Experiments 2 and 3, a white solid accumulated at the bottom of the test tube. What was this solid?
- C_4H_9Br
 - NaI
 - C_4H_9I
 - NaBr
34. Suppose that at 40°C, 10 mL of a 100 mmol/L NaI-acetone solution is mixed with 10 mL of a 300 mmol/L NaI-acetone solution. Based on Experiment 1, the conductivity of the resulting solution will most likely be closest to which of the following?
- 11 mS/cm
 - 16 mS/cm
 - 21 mS/cm
 - 30 mS/cm

Passage VII

The 3 primary interactions between *photons* (particles of light) and matter are:

- the *Compton effect*: A photon collides with, and gives some of its energy to, a free electron (e^-). The photon and e^- are scattered away from the collision site.
- the *photoelectric effect*: A photon is absorbed by, and gives all of its energy to, an e^- bound to an atom. The e^- is scattered away from the atom.
- *pair production*: A photon passes close to an atom and is transformed into an e^- and a *positron* (e^+ , a particle with the same mass as an e^- , but the opposite charge), converting energy to mass. The e^- and e^+ are scattered away from the nearby atom.

Study 1

A slab of carbon (C) surrounded by particle detectors was bombarded by photons that each had an energy between 0.01 million electron volts (MeV) and 100 MeV. When an incident photon interacted with the slab and scattered 1 or more particles into the detectors, a *successful* event was registered. When the photon passed through the slab without interacting, an *unsuccessful* event was registered. In each successful event, the energy of the incident photon and the type(s) of scattered particle(s) were recorded. When 500,000 successful events had occurred, data from these events were then used to calculate the relative probability (P) for each known type of photon-matter interaction to occur at various incident photon energies. Plots of P versus incident photon energy for the 3 primary interactions are shown in Figure 1.

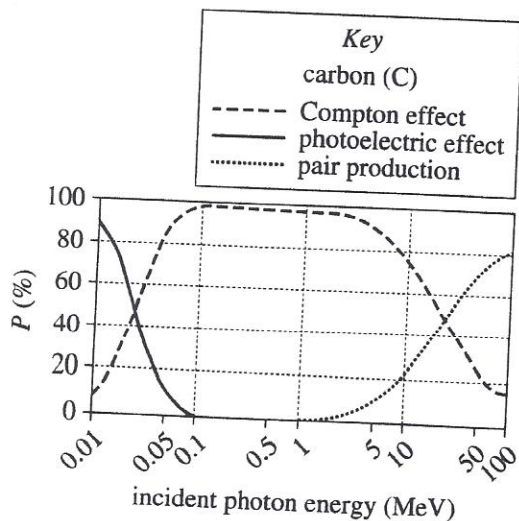


Figure 1

Study 2

The procedure of Study 1 was repeated, except a *lead* (Pb) slab was bombarded. Plots of P versus incident photon energy for the 3 primary interactions are shown in Figure 2.

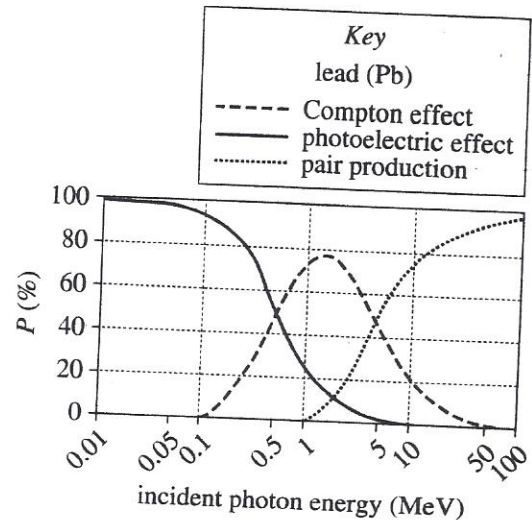


Figure 2

Figures adapted from Arthur Beiser, *Concepts of Modern Physics*. ©1995 by McGraw-Hill, Inc.

35. In Study 2, at approximately what incident photon energy was P for the Compton effect in Pb at its maximum value?
- A. 0.02 MeV
B. 0.2 MeV
C. 2 MeV
D. 20 MeV
36. In any given event, what scattered particle(s) was(were) registered by the detectors as evidence that the Compton effect, the photoelectric effect, and pair production, respectively, had occurred?

(Note: The symbol for a photon is γ .)

	Compton effect	photoelectric effect	pair production
F.	γ, e^-	e^-	e^-, e^+
G.	γ, e^-	e^-, e^+	e^-, e^+
H.	e^-, e^+	e^-	γ, e^-
J.	e^-, e^+	γ, e^-	e^-



37. Pair production cannot occur unless the incident photon has sufficient energy. Based on the results of Studies 1 and 2, the *minimum* incident photon energy for pair production is closest to which of the following values?
- 0.1 MeV
 - 1 MeV
 - 10 MeV
 - 100 MeV
38. Which of the following questions CANNOT be answered by an analysis of Figure 2?
- What is P for the photoelectric effect in Pb at an incident photon energy of 1 MeV?
 - What is the probability of an event being successful in Pb at an incident photon energy of 1 MeV?
 - Above what incident photon energy is P for pair production higher than 50% in Pb?
 - At what incident photon energy are P for the photoelectric effect and P for pair production equal in Pb?
39. Which of the following statements about the data used to generate the plots of P versus incident photon energy is correct? The plots shown in Figures 1 and 2 were generated using:
- only data from successful events.
 - only data from unsuccessful events.
 - data primarily from successful events in addition to some data from unsuccessful events.
 - data primarily from unsuccessful events in addition to some data from successful events.
40. An element is considered *light* if its atomic number is less than that of iron or *heavy* if its atomic number is greater than that of iron. Based on the results of Studies 1 and 2, for 0.1 MeV photons bombarding light elements and heavy elements, respectively, which primary interaction most likely has the highest P ?
- | <u>light elements</u> | <u>heavy elements</u> |
|-------------------------|-----------------------|
| F. Compton effect | photoelectric effect |
| G. photoelectric effect | Compton effect |
| H. Compton effect | pair production |
| J. pair production | photoelectric effect |

END OF TEST 4

STOP! DO NOT RETURN TO ANY OTHER TEST.