GRE® Chemistry Test
Practice Book

This practice book contains

- one actual, full-length *GRE*® Chemistry Test
- test-taking strategies

Become familiar with

- test structure and content
- test instructions and answering procedures

Compare your practice test results with the performance of those who took the test at a GRE administration.

www.ets.org/gre

Table of Contents

Alt text is provided for 77 of the 130 *GRE®* Chemistry Test questions in this practice book. However, because of the complexity and length of the verbal descriptions that the graphics associated with some of the questions would require, it is not practical to provide alt text for all 130 questions in this test. The statement "No alt text" is included for each of the 53 questions for which alt text is not provided.

If you need additional accessible practice material for the GRE Chemistry Test, contact ETS Disability Services at 1-609-771-7780 or **stassd@ets.org.**

Overview

The *GRE*® Chemistry Test consists of about 130 multiple-choice questions. Testing time is 2 hours and 50 minutes; there are no separately-timed sections.

A periodic table is printed in the test booklet as well as a table of information (see pages 8 and 9) presenting various physical constants and a few conversion factors among SI units. Whenever necessary, additional values of physical constants are printed with the text of the question. Test questions are constructed to simplify mathematical manipulations. As a result, neither calculators nor tables of logarithms are needed. If the solution to a problem requires the use of logarithms, the necessary values are included with the question.

This publication provides a comprehensive overview of the GRE Chemistry Test to help you get ready for test day. It is designed to help you:

- Understand what is being tested
- Gain familiarity with the question types
- Review test-taking strategies
- Understand scoring
- Practice taking the test

To learn more about the GRE Subject Tests, visit **www.ets.org/gre**.

Test Content

The content of the Chemistry Test emphasizes the four fields into which chemistry has been traditionally divided and some interrelationships, individual questions may test more than one field of chemistry. Some test takers may associate a particular question with one field, whereas other test takers may have encountered the same material in a different field. For example, the knowledge necessary to answer some questions classified as testing organic chemistry may well have been acquired in analytical chemistry courses by some test takers. Consequently, the emphases of the four fields indicated in the following outline of material covered by the test should not be considered definitive.

I. **Analytical Chemistry (15%)**

A. Data Acquisition and Use of Statistics — Errors, statistical considerations

B. Solutions and Standardization — Concentration terms, primary standards

C. Homogeneous Equilibria — Acid-base, oxidation-reduction, complexometry

D. Heterogeneous Equilibria — Gravimetric analysis, solubility, precipitation titrations, chemical separations

E. Instrumental Methods — Electrochemical methods, spectroscopic methods, chromatographic methods, thermal methods, calibration of instruments

F. Environmental Applications

G. Radiochemical Methods — Detectors, Applications

II. **Inorganic Chemistry (25%)**

A. General Chemistry — Periodic trends, oxidation states, nuclear chemistry

B. Ionic Substances — Lattice geometries, lattice energies, ionic radii and radius/ratio effects

C. Covalent Molecular Substances — Lewis diagrams, molecular point groups, VSEPR concept, valence bond description and hybridization, molecular orbital description, bond energies, covalent and van der Waals radii of the elements, intermolecular forces

D. Metals and Semiconductors — Structure, band theory, physical and chemical consequences of band theory

E. Concepts of Acids and Bases — Brønsted-Lowry approaches, Lewis theory, solvent system approaches

F. Chemistry of the Main Group Elements — Electronic structures, occurrences and recovery, physical and chemical properties of the elements and their compounds

G. Chemistry of the Transition Elements —
Electronic structures, occurrences and
recovery, physical and chemical properties
of the elements and their compounds,
coordination chemistry

H. Special Topics — Organometallic
chemistry, catalysis, bioinorganic
chemistry, applied solid-state chemistry,
environmental chemistry

III. Organic Chemistry (30%)

A. Structure, Bonding, and Nomenclature —
Lewis structures, orbital hybridization,
configuration and stereochemical
notation, conformational analysis,
systematic IUPAC nomenclature,
spectroscopy (IR and 1H and 13C NMR)

B. Functional Groups — Preparation,
reactions, and interconversions of alkanes,
alkenes, alkynes, dienes, alkyl halides,
alcohols, ethers, epoxides, sulfides, thiols,
aromatic compounds, aldehydes, ketones,
carboxylic acids and their derivatives,
amines

C. Reaction Mechanisms — Nucleophilic
displacements and addition, nucleophilic
aromatic substitution, electrophilic
additions, electrophilic aromatic
substitutions, eliminations, Diels-Alder
and other cycloadditions

D. Reactive Intermediates — Chemistry and
nature of carbocations, carbanions, free
radicals, carbenes, benzynes, enols

E. Organometallics — Preparation and
reactions of Grignard and organolithium
reagents, lithium organocuprates, and
other modern main group and transition
metal reagents and catalysts

F. Special Topics — Resonance, molecular
orbital theory, catalysis, acid-base
theory, carbon acidity, aromaticity,
antiaromaticity, macromolecules, lipids,
amino acids, peptides, carbohydrates,
nucleic acids, terpenes, asymmetric
synthesis, orbital symmetry, polymers

IV. Physical Chemistry (30%)

A. Thermodynamics — First, second, and
third laws, thermochemistry, ideal and real
gases and solutions, Gibbs and Helmholtz
energy, chemical potential, chemical
equilibria, phase equilibria, colligative
properties, statistical thermodynamics

B. Quantum Chemistry and Applications to
Spectroscopy — Classical experiments,
principles of quantum mechanics, atomic
and molecular structure, molecular
spectroscopy

C. Dynamics — Experimental and theoretical
chemical kinetics, solution and liquid
dynamics, photochemistry

Preparing for the Test

GRE Subject Test questions are designed to measure
skills and knowledge gained over a long period of
time. Although you might increase your scores to
some extent through preparation a few weeks or
months before you take the test, last minute cramming
is unlikely to be of further help. The following
information may be helpful.

- A general review of your college courses is
probably the best preparation for the test.
However, the test covers a broad range of
subject matter, and no one is expected to be
familiar with the content of every question.

- Become familiar with the types of questions
in the GRE Chemistry Test, paying special
attention to the directions. If you thoroughly
understand the directions before you take the
test, you will have more time during the test to
focus on the questions themselves.

Test-Taking Strategies

The questions in the practice test illustrate the types
of multiple-choice questions in the test. When you
take the actual test, you will mark your answers on a
separate machine-scorable answer sheet.

The following are some general test-taking strategies you may want to consider.

- Read the test directions carefully, and work as rapidly as you can without being careless. For each question, choose the best answer from the available options.

- All questions are of equal value; do not waste time pondering individual questions you find extremely difficult or unfamiliar.

- You may want to work through the test quickly, first answering only the questions about which you feel confident, then going back and answering questions that require more thought, and concluding with the most difficult questions if there is time.

- If you decide to change an answer, make sure you completely erase it and fill in the oval corresponding to your desired answer.

- Your score will be determined by the number of questions you answer correctly. Questions you answer incorrectly or for which you mark no answer or more than one answer are counted as incorrect. Nothing is subtracted from a score if you answer a question incorrectly. Therefore, to maximize your score it is better for you to guess at an answer than not to respond at all.

- Record all answers on your answer sheet. Answers recorded in your test book will not be counted.

- Do not wait until the last few minutes of a testing session to record answers on your answer sheet.

What Your Scores Mean

The number of questions you answered correctly on the whole test (total correct score) is converted to the total reported scaled score. This conversion ensures that a scaled score reported for any edition of a GRE Chemistry Test is comparable to the same scaled score earned on any other edition of the test. Thus, equal scaled scores on a particular test indicate essentially equal levels of performance regardless of the test edition taken.

GRE Chemistry Test scores are reported on a 200 to 990 score scale in ten-point increments.

Test scores should be compared only with other scores on the Chemistry Test. For example, a 750 on the Chemistry Test is not equivalent to a 750 on the Biology Test.

Taking the Practice Test

The practice test begins on page 7. The total time that you should allow for this practice test is 2 hours and 50 minutes. An answer sheet is provided for you to mark your answers to the test questions.

It is best to take this practice test under timed conditions. Find a quiet place to take the test and make sure you have a minimum of 2 hours and 50 minutes available.

To simulate how the administration will be conducted at the test center, print the answer sheet (pages 53 and 54). Then go to the back cover of the test book (page 50) and follow the instructions for completing the identification areas of the answer sheet. When you are ready to begin the test, note the time and begin marking your answers on the answer sheet. Stop working on the test when 2 hours and 50 minutes have elapsed.

Scoring the Practice Test

The worksheet on page 51 lists the correct answers to the questions. The "Correct Response" columns are provided for you to mark those questions for which you chose the correct answer.

Mark each question that you answered correctly. Then, add up your correct answers and enter your total number of correct answers in the space labeled "Total Correct" at the bottom of the page. Next, use the "Total Score" conversion table on page 52 to find the corresponding scaled score. For example, suppose you chose the correct answers to 101 questions on the test. The "Total Correct" entry in the conversion table that matches 101 is 100-101 and your total scaled score is 790.

Evaluating Your Performance

Now that you have scored your test, you may wish to compare your performance with the performance of others who took this test.

The data in the worksheet on page 51 are based on the performance of a sample of the test takers who took the GRE Chemistry Test in the United States.

The numbers in the column labeled "P+" on the worksheet indicate the percentages of examinees in this sample who answered each question correctly. You may use these numbers as a guide for evaluating your performance on each test question.

Interpretive data based on the scores earned by a recent cohort of test takers are available on the GRE website at **www.ets.org/gre/subject/scores/understand**. The interpretive data show, for selected scaled score, the percentage of test takers who received lower scores. To compare yourself with this population, look at the percentage next to the scaled score you earned on the practice test. Note that these interpretive data are updated annually and reported on GRE score reports.

It is important to realize that the conditions under which you tested yourself were not exactly the same as those you will encounter at a test center. It is impossible to predict how different test-taking conditions will affect test performance, and this is only one factor that may account for differences between your practice test scores and your actual test scores. By comparing your performance on this practice test with the performance of other individuals who took GRE Chemistry Test, however, you will be able to determine your strengths and weaknesses and can then plan a program of study to prepare yourself for taking the GRE Chemistry Test under standard conditions.

GRE

FORM GR1727

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GRADUATE RECORD EXAMINATIONS®

CHEMISTRY TEST

PERIODIC TABLE OF THE ELEMENTS

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1 **H** 1.008																	2 **He** 4.00
3 **Li** 6.94	4 **Be** 9.01											5 **B** 10.81	6 **C** 12.01	7 **N** 14.01	8 **O** 16.00	9 **F** 19.00	10 **Ne** 20.18
11 **Na** 22.99	12 **Mg** 24.30											13 **Al** 26.98	14 **Si** 28.09	15 **P** 30.97	16 **S** 32.06	17 **Cl** 35.45	18 **Ar** 39.95
19 **K** 39.10	20 **Ca** 40.08	21 **Sc** 44.96	22 **Ti** 47.90	23 **V** 50.94	24 **Cr** 52.00	25 **Mn** 54.94	26 **Fe** 55.85	27 **Co** 58.93	28 **Ni** 58.69	29 **Cu** 63.55	30 **Zn** 65.39	31 **Ga** 69.72	32 **Ge** 72.59	33 **As** 74.92	34 **Se** 78.96	35 **Br** 79.90	36 **Kr** 83.80
37 **Rb** 85.47	38 **Sr** 87.62	39 **Y** 88.91	40 **Zr** 91.22	41 **Nb** 92.91	42 **Mo** 95.94	43 **Tc** (98)	44 **Ru** 101.1	45 **Rh** 102.91	46 **Pd** 106.42	47 **Ag** 107.87	48 **Cd** 112.41	49 **In** 114.82	50 **Sn** 118.71	51 **Sb** 121.75	52 **Te** 127.60	53 **I** 126.91	54 **Xe** 131.29
55 **Cs** 132.91	56 **Ba** 137.33	57 ***La** 138.91	72 **Hf** 178.49	73 **Ta** 180.95	74 **W** 183.85	75 **Re** 186.21	76 **Os** 190.2	77 **Ir** 192.2	78 **Pt** 195.08	79 **Au** 196.97	80 **Hg** 200.59	81 **Tl** 204.38	82 **Pb** 207.2	83 **Bi** 208.98	84 **Po** (209)	85 **At** (210)	86 **Rn** (222)
87 **Fr** (223)	88 **Ra** 226.02	89 †**Ac** 227.03	104 **Rf** (261)	105 **Db** (262)	106 **Sg** (266)	107 **Bh** (264)	108 **Hs** (277)	109 **Mt** (268)	110 **Ds** (271)	111 **Rg** (272)							

*Lanthanide Series

58 **Ce** 140.12	59 **Pr** 140.91	60 **Nd** 144.24	61 **Pm** (145)	62 **Sm** 150.4	63 **Eu** 151.97	64 **Gd** 157.25	65 **Tb** 158.93	66 **Dy** 162.50	67 **Ho** 164.93	68 **Er** 167.26	69 **Tm** 168.93	70 **Yb** 173.04	71 **Lu** 174.97

†Actinide Series

90 **Th** 232.04	91 **Pa** 231.04	92 **U** 238.03	93 **Np** (237)	94 **Pu** (244)	95 **Am** (243)	96 **Cm** (247)	97 **Bk** (247)	98 **Cf** (251)	99 **Es** (252)	100 **Fm** (257)	101 **Md** (258)	102 **No** (259)	103 **Lr** (262)

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TABLE OF INFORMATION

Electron rest mass	$m_e = 9.11 \times 10^{-31}$ kg
Proton rest mass	$m_p = 1.672 \times 10^{-27}$ kg
Neutron rest mass	$m_n = 1.675 \times 10^{-27}$ kg
Magnitude of the electron charge	$e = 1.60 \times 10^{-19}$ C
Bohr radius	$a_0 = 5.29 \times 10^{-11}$ m
Avogadro constant	$N_A = 6.02 \times 10^{23}$ mol^{-1}
Gas constant	$R = 8.314$ J mol^{-1} K^{-1}
	$= 0.0821$ L $\cdot$ atm mol^{-1} K^{-1}
	$= 0.08314$ L $\cdot$ bar mol^{-1} K^{-1}
Boltzmann constant	$k = 1.38 \times 10^{-23}$ J K^{-1}
Planck constant	$h = 6.63 \times 10^{-34}$ J $\cdot$ s
	$\hbar = h/2\pi = 1.05 \times 10^{-34}$ J $\cdot$ s
Speed of light	$c = 3.00 \times 10^8$ m s^{-1} = 3.00×10^{10} cm s^{-1}
1 bar pressure	1 bar $= 1.000 \times 10^5$ N m^{-2}
	$= 1.000 \times 10^5$ Pa
	$= 0.987$ atm
1 atmosphere pressure	1 atm $= 1.013 \times 10^5$ N m^{-2}
	$= 1.013 \times 10^5$ Pa
	$= 1.013$ bar
Faraday constant	$\mathscr{F} = 9.65 \times 10^4$ C mol^{-1}
1 atomic mass unit (amu)	1 amu $= 1.66 \times 10^{-27}$ kg
1 electron volt (eV)	1 eV $= 1.602 \times 10^{-19}$ J
Angstrom	1 Å $= 10^{-10}$ m $= 10^{-1}$ nm
Volume of 1 mol of ideal gas at 0° C, 1 atmosphere	$= 22.4$ L

CHEMISTRY TEST
Time—170 minutes
130 Questions

Directions: Each of the questions or incomplete statements below is followed by five suggested answers or completions. Select the one that is best in each case and then fill in the corresponding space on the answer sheet.

<u>Note:</u> Solutions are aqueous unless otherwise specified.

Throughout the test the following symbols have the specified definitions unless otherwise noted.

T	=	temperature	M	=	molar
P	=	pressure	m	=	molal
V	=	volume	L	=	liter(s)
S	=	entropy	mL	=	milliliter(s)
H	=	enthalpy	g	=	gram(s)
U	=	internal energy	kg	=	kilogram(s)
G	=	Gibbs energy	m	=	meter(s)
A	=	Helmholtz energy	nm	=	nanometer(s)
R	=	gas constant	atm	=	atmosphere(s)
n	=	number of moles	J	=	joule(s)
s	=	seconds	kJ	=	kilojoule(s)
mol	=	mole(s)	ppm	=	parts per million
C	=	coulomb(s)	Pa	=	Pascal(s)
			V	=	volt(s)

CHO 1. CH$_3$MgBr
     ———————————→
     2. H$_2$O, H$^+$

1. Which of the following is the major product of the reaction shown above?

(A)

   O
   ‖
   CH$_3$

(B)

   O
   ‖
   H
   CH$_3$

(C)

   HO   OH
   CH$_3$

(D)

   OH
   CH$_3$

(E)   CHO
      CH$_3$

_____

   O
   ‖
   O
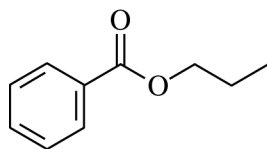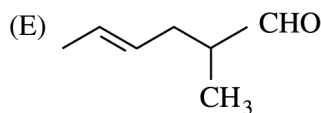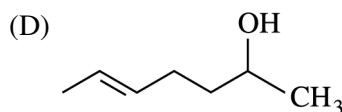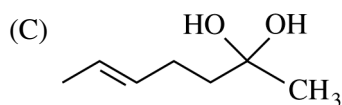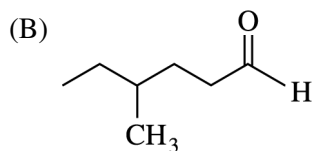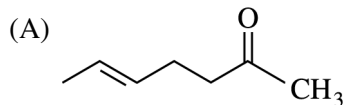
2. According to IUPAC rules, what is the name of the molecule shown above?

(A) Benzyl propanoate
(B) Phenyl propanoate
(C) Phenyl butanoate
(D) Propanoyl benzene
(E) Propyl benzoate

3. Of the following ions, which has the smallest radius?

(A) K$^+$
(B) Ca^{2+}
(C) Sc^{3+}
(D) Rb$^+$
(E) Sr^{2+}

4. The molecular geometry of thionyl chloride, SOCl$_2$, is best described as

(A) trigonal planar
(B) T-shaped
(C) tetrahedral
(D) trigonal pyramidal
(E) linear

e$^-$

M   N

M^{2+} N^{2+}
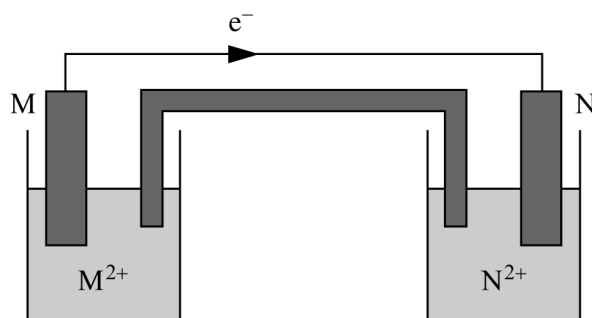
5. Which of the following is true of the cell represented above?

(A) Metal M is being oxidized.
(B) Metal N is the reducing agent.
(C) N^{2+} ions are being oxidized.
(D) M^{2+} ions are being reduced.
(E) The cell potential must be zero.

$$\left(P + \frac{an^2}{V^2}\right)(V - nb) = nRT$$

6. Of the following substances, which is likely to have the largest value of the coefficient a in the van der Waals equation of state for real gases shown above?

(A) H_2

(B) N_2

(C) CH_4

(D) NH_3

(E) CO_2

7. What is the orbital angular momentum quantum number, l, of the electron that is most easily removed when ground-state aluminum is ionized?

(A) 3

(B) 2

(C) 1

(D) 0

(E) 1/2

$$\_\_ MnO_4^- + \_\_ I^- + \_\_ H^+ \rightleftharpoons \_\_ Mn^{2+} + \_\_ IO_3^- + \_\_ H_2O$$
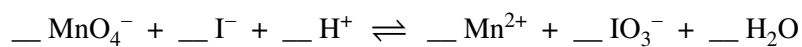
8. When the equation shown above is balanced, which of the following is true?

(A) The $I^- : IO_3^-$ ratio is 3:1.

(B) The $MnO_4^- : I^-$ ratio is 6:5.

(C) The $MnO_4^- : Mn^{2+}$ ratio is 3:1.

(D) The $H^+ : I^-$ ratio is 2:1.

(E) The $MnO_4^- : IO_3^-$ ratio is 1:1.

$$CH_3CH_2CH_2CO_2H \xrightarrow[\text{2. } H_3O^+]{\text{1. LiAlH}_4 \text{ (excess)}}$$
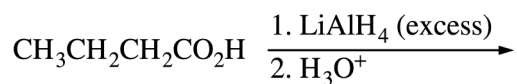
9. Which of the following is the major organic product of the reaction shown above?

(A) $CH_3CH_2CH_2CH(OH)_2$

(B) $CH_3CH_2CH_2CHO$

(C) $CH_3CH_2CH_2CH_2OH$

(D) $CH_3CH_2CH_2CH_3$

(E) $CH_3CH_2C\equiv CH$

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10. All of the following are aromatic EXCEPT

(A)

(B)

(C)

(D)

(E)
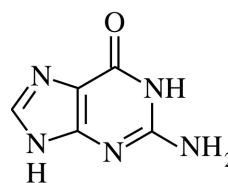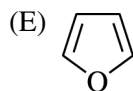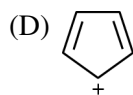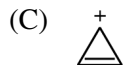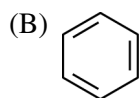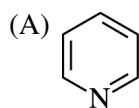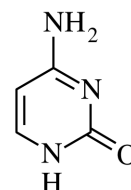
Guanine

Cytosine

11. In a DNA double-helix, guanine and cytosine bases, shown above, are paired together by

(A) covalent bonds
(B) hydrogen bonds
(C) peptide bonds
(D) hyperconjugation
(E) π-stacking

GO ON TO THE NEXT PAGE.

12. Of the following isomers, which is the most thermodynamically stable?

(A)

(B)

(C)

(D)

(E)
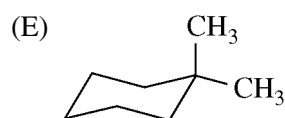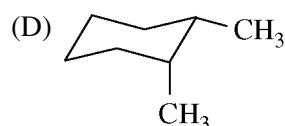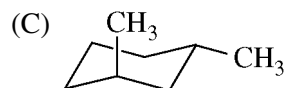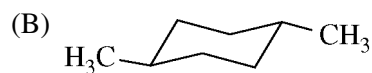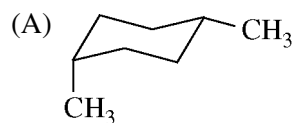
13. Under constant current electrolysis, how many coulombs would be required to reduce 2 mol of Cu^{2+} to metallic copper?
($\mathcal{F}$ = 96,500 coulombs/mol)

(A)   2
(B)   48,250
(C)   96,500
(D) 193,000
(E) 386,000

[A]	[B]	Initial Rate
0.10 M	0.30 M	1.5×10^{-4} M s^{-1}
0.20 M	0.30 M	3.0×10^{-4} M s^{-1}
0.20 M	0.60 M	12.0×10^{-4} M s^{-1}

14. For the reaction $A + B \rightarrow C + D$ carried out at constant temperature, the initial rates of reaction given above were found experimentally. The rate law of this reaction, expressed as a function of reactant concentrations, is

(A) rate $= k\,([A] + [B])$
(B) rate $= k\,[A][B]$
(C) rate $= k\,[A]^2[B]$
(D) rate $= k\,[A][B]^2$
(E) rate $= k\,[A]^2[B]^4$

15. Which of the following must be true about a binary liquid mixture that obeys Raoult's law?

I. The partial pressure of each component at equilibrium is proportional to its mole fraction in the liquid mixture.
II. The volume of the mixture is equal to the sum of the volumes of each component before mixing.
III. Intermolecular interactions in the mixture are identical to intermolecular interactions in the pure components.

(A) I only
(B) III only
(C) I and III only
(D) II and III only
(E) I, II, and III

GO ON TO THE NEXT PAGE.

$$3 \text{ Cl}^-(aq) + 4 \text{ CrO}_4{}^{2-}(aq) + 23 \text{ H}^+(aq) \rightarrow 3 \text{ HClO}_2(aq) + 4 \text{ Cr}^{3+}(aq) + 10 \text{ H}_2\text{O}(l)$$
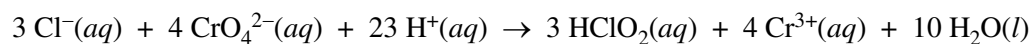
16. In the reaction shown above, $\text{Cl}^-(aq)$ behaves as

(A) an acid
(B) a base
(C) a catalyst
(D) an oxidizing agent
(E) a reducing agent

---

17. Elements with partially filled $4f$ or $5f$ orbitals include all of the following EXCEPT

(A) Cu
(B) Gd
(C) Eu
(D) Am
(E) Cm

$$\text{CH}_3\text{CH}_2\overset{\displaystyle O}{\overset{\displaystyle \|}{\text{C}}}\text{CH}_3$$
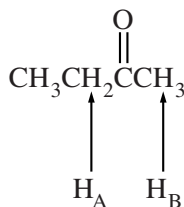
$$\underset{\text{H}_A}{\uparrow} \quad \underset{\text{H}_B}{\uparrow}$$

18. Which of the following gives the multiplicities of the signals for the protons designated H_A and H_B in the ^1H NMR spectrum of the compound shown above?

$\underline{\text{H}_A}$	$\underline{\text{H}_B}$
(A) Singlet	Singlet
(B) Triplet	Doublet
(C) Septet	Singlet
(D) Quartet	Triplet
(E) Quartet	Singlet

$$\overset{\displaystyle \text{CH}_3}{\underset{}{|}}$$
$$\text{CH}_3\text{—CH}{=}\text{CH}\text{—CH}\text{—CH}_3$$
$$\quad 1 \quad\ \ 2 \quad 3 \quad\ 4 \quad\ 5$$
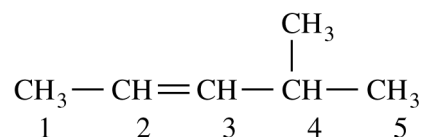
19. In the compound shown above, which hydrogen is most easily abstracted in a free radical bromination reaction?

(A) 1
(B) 2
(C) 3
(D) 4
(E) 5
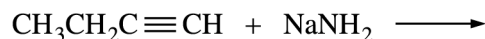
$$\text{CH}_3\text{CH}_2\text{C}{\equiv}\text{CH} + \text{NaNH}_2 \longrightarrow$$

20. Which of the following is the major product of the reaction shown above?

(A) $\text{NaCH}_2\text{CH}_2\text{C}{\equiv}\text{CH}$

(B) $\text{CH}_3\text{CH}_2\text{C}{\equiv}\text{CNH}_2$

(C) $\text{CH}_3\text{CH}_2\text{C}{\equiv}\text{CNa}$

(D)
$$\overset{\displaystyle \text{NH}_2}{\underset{}{|}}$$
$$\text{CH}_3\text{CH}_2\text{C}{=}\text{CHNa}$$

(E)
$$\overset{\displaystyle \text{NH}_2}{\underset{}{|}}$$
$$\text{CH}_3\text{CH}_2\text{C}{=}\text{CH}_2$$

21. Which of the following is always true of a spontaneous process?

(A) The process is exothermic.
(B) The process does not involve any work.
(C) The entropy of the system increases.
(D) The internal energy of the system decreases.
(E) The total entropy of the system plus surroundings increases.

22. The equation $\Delta H = \Delta U + P\Delta V$ is applicable

(A) always
(B) only for constant pressure processes
(C) only for constant temperature processes
(D) only for constant volume processes
(E) only for constant entropy processes

23. A system that consists of a sample of nitrogen gas behaving as an ideal gas is compressed at a constant temperature. Which of the following is true about w (work) and q (heat transfer) for this process?

	w	q
(A)	> 0	< 0
(B)	> 0	> 0
(C)	< 0	< 0
(D)	< 0	> 0
(E)	$= 0$	$= 0$

24. What is the maximum number of phases that can be at equilibrium with each other in a three-component mixture?

(A) 2
(B) 3
(C) 4
(D) 5
(E) 6

25. Infrared (IR) spectroscopy is useful for determining certain aspects of the structure of organic molecules because

(A) all molecular bonds absorb IR radiation
(B) IR peak intensities are related to molecular mass
(C) most organic functional groups absorb in a characteristic region of the IR spectrum
(D) each element absorbs at a characteristic wavelength
(E) vibrational transitions are correlated to spin-spin coupling

26. Which of the following statements about nuclear binding energies is NOT true?

(A) Binding energy per nucleon reaches a maximum for ^{56}Fe.
(B) Nuclear binding energies have about the same magnitude as chemical bond energies.
(C) Nuclei have slightly less mass than the sum of their component nucleons.
(D) The nuclei of heavy elements have more neutrons than protons in order to provide sufficient binding energy to hold the nuclei together.
(E) When very light elements undergo exothermic fusion reactions, the released energy arises from an increased binding energy per nucleon in the fusion products.

27. The dissociation energy for a hydrogen-bromine bond is defined as the change in enthalpy, ΔH, for which of the following reactions?

(A) $2\,HBr(g) \rightarrow H_2(g) + Br_2(l)$

(B) $HBr(g) \rightarrow H^+(g) + Br^-(g)$

(C) $H(g) + Br(g) \rightarrow HBr(g)$

(D) $H_2(g) + Br_2(l) \rightarrow 2\,HBr(g)$

(E) $HBr(g) \rightarrow H(g) + Br(g)$

28. A radioactive isotope, which is used in diagnostic imaging, has a half-life of 6.0 hours. If a quantity of this isotope has an activity of $150\,\mu Ci$ when it is delivered to a hospital, how much activity will remain 24 hours after delivery?
(μCi = microcuries)

(A) $150\ \mu Ci$
(B) $\ \ 38\ \mu Ci$
(C) $\ \ 19\ \mu Ci$
(D) $\ \ \ 9.4\ \mu Ci$
(E) $\ \ \ 4.7\ \mu Ci$

29. The rate, r, of a zero-order chemical reaction $A \rightarrow B$ can be expressed as which of the following?

(A) $r = k\ln[A]$
(B) $r = k\,[A]^2$
(C) $r = k\,[A]$
(D) $r = k\,[A]^{1/2}$
(E) $r = k$

30. Which of the following is classified as a conjugate acid-base pair?

(A) HCl / $NaOH$
(B) H_3O^+ / H_2O
(C) O_2 / H_2O
(D) H^+ / Cl^-
(E) $NaCl$ / $NaOH$

31. An impure sample of K_2O was analyzed by precipitating the potassium as the insoluble tetraphenyl borate salt, $KB(C_6H_5)_4$. The precipitate, $KB(C_6H_5)_4$ had a mass of 1.57 g. The mass of K_2O in the original sample is obtained from which of the following? (Molar masses: $KB(C_6H_5)_4$ = 358.3 g and K_2O = 94.2 g)

(A) $\dfrac{(1.57)(94.2)}{(358.3)}$

(B) $\dfrac{(358.3)}{(1.57)(94.2)}$

(C) $\dfrac{(1.57)(94.2)}{2(358.3)}$

(D) $\dfrac{2(1.57)(94.2)}{(358.3)}$

(E) $\dfrac{2(358.3)}{(1.57)(94.2)}$

$$\text{(structure: benzene ring with OCH}_3\text{)} \xrightarrow{\text{HI}}$$
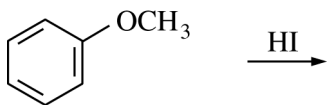
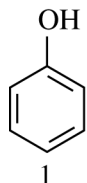32. Which of the following are the major products of the reaction shown above?

(A) benzene + CH_3OH

(B) phenol (OH) + CH_4

(C) iodobenzene (I) + CH_3OH

(D) phenol (OH) + CH_3I

(E) benzene + CH_3I
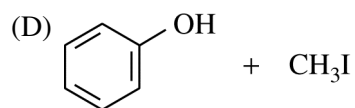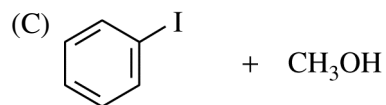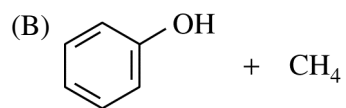
33. Of the following compounds, which has the fastest S_N1 reaction rate with H_2O in acetone?

(A)
$$H_3C-\underset{\underset{C_6H_4-OCH_3}{|}}{\overset{\overset{CH_3}{|}}{C}}-Cl$$
(with para-OCH_3 substituted benzene ring)

(B)
$$H_3C-\underset{\underset{C_6H_4-CH_3}{|}}{\overset{\overset{CH_3}{|}}{C}}-Cl$$
(with para-CH_3 substituted benzene ring)

(C)
$$H_3C-\underset{\underset{C_6H_4-NO_2}{|}}{\overset{\overset{CH_3}{|}}{C}}-Cl$$
(with para-NO_2 substituted benzene ring)

(D)
$$H_3C-\underset{\underset{C_6H_4-CN}{|}}{\overset{\overset{CH_3}{|}}{C}}-Cl$$
(with para-CN substituted benzene ring)

(E)
$$H_3C-\underset{\underset{C_6H_5}{|}}{\overset{\overset{CH_3}{|}}{C}}-Cl$$
(with unsubstituted benzene ring)

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18
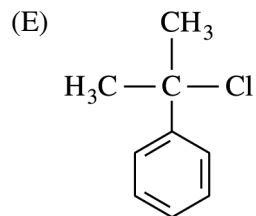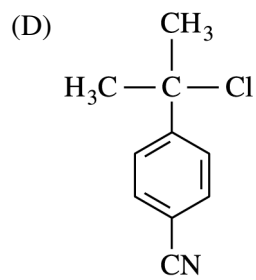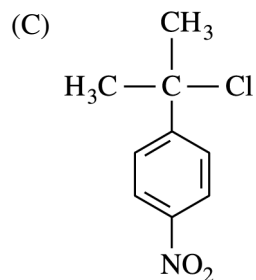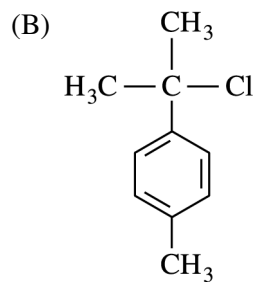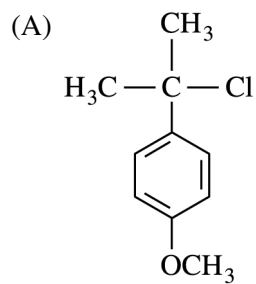
34. Of the following, which compound is in equilibrium with the greatest percentage of its enol isomer?

(A)

(B)

(C)

(D)

(E)

1   2   3   4
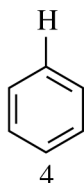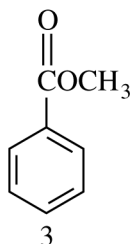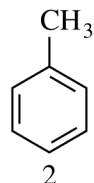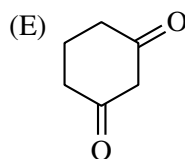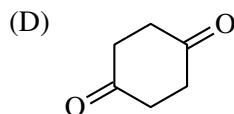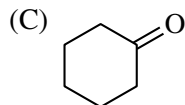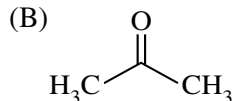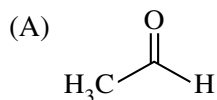
35. In which of the following are the molecules shown above listed in order of increasing reactivity toward electrophilic aromatic substitution?

(A) $2 < 4 < 1 < 3$
(B) $3 < 2 < 4 < 1$
(C) $3 < 4 < 2 < 1$
(D) $4 < 2 < 1 < 3$
(E) $4 < 3 < 1 < 2$

36. Considering 0.1 M aqueous solutions of each of the following, which solution has the lowest pH ?

(A) Na_2CO_3
(B) Na_3PO_4
(C) Na_2S
(D) $NaCl$
(E) CH_3COONa

37. Of the following compounds, which has the lowest melting point?

(A) HCl
(B) $AgCl$
(C) $CaCl_2$
(D) CCl_4
(E) $SnCl_4$

38. Of the following solutions, which will have the highest ionic strength? (Assume complete dissociation.)

(A) 0.050 M $AlCl_3$
(B) 0.100 M $NaCl$
(C) 0.050 M $CaCl_2$
(D) 0.100 M HCl
(E) 0.050 M $Ca(NO_3)_2$

$$2\ SO_3(g) \rightleftharpoons 2\ SO_2(g) + O_2(g)$$
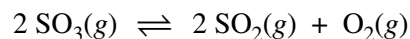
39. The K_P for the reaction shown above is 0.26 at 1,000°C and 40.8 at 1,300°C. Which of the following combinations of ΔH and ΔS are most plausible for this reaction at these temperatures?

ΔH	ΔS
(A) = 0	= 0
(B) > 0	> 0
(C) > 0	< 0
(D) < 0	> 0
(E) < 0	< 0

$$H_2(g) + I_2(g) \underset{k_{-1}}{\overset{k_1}{\rightleftharpoons}} 2\,HI(g)$$
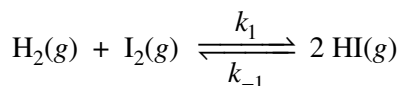
40. At a given temperature, the forward rate constant, k_1, for the one-step reaction shown above is $4 \times 10^{-7}\ M^{-1}\,s^{-1}$. Given that the equilibrium constant is 1×10^{-2}, what is the reverse rate constant, k_{-1}?

(A) $8 \times 10^{-5}\ M^{-1}\,s^{-1}$
(B) $4 \times 10^{-5}\ M^{-1}\,s^{-1}$
(C) $4 \times 10^{-7}\ M^{-1}\,s^{-1}$
(D) $8 \times 10^{-9}\ M^{-1}\,s^{-1}$
(E) $4 \times 10^{-9}\ M^{-1}\,s^{-1}$

$CaCO_3(s)$	$S° = 92.9\ J\,K^{-1}\,mol^{-1}$
$CaO(s)$	$S° = 39.8\ J\,K^{-1}\,mol^{-1}$
$CO_2(g)$	$S° = 213.7\ J\,K^{-1}\,mol^{-1}$
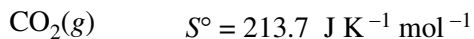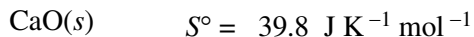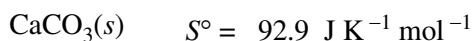
41. Given the standard molar entropies listed above, the standard reaction entropy, $\Delta S°$, in $J\,K^{-1}\,mol^{-1}$, for the decomposition of calcium carbonate into calcium oxide and carbon dioxide is

(A) $(92.9 + 39.8 + 213.7)$
(B) $(-92.9 - 39.8 - 213.7)$
(C) $(-92.9 - 39.8 + 213.7)$
(D) $(39.8 + 213.7)$
(E) $(-92.9 + 39.8 + 213.7)$

$$\overline{v} = R_H\left(\frac{1}{n_1^2} - \frac{1}{n_2^2}\right)$$

42. The Rydberg equation given above accurately predicts the UV-visible emission spectrum of the hydrogen atom. A form of the Rydberg equation may also be used to predict the UV-visible emission for all of the following EXCEPT

(A) hydride ion, H^-
(B) deuterium atom, D
(C) tritium atom, T
(D) helium cation, He^+
(E) beryllium cation, Be^{3+}

$$pK_{a1} = 2.95$$
$$pK_{a2} = 6.79$$

43. Phthalic acid, $(COOH)C_6H_4(COOH)$, is a weak, diprotic acid with dissociation constants above. The pH of an aqueous solution of potassium acid phthalate, $(COOH)C_6H_4(COO^-K^+)$, is closest to

(A) 9.74
(B) 7.00
(C) 6.79
(D) 4.87
(E) 2.95

44. Which of the following is true for Br_2 at standard temperature and pressure?

(A) It is a colorless gas.
(B) It is a red-brown volatile liquid.
(C) It is a colorless volatile liquid.
(D) It is a yellow metallic solid.
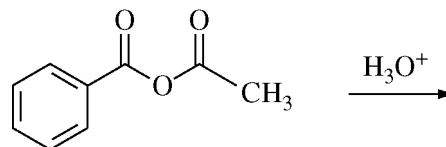(E) It is a yellow insulating solid.

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45. On the basis of oxidation-reduction potential, which of the following is most likely to occur?
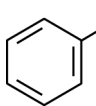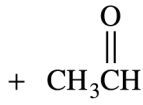
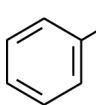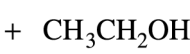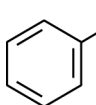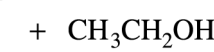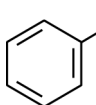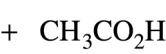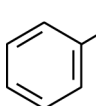(A) $Al(s) + 3\ NaNO_3(aq) \rightarrow 3\ Na(s) + Al(NO_3)_3(aq)$

(B) $Zn(s) + 2\ Ag(NO_3)(aq) \rightarrow 2\ Ag(s) + Zn(NO_3)_2(aq)$

(C) $Pb(s) + Ca(NO_3)_2(aq) \rightarrow Ca(s) + Pb(NO_3)_2(aq)$

(D) $Pb(s) + 2\ LiNO_3(aq) \rightarrow 2\ Li(s) + Pb(NO_3)_2(aq)$

(E) $Ca(s) + 2\ NaNO_3(aq) \rightarrow 2\ Na(s) + Ca(NO_3)_2(aq)$

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46. Cobalt-60 is used in the radiation therapy of cancer and can be produced by bombardment of cobalt-59 with which of the following?
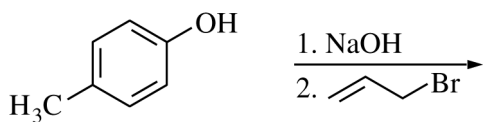
(A) Neutrons
(B) Alpha particles
(C) Beta particles
(D) X-rays
(E) Gamma rays

47. Which of the following are the products of the reaction shown above?

(A)
CHO
$+\ CH_3CH$ (with $=O$)

(B)
CO_2H
$+\ CH_3CH_2OH$

(C)
CH_2OH
$+\ CH_3CH_2OH$

(D)
CHO
$+\ CH_3CO_2H$

(E)
CO_2H
$+\ CH_3CO_2H$

$\xrightarrow[\text{2.}]{\text{1. NaOH}}$

48. What is the product of the reaction shown above for *para*-cresol?

(A)

(B)

(C)

(D)

(E)

49. At 25°C, the maximum amount of PbI_2 that can be dissolved in 1.00 L of pure water is 1.0 mmol. Assuming complete dissociation, the solubility product, K_{sp}, for lead iodide at 25°C is

(A) 1.0×10^{-3}
(B) 1.0×10^{-6}
(C) 1.0×10^{-9}
(D) 2.0×10^{-9}
(E) 4.0×10^{-9}

50. Which of the following must be true if the wavefunction $\psi(x)$ is normalized?

(A) $\psi^*(x)\,\psi(x) = 0$

(B) $\psi^*(x)\,\psi(x) = 1$

(C) $\displaystyle\int_{-\infty}^{+\infty} \psi^*(x)\,\psi(x)\,dx = 0$

(D) $\displaystyle\int_{-\infty}^{+\infty} \psi^*(x)\,\psi(x)\,dx = 1$

(E) $\dfrac{d^2\psi(x)}{dx^2} = 1$

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51. If $\psi(r)$ is the wavefunction for a $1s$ electron, the average distance from the nucleus for the electron is equal to

(A) $\psi^*(r)\,\psi(r)$

(B) $\int_0^r \psi^*(r)\psi(r)\,dr$

(C) $\int_0^\infty \psi^*(r)\psi(r)\,dr$

(D) $\psi^*(r)\,\hat{r}\,\psi(r)$

(E) $4\pi \int_0^\infty \psi^*(r)\,\hat{r}\,\psi(r)\ r^2 dr$

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52. Which of the following experimental observations were explained by Planck's quantum theory?

(A) Blackbody radiation curves
(B) Emission spectra of diatomic molecules
(C) Electron diffraction patterns
(D) Temperature dependence of reaction rates
(E) Pressure dependence of boiling points

53. The $+1$ oxidation state is more stable than the $+3$ oxidation state for which group 13 element?

(A) B
(B) Al
(C) In
(D) Ga
(E) Tl

54. The anhydride of $Ba(OH)_2$ is

(A) BaH_2
(B) $BaOH$
(C) Ba
(D) BaO_2
(E) BaO

$$HgO + 4I^- + H_2O \rightarrow HgI_4^{2-} + 2OH^-$$
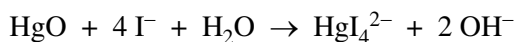
55. A 0.217 g sample of HgO (molar mass $= 217$ g) reacts with excess iodide ions according to the reaction shown above. Titration of the resulting solution requires how many mL of 0.10 M HCl to reach equivalence point?

(A) 1.0 mL
(B) 10 mL
(C) 20 mL
(D) 50 mL
(E) 100 mL

56. The Hamiltonian operator for a particle in a one-dimensional box, whose potential is zero inside the box and infinite outside the box, is

(A) $\hat{H} = \dfrac{-\hbar^2}{2m}\dfrac{d^2}{dx^2}$

(B) $\hat{H} = \dfrac{-\hbar^2}{2mR^2}\dfrac{d^2}{d\phi^2} + \dfrac{a\phi}{\pi}$

(C) $\hat{H} = \dfrac{-\hbar^2}{2m}\dfrac{d^2}{dx^2} + \dfrac{1}{2}kx^2$

(D) $\hat{H} = \dfrac{-\hbar^2}{2m}\left(\dfrac{\partial^2}{\partial x^2} + \dfrac{\partial^2}{\partial y^2} + \dfrac{\partial^2}{\partial z^2}\right) - \dfrac{Ze^2}{r}$

(E) $\hat{H} = \dfrac{-\hbar^2}{2mR^2}\left(\dfrac{\partial^2}{\partial x^2} + \dfrac{\partial^2}{\partial y^2} + \dfrac{\partial^2}{\partial z^2}\right)$

57. The normal modes of a carbon dioxide molecule that are infrared-active include which of the following?

   I. Bending
  II. Symmetric stretching
 III. Asymmetric stretching

(A) I only
(B) II only
(C) III only
(D) I and III only
(E) I, II, and III

58. Which of the following types of spectroscopy is a light-scattering technique?

(A) Nuclear magnetic resonance
(B) Infrared
(C) Raman
(D) Ultraviolet-visible
(E) Electron paramagnetic resonance

59. When a certain metal is irradiated with radiation of frequency $5.5 \times 10^{14}\,s^{-1}$, electrons are ejected. If the work function of the metal is $2.9 \times 10^{-19}\,J$, which of the following expresses the kinetic energy (in joules) of the ejected electrons?

(A) $h(5.5 \times 10^{14}\,s^{-1}) - (2.9 \times 10^{-19}\,J)$

(B) $(2.9 \times 10^{-19}\,J) - h(5.5 \times 10^{14}\,s^{-1})$

(C) $h(5.5 \times 10^{14}\,s^{-1}) + (2.9 \times 10^{-19}\,J)$

(D) $\dfrac{h(5.5 \times 10^{14}\,s^{-1})}{(2.9 \times 10^{-19}\,J)}$

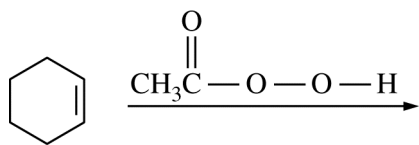(E) $\dfrac{(2.9 \times 10^{-19}\,J)}{h(5.5 \times 10^{14}\,s^{-1})}$
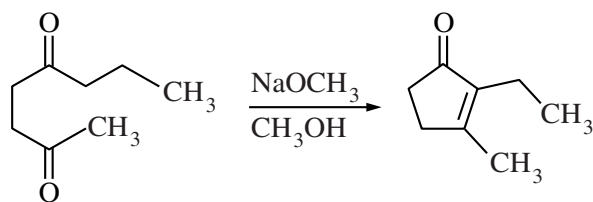
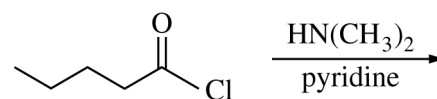60. The product of the reaction shown above is produced via which of the following intermediates?

(A)

(B)

(C)

(D)

(E)

61. Which of the following is the major product of the reaction shown above?

(A)

(B) OH

(C)

(D) OH

(E) CH$_3$, OH

62. What is the product of the reaction shown above?

(A) N(CH$_3$)$_2$

(B) N(CH$_3$)$_2$

(C) Cl, N(CH$_3$)$_2$

(D) OH N(CH$_3$)$_2$

(E) N(CH$_3$)$_2$

GO ON TO THE NEXT PAGE.

63. Which of the following procedures tend(s) to minimize the influence of random errors on measured results?

   I. Signal averaging
  II. Use of internal standards
 III. Averaging the results from multiple samples

(A) I only
(B) II only
(C) III only
(D) I and III only
(E) I, II, and III

64. A buffer is made from equal concentrations of a weak acid and its conjugate base. Doubling the volume of the buffer solution by adding water has what effect on its pH ?

(A) It has little effect.
(B) It significantly increases the pH.
(C) It significantly decreases the pH.
(D) It changes the pH asymptotically to the pK_a of the acid.
(E) It changes the pH asymptotically to the pK_b of the conjugate base.

65. Which of the following is the most common naturally-occurring form in which silicon is found?

(A) Metallic element
(B) Sulfide
(C) Fluoride
(D) Oxide
(E) Nitride

66. A substance that is NOT generally considered to be a toxic pollutant in water is

(A) carbonic acid
(B) a halogenated hydrocarbon
(C) lead
(D) mercury
(E) cadmium

67. Which of the following is an n-type semiconductor?

(A) Silicon
(B) Diamond
(C) Silicon carbide
(D) Arsenic-doped silicon
(E) Gallium-doped silicon

68. Which of the following is lower for argon than for neon?

(A) Melting point
(B) Boiling point
(C) Polarizability
(D) Heat of vaporization
(E) First ionization energy

69. For EDTA titrations, the analyte solution and the titrant solution are both buffered at the same pH for which of the following reasons?

   I. The conditional formation constant is affected by pH.
  II. The fraction of EDTA in the fully deprotonated Y^{4-} form varies with pH.
 III. When EDTA reacts to form a metal complex, H^+ is a product in most cases.

(A) I only
(B) I and II only
(C) I and III only
(D) II and III only
(E) I, II, and III

70. The Henry's law constant for CO_2 dissolved in water at 25°C is 30.0 atm M^{-1}. The concentration of dissolved CO_2 in a vessel pressurized with 2.0 atm of CO_2 is

(A) 1.5 M
(B) 0.15 M
(C) 0.067 M
(D) 0.015 M
(E) 0.0067 M

$$A + M \xrightarrow{k_1} A^* + M$$

$$A^* + M \xrightarrow{k_2} A + M$$

$$A^* \xrightarrow{k_3} \text{products}$$

71. The gas-phase reaction $A \rightarrow$ products is postulated to proceed by the mechanism shown above, in which A^* is an activated A molecule and M is a chemically inert gas. Assuming the steady-state approximation for A^*, this mechanism yields the rate equation

$$\text{rate} = \frac{k_1 k_3 [M][A]}{k_3 + k_2 [M]}.$$

Which of the following is NOT consistent with this mechanism?

(A) When the partial pressure of M is very high, the reaction is first order in A.
(B) When the partial pressure of M is very high, the reaction is first order overall.
(C) When the partial pressure of M is very low, the reaction is second order overall.
(D) When the partial pressure of M is very low, the rate is independent of the concentration of A.
(E) M can be any molecule capable of transferring energy to A upon collision.

Process	Work
System A	Adiabatic	-300 J
System B	Nonadiabatic	-200 J

72. System A and system B above are identical closed systems that undergo a change of state from the same initial conditions (P_1, V_1, T_1) to the same final conditions (P_2, V_2, T_2), but by a different process. What are ΔU and q for the change in state for system B?

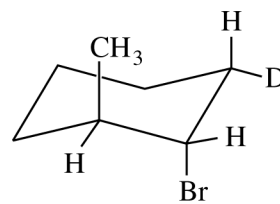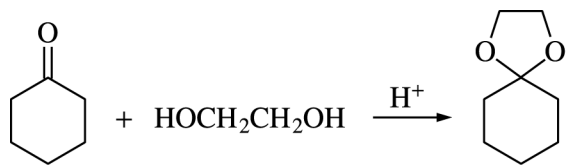|	ΔU(J)	q(J)
(A)	-300	0
(B)	-300	-100
(C)	-100	-100
(D)	0	-300
(E)	200	0

GO ON TO THE NEXT PAGE.

73. Chlorofluorocarbons (CFCs) such as F_3CCCl_3 are implicated in the decomposition of stratospheric ozone. Which of the following methods would be best suited to measurement of trace amounts (sub-ppb) of CFCs in an air sample?

(A) Gas chromatographic separation of the air sample on a capillary column followed by electron capture detection

(B) Gas chromatographic separation of the air sample on a packed column followed by thermal conductivity detection

(C) Gas chromatographic separation of the air sample on a capillary column followed by flame ionization detection

(D) Conversion of the sample of the chlorinated compounds to chloride ions, followed by titration with Ag^+

(E) Conversion of the sample of the chlorinated compounds to chloride ions, followed by direct measurement of chloride with chloride selective electrode

$$CH_3CN \xrightarrow[\text{heat}]{H_2O, \ H^+} CH_3CO_2H$$
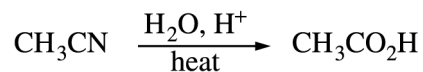
74. Which of the following best depicts the initial nucleophilic addition step in the acid-catalyzed hydrolysis of acetonitrile shown above?

(A) CH$_3$—C≡N:
    H—Ö:
        \
         H

(B) CH$_3$—C≡N$^+$—H
    H—Ö:
        \
         H

(C) CH$_3$—C≡N$^+$—H
    H—Ö:
        \
         H

(D) CH$_3$—C≡N$^+$—H
    H—Ö:$^-$

(E) CH$_3$—C≡N:
    H—Ö:
        \
         H
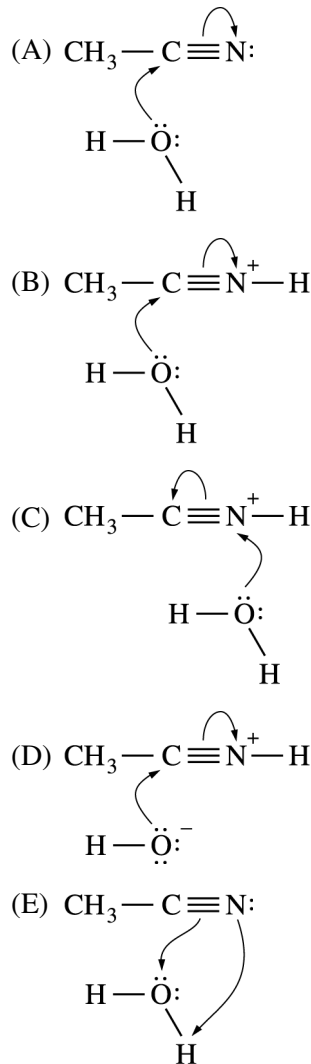
75. Which of the following is the hemiacetal intermediate in the reaction shown above?

(A) HO   OH

(B)   OH

(C) HO   OCH$_2$CH$_2$OH

(D) HO   CH$_2$CH$_2$OH

(E)   OCH$_2$CH$_2$OH

76. What is the major product of an E2 reaction of the compound shown above?

(A)

(B)

(C)

(D)

(E)

77. Of the following fatty acids, which has the lowest melting point?

(A) COOH

(B) COOH

(C) COOH

(D) COOH

(E) COOH

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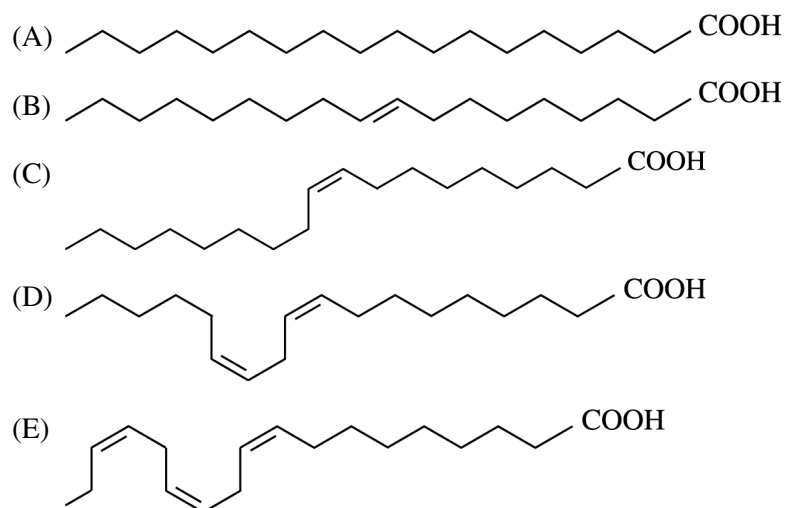
78. Of the following compounds, which is LEAST likely to behave as a Lewis acid?

(A) $BeCl_2$

(B) $MgCl_2$

(C) $ZnCl_2$

(D) SCl_2

(E) $SnCl_2$

79. The strongest base in liquid ammonia is

(A) NH_3

(B) NH_2^-

(C) NH_4^+

(D) N_2H_4

(E) OH^-

80. Which of the following lists the hydrides of group-14 elements in order of thermal stability, from lowest to highest?

(A) $PbH_4 < SnH_4 < GeH_4 < SiH_4 < CH_4$
(B) $PbH_4 < SnH_4 < CH_4 < GeH_4 < SiH_4$
(C) $CH_4 < SiH_4 < GeH_4 < SnH_4 < PbH_4$
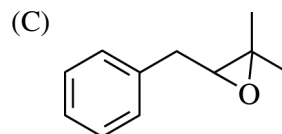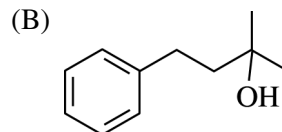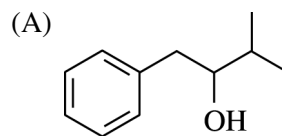(D) $CH_4 < PbH_4 < GeH_4 < SnH_4 < SiH_4$
(E) $GeH_4 < PbH_4 < SiH_4 < SnH_4 < CH_4$
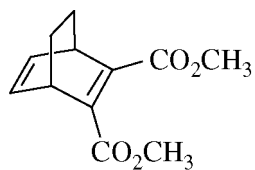
81. Which of the following starting materials could be used in a Diels-Alder reaction to prepare the bicyclic product shown above?

(A) and

(B) and

(C) and
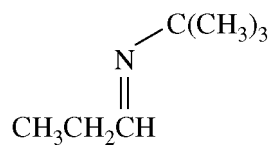
(D) and

(E) and and
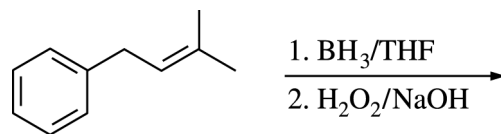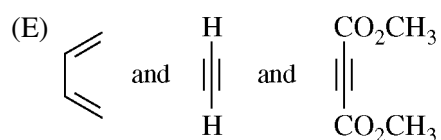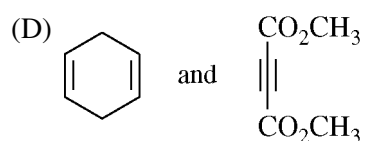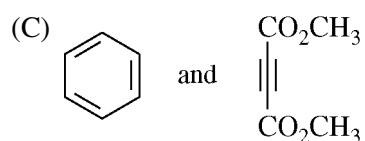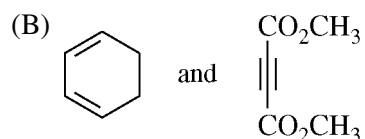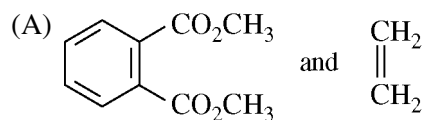
82. Which of the following is the major organic product of the reaction shown above?

(A)

(B)

(C)

(D)

(E)

$$\underset{CH_3CH_2CH}{\overset{\overset{\displaystyle N}{\parallel}}{}} \!\!\!\!\!\! \overset{\displaystyle \diagup C(CH_3)_3}{}$$
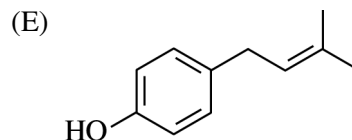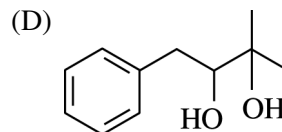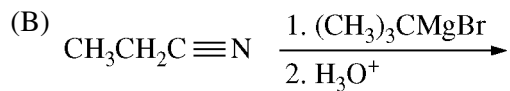
83. Which of the following procedures gives the compound shown above?

(A)

$$\underset{CH_3CH_2CH}{\overset{\overset{\displaystyle O}{\parallel}}{}} \; + \; (CH_3)_3CNH_2 \; \xrightarrow{\; H^+ \;}$$

(B)

$$CH_3CH_2C\equiv N \; \xrightarrow[\; 2.\ H_3O^+ \;]{\; 1.\ (CH_3)_3CMgBr \;}$$

(C)

$$CH_3CH_2CH_2Br \; \xrightarrow[\; 2.\ NaOH \;]{\; 1.\ (CH_3)_3CNH_2 \;}$$

(D)

$$CH_3CH_2MgBr \; \xrightarrow[\; 2.\ H_3O^+ \;]{\; 1.\ (CH_3)_3CCN \;}$$

(E)

$$\underset{CH_3CH_2COH}{\overset{\overset{\displaystyle O}{\parallel}}{}} \; + \; (CH_3)_3CNH_2 \; \longrightarrow$$

Applied Potential, *V*
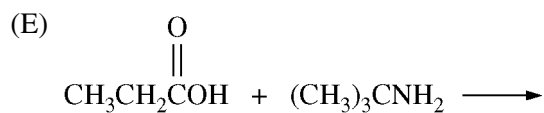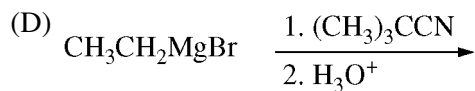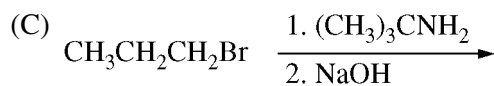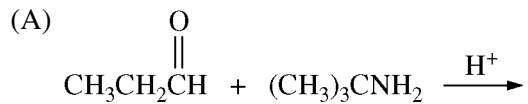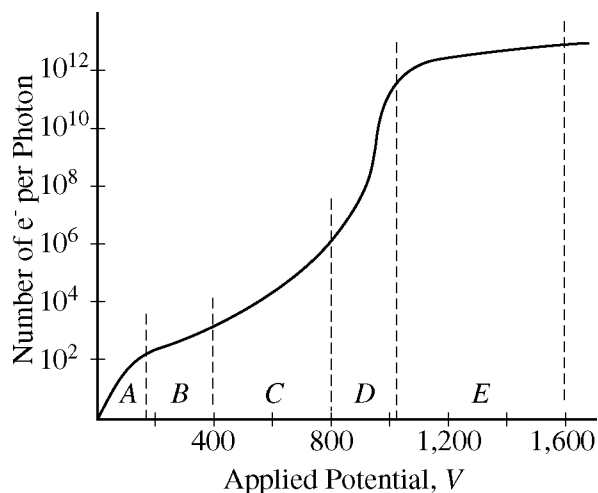
84. Ionizing radiation can be detected using gas-filled tubes in which released electrons migrate to a collector electrode, producing a pulse. On the figure shown above, which region would give the largest detector response per incident photon?

(A) *A*
(B) *B*
(C) *C*
(D) *D*
(E) *E*

85. Which of the following is required for both paramagnetism and ferromagnetism?

(A) Strong oxidizing conditions
(B) Low-spin electron configuration
(C) Metallic physical properties
(D) Superexchange
(E) Unpaired electrons

86. Redox enzyme catalysis involves the cyclic oxidation and reduction of metal ions that have at least two stable positive oxidation states. Which of the following groups of metals could be found at the active site of redox enzymes?

(A) Cu, Fe, Co
(B) Zn, Ca, Ga
(C) Sr, Ga, Mg
(D) Na, Ba, Al
(E) Mg, Li, K

87. The solid-state structures of the principal allotropes of elemental boron are made up of which of the following structural units?

(A) B_{12} icosahedra
(B) B_8 cubes
(C) B_6 octahedra
(D) B_4 tetrahedra
(E) Chains of B atoms

88. All proteins absorb electromagnetic radiation of wavelength around 190 nm, which corresponds to a $\pi \rightarrow \pi^*$ excitation in the protein molecule. In which region of the spectrum is this wavelength found?

(A) X-ray
(B) Ultraviolet
(C) Visible
(D) Infrared
(E) Microwave

$$E + S \underset{k_{-1}}{\overset{k_1}{\rightleftharpoons}} ES \xrightarrow{k_2} P + E$$
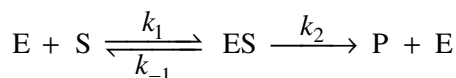
89. The mechanism shown above has been proposed for the enzyme-catalyzed hydrolysis of certain biochemical compounds (substrates), where ES is an enzyme-substrate complex. Given a fixed amount of enzyme, E, which of the following could be the plot of the initial rate of the production of product, P, when using varying initial concentrations of substrate, $[S]_0$?

(A)

(B)

(C)

(D)

(E)

$$k = Ae^{-E_a/RT}$$
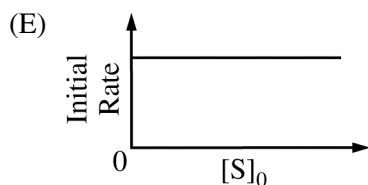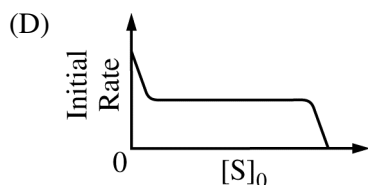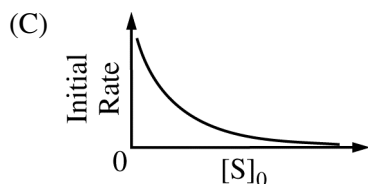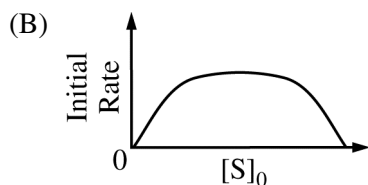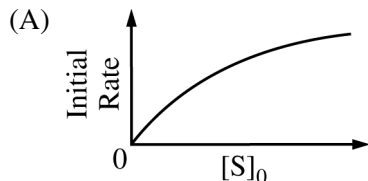
90. The rate constant of a bimolecular gas phase reaction is found to follow the Arrhenius equation shown above. Which of the following will result in a smaller rate constant?

(A) Reducing activation energy
(B) Reducing temperature
(C) Reducing pressure
(D) Reducing concentrations of reactants
(E) Increasing molecular speeds

$$X_2(g) \xrightarrow{k} 2\,X(g)$$
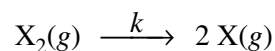
91. If the dissociation of X_2 proceeds by the elementary process shown above, the rate of change in $[X]$ with respect to time is given by
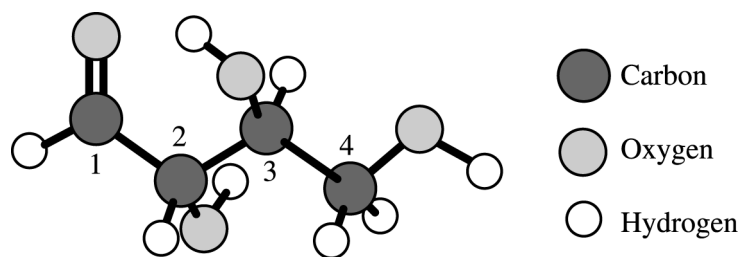
(A) $\dfrac{d[X]}{dt} = \dfrac{k[X]}{[X_2]}$

(B) $\dfrac{d[X]}{dt} = 2k[X_2]$

(C) $\dfrac{d[X]}{dt} = k$

(D) $\dfrac{d[X]}{dt} = k[X_2]^{1/2}$

(E) $\dfrac{d[X]}{dt} = k[X_2]^2$
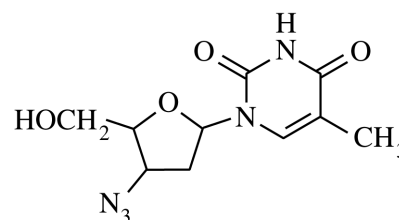
92. The compound shown above is AZT, a drug used in the treatment of acquired immune deficiency syndrome (AIDS). What is the total number of stereoisomers for this compound?
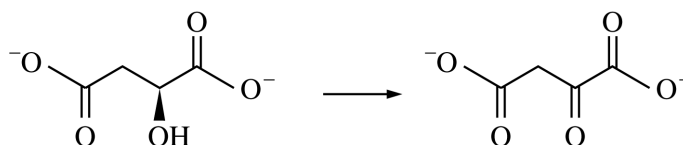
(A) 2
(B) 4
(C) 6
(D) 8
(E) 10

GO ON TO THE NEXT PAGE.

	Carbon
	Oxygen
	Hydrogen

93. What is the stereochemistry of the carbohydrate structure shown above?

  (A) 2R, 3R
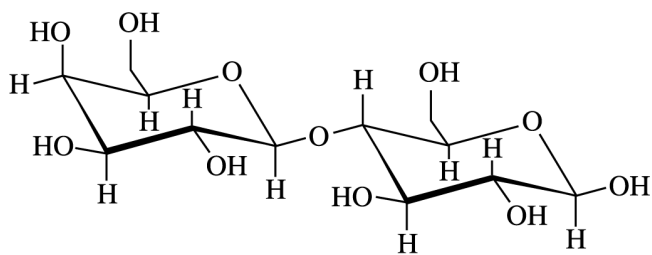 (B) 2R, 3S
  (C) 2S, 3R
  (D) 2S, 3S
  (E) Meso

94. The enzyme-catalyzed transformation above, which occurs in the citric acid cycle (tricarboxylic acid or Krebs cycle), is best described as belonging to which of the following categories of reactions?

  (A) Oxidation
  (B) Reduction
  (C) Nucleophilic alkyl substitution
  (D) Aldol condensation
  (E) Hydrolysis

GO ON TO THE NEXT PAGE.

95. Which of the following is NOT true about the disaccharide lactose shown above?

(A) Lactose is a reducing sugar.
(B) Lactose undergoes mutarotation.
(C) Lactose is optically active.
(D) Lactose can be hydrolyzed to monosaccharides with H_2O/H_2SO_4.
(E) Lactose has a $1,1'-\alpha$- glycosidic linkage.
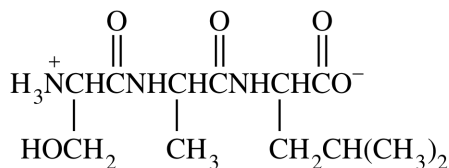
96. The compound shown above is a

(A) triglyceride
(B) trinucleotide
(C) tripeptide
(D) trisaccharide
(E) triterpene

AAK	ALLLG	AGGLLGGL
I	II	III

97. A peptide digest yields the three polypeptides listed above. The three peptides are separated using capillary electrophoresis at a pH (above 3) at which each peptide has the same total positive charge. Which of the following indicates the order, from first to last, that the peptides will reach the detector? (A = alanine; L = leucine; G = glycine; K = lysine).

(A) I, II, III
(B) I, III, II
(C) II, I, III
(D) II, III, I
(E) III, II, I

98. In fluorescence spectroscopy, the quantum yield (Φ_f) is best defined as the

(A) rate of fluorescence emission
(B) number of photons emitted
(C) number of photons emitted, divided by the number of photons absorbed
(D) number of excitation photons impinging on the sample, divided by the number of photons absorbed
(E) fraction of excited molecules produced by direct excitation

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99. When ferric oxide, Fe_2O_3, is dissolved in 6 M HNO_3, which iron-containing species predominates in solution?

(A) FeO_2^-

(B) $Fe(OH)_4^-$

(C) $Fe(OH)_3$

(D) $Fe(H_2O)_6^{2+}$

(E) $Fe(H_2O)_6^{3+}$

100. Of the following ionic substances, which has the greatest lattice enthalpy?

(A) MgO
(B) MgS
(C) NaF
(D) NaCl
(E) NaBr

---

101. Which of the following reactions is best classified as an oxidative addition?

(A) $[Cr(CO)_6] + Br^- \rightarrow [Cr(CO)_5Br]^- + CO$

(B) $[PtH(CH_3)\{P(C_6H_5)_3\}_2] + P(C_6H_5)_3 \rightarrow [Pt\{P(C_6H_5)_3\}_3] + CH_4$

(C) $[Pt(NH_3)Cl_3]^- + NH_3 \rightarrow [Pt(NH_3)_2Cl_2] + Cl^-$

(D) $[Pt\{P(C_2H_5)_3\}_2HCl] + HCl \rightarrow [Pt\{P(C_2H_5)_3\}_2(H)_2Cl_2]$

(E) $[MnH(CO)_5] + CF_2=CF_2 \rightarrow [Mn(CF_2CF_2H)(CO)_5]$

102. Of the following colligative properties, which is most practical for determining the extent of protein aggregation?

(A) Osmotic pressure
(B) Freezing point depression
(C) Boiling point elevation
(D) Solvent vapor pressure lowering
(E) Solute vapor pressure

$$\psi_1 = 2s + 2p_x + 2p_y + 2p_z$$
$$\psi_2 = 2s + 2p_x - 2p_y - 2p_z$$
$$\psi_3 = 2s - 2p_x + 2p_y - 2p_z$$
$$\psi_4 = 2s - 2p_x - 2p_y - 2p_z$$

103. A set of hybrid sp^3 orbitals for a carbon atom is given above. Which of the following is NOT true about the orbitals?

(A) The orbitals are degenerate.
(B) The set of orbitals has a tetrahedral geometry.
(C) These orbitals are constructed from a linear combination of atomic orbitals.
(D) The four electrons in these orbitals can form σ bonds with other atoms.
(E) Each hybrid orbital may hold four electrons.

$$\begin{vmatrix} \alpha\text{-}E & \beta & 0 & 0 \\ \beta & \alpha\text{-}E & \beta & 0 \\ 0 & \beta & \alpha\text{-}E & \beta \\ 0 & 0 & \beta & \alpha\text{-}E \end{vmatrix} = 0$$

104. According to Hückel molecular orbital theory, the secular equation above can be used to find possible energy levels of the π-electrons in

(A) $HC{\equiv}C{-}CH_2CH_3$

(B) $CH_3CH_2CH_2CH_3$

(C)

(D) $H_2C{=}CH{-}CH{=}CH_2$

(E)
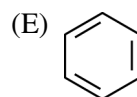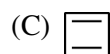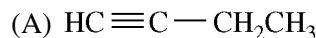
105. Which of the following is(are) characteristic of mass spectrometry?

I. Analyte molecules are converted to gaseous ions.
II. The ions are separated according to their mass-to-charge ratio.
III. In addition to compound identification, mass spectra can be utilized to determine precise isotopic masses and isotopic ratios.

(A) II only
(B) I and II only
(C) I and III only
(D) II and III only
(E) I, II, and III

OH
(structure: cyclobutane with CH2OH substituent)

HBr →
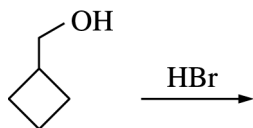
106. Which of the following is the major
rearrangement product of the reaction shown
above?

(A) HO ⟍ Br
(structure: cyclobutane with HO and Br on same carbon)

(B) Br
(structure: cyclobutane with CH2Br substituent)
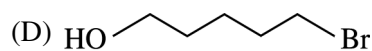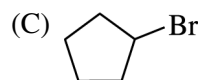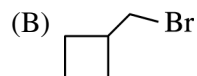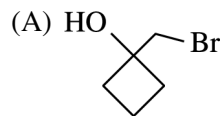
(C) Br
(structure: cyclopentane with Br)

(D) HO ⌒⌒⌒⌒ Br

(E) ⌒⌒⌒ Br
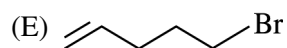
107. Which of the following substituents is NOT an
ortho, para director in an electrophilic aromatic
substitution reaction?

(A) — Cl

(B)
$$\overset{O}{\overset{\|}{-NHCCH_3}}$$

(C)
$$\overset{O}{\overset{\|}{-CNH_2}}$$

(D) — OH

(E) — CH$_3$

$$Cl-\overset{O}{\overset{\|}{C}}-\text{(benzene ring)}-\overset{O}{\overset{\|}{C}}-Cl \ + \ HOCH_2CH_2OH \longrightarrow$$
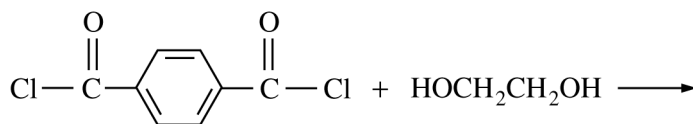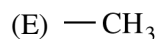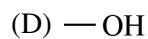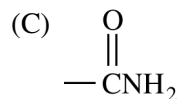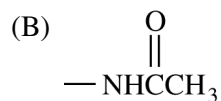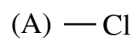
108. The reaction of terephthaloyl chloride with ethylene glycol,
shown above, forms a

(A) polyamide
(B) polyester
(C) polyether
(D) polycarbonate
(E) polyurethane
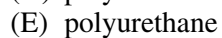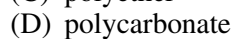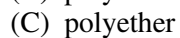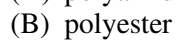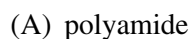
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109. The proton NMR spectrum of an aromatic compound, $C_8H_8Br_2$, includes two methyl singlets. Its proton-decoupled ^{13}C NMR spectrum displays a total of six peaks. Of the following, which structure best fits these data?

(A)
    CH₃
    Br
    Br
    CH₃

(B)
    CH₃
    Br   Br
    CH₃

(C)
    Br
    CH₃
    CH₃
    Br

(D) Br — CH₃
    Br — CH₃

(E)
    CH₃
    Br
    CH₃
    Br
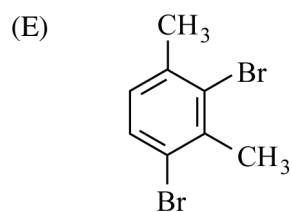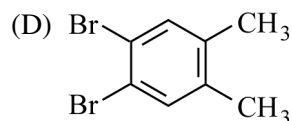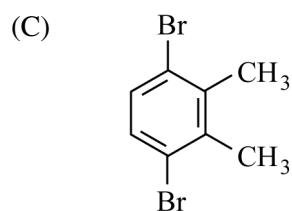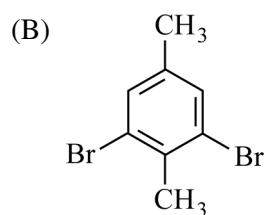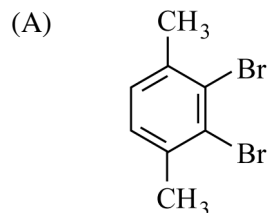
110. The fact that the infrared absorption frequency of deuterium chloride (DCl) is shifted from that of hydrogen chloride (HCl) is due to the differences in their

(A) electron distribution
(B) dipole moment
(C) force constant
(D) polarizability
(E) reduced mass

111. In the vibrational-rotational spectrum of a diatomic molecule, the R-branch of the spectrum is the result of which of the following transitions?

(A) $\Delta J = 0;\ \Delta v = 0$
(B) $\Delta J = 1;\ \Delta v = 0$
(C) $\Delta J = 2;\ \Delta v = 0$
(D) $\Delta J = 1;\ \Delta v = 1$
(E) $\Delta J = 2;\ \Delta v = 1$

112. When an activated complex is formed from two reactant molecules in the gas phase, it is usually assumed that the entropy has been lowered; that is, $\Delta S^{\ddagger}$ is less than zero. This assumption is based on which of the following?

(A) $\Delta U^{\ddagger}$ is positive.

(B) $\Delta H^{\ddagger}$ is positive.

(C) The preexponential factor A in the Arrhenius equation is always positive.

(D) The activated complex is ill defined and transitory.

(E) Forming the activated complex involves conversion of translational and rotational degrees of freedom into vibrational degrees of freedom.

113. A student performs five titrations and obtains a mean result of 0.110 M, with a standard deviation of 0.001 M. If the actual concentration of the titrated solution is 0.100 M, which of the following is true about the titration results?

(A) Accurate but not precise
(B) Precise but not accurate
(C) Both accurate and precise
(D) Neither accurate nor precise
(E) There are insufficient data to determine the accuracy and precision of the results.

114. Which of the following statements about the lanthanide elements is NOT true?

(A) The most common oxidation state for the lanthanide elements is $+3$.
(B) Lanthanide complexes often have high coordination numbers (> 6) .
(C) All of the lanthanide elements react with aqueous acid to liberate hydrogen.
(D) The lanthanides form stable complexes with chelating oxygen ligands.
(E) The atomic radii of the lanthanide elements increase across the period from La to Lu.

$$Ni^{2+}(aq) \ + \ 3 \ en(aq) \ \rightleftharpoons \ Ni(en)_3{}^{2+}(aq) \qquad (en = 1,2\text{-ethylenediamine})$$

$$Ni^{2+}(aq) \ + \ 6 \ NH_3(aq) \ \rightleftharpoons \ Ni(NH_3)_6{}^{2+}(aq)$$
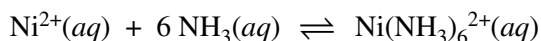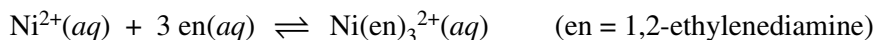
115. The equilibrium constant for the formation of $Ni(en)_3{}^{2+}$, shown above, is 10^{10}-fold greater than the equilibrium constant for the formation of $Ni(NH_3)_6{}^{2+}$. The primary explanation for this large difference is termed the

(A) Jahn-Teller effect
(B) Tyndall effect
(C) ammonia effect
(D) crystal field effect
(E) chelate effect

116. Which of the following is a true statement about optical isomerism of complexes containing achiral ligands?

(A) Square planar complexes can display optical isomerism only if all four ligands are identical.
(B) Tetrahedral complexes never display optical isomerism.
(C) Linear complexes can display optical isomerism when both ligands are different.
(D) Octahedral complexes of monodentate ligands can display optical isomerism only when they have at least three different ligands.
(E) Trigonal bipyramidal complexes display optical isomerism when their axial ligands differ from their equatorial ligands.

117. An organic compound has a distribution coefficient, K_p, of 2.00 between an ether and water. If 10.0 g of the compound is dissolved in 100 mL of water that is then extracted twice with 100 mL portions of the ether, what fraction of the compound remains in the water? $\left(K_P = \dfrac{C_{ether}}{C_{water}} \right)$

(A) 0.111
(B) 0.200
(C) 0.250
(D) 0.500
(E) 0.889

118. Exact solutions of the Schrödinger equation CANNOT be obtained for a

(A) simple harmonic oscillator
(B) particle in a one-dimensional box
(C) rigid rotor
(D) hydrogen atom
(E) helium atom

119. When the Heisenberg uncertainty principle is applied to a quantum mechanical particle in the lowest energy level of a one-dimensional box, which of the following is true?

(A) Momentum is known exactly, but no information about position can be known.
(B) Position is known exactly, but no information about momentum can be known.
(C) No information about either position or momentum can be known.
(D) Both position and momentum can be known exactly.
(E) Neither position nor momentum can be known exactly.

Reaction Coordinate
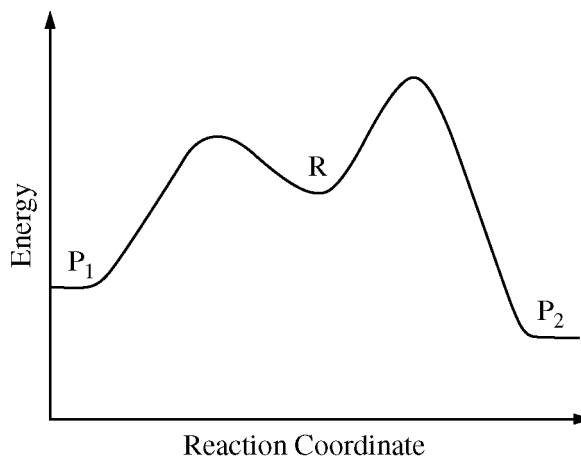
120. A reactant, R, can produce either of two products, P_1 or P_2, with competing pathways, as illustrated in the reaction profile shown above. If the reaction is carried out at low temperature, which of the following best indicates the preferred product and the type of control?

	Preferred Product	Control
(A)	P_1	Kinetic
(B)	P_1	Thermodynamic
(C)	P_2	Kinetic
(D)	P_2	Thermodynamic
(E)	R	Thermodynamic

Substance	Wavelengths Absorbed (nm)
A	400–600, 700–800
B	< 400, 500–700
C	< 400

121. For the titration reaction A + B → C, where A = analyte, B = titrant, and C = product, the end point is to be detected spectrophotometrically at 550 nm, based on the absorbance information shown above. The shape of the titration curve at 550 nm would most closely resemble which of the following?

(A) Absorbance vs mL B

(B) Absorbance vs mL B

(C) Absorbance vs mL B

(D) Absorbance vs mL B

(E) Absorbance vs mL B

OH   Br
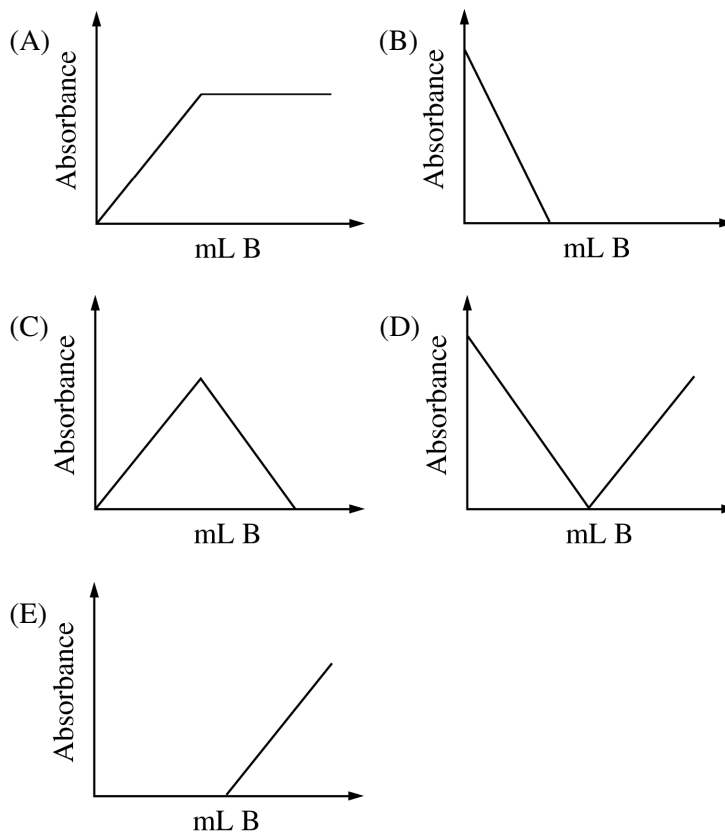
(cyclopentanol → bromocyclopentane)
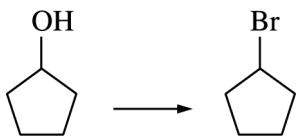
122. Which of the following reagents can be used to convert cyclopentanol to bromocyclopentane, as shown above?

(A) NaBr
(B) PBr_3
(C) Br_2, CCl_4
(D) *N*-bromosuccinimide (NBS), *hv*
(E) Br_2, H_2O

```
        CHO
   H ——— OH        NaBH_4
  HO ——— H      ————————
   H ——— OH         H_2O
        CH_2OH
```
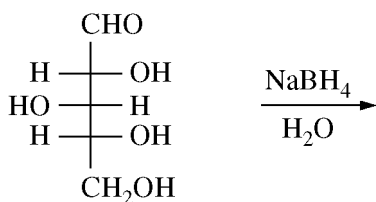
D-xylose

123. Reduction of D-xylose with $NaBH_4$ yields a product that is a

(A) racemic mixture
(B) single pure enantiomer
(C) mixture of two diastereomers in equal amounts
(D) mixture of two diastereomers in unequal amounts
(E) meso compound

124. Which of the following structures represents the amino acid lysine at pH 1 ?

(A) $H_2N(CH_2)_4CHCO_2H$
               |
               $\overset{+}{N}H_3$

(B) $H_3\overset{+}{N}(CH_2)_4CHCO_2H$
               |
               NH_2

(C) $H_2N(CH_2)_4CHCO_2H$
               |
               NH_2

(D) $H_3\overset{+}{N}(CH_2)_4CHCO_2H$
               |
               $\overset{+}{N}H_3$

(E) $H_2N(CH_2)_4CHCO_2^-$
               |
               NH_2
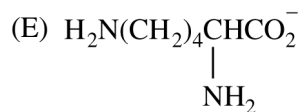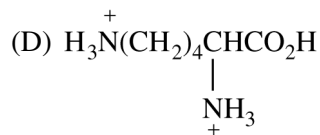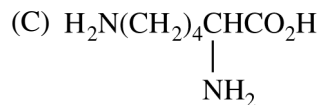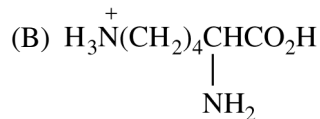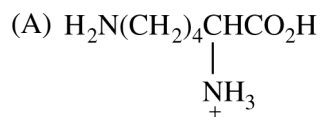
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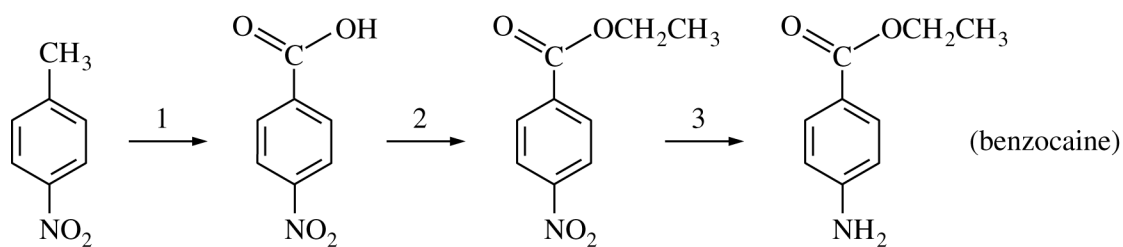
125. The reaction sequence shown above can be used to prepare benzocaine from 4-nitrotoluene. Which of the following reaction sequences would accomplish this synthesis?

(A) 1. $Na_2Cr_2O_7$, H_2SO_4
    2. CH_3CH_2OH, H^+
    3. Sn, HCl followed by NaOH

(B) 1. $NaBH_4$, CH_3OH
    2. CH_3CH_2OH, H^+
    3. Sn, HCl followed by NaOH

(C) 1. H_2O, HCl
    2. CH_3CH_2ONa
    3. Sn, HCl followed by NaOH

(D) 1. $Na_2Cr_2O_7$, H_2SO_4
    2. CH_3CH_2ONa
    3. $NaBH_4$, CH_3OH

(E) 1. $Na_2Cr_2O_7$, H_2SO_4
    2. CH_3CH_2OH, H^+
    3. H_2O, HCl

$$CH_4 + Cl_2 \xrightarrow{\text{light}} CH_3Cl + HCl$$
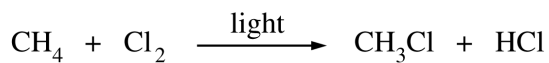
126. Which two of the following are the propagation steps in the free-radical chlorination of methane shown above?

I. $Cl_2 \xrightarrow{\text{light}} 2\ Cl\bullet$

II. $CH_4 + Cl\bullet \longrightarrow CH_3\bullet + HCl$

III. $CH_3\bullet + Cl\bullet \longrightarrow CH_3Cl$

IV. $CH_3\bullet + Cl_2 \longrightarrow CH_3Cl + Cl\bullet$

V. $2\ CH_3\bullet \longrightarrow CH_3CH_3$
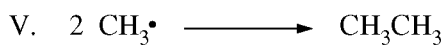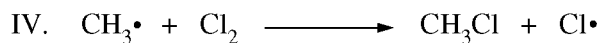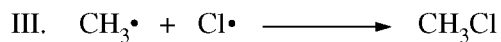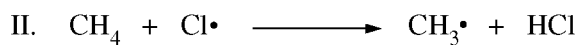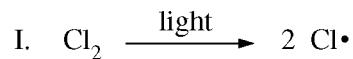
(A) I and II
(B) II and III
(C) II and IV
(D) III and IV
(E) IV and V

127. What is the limiting high-temperature molar heat capacity at constant volume (C_V) of a gas-phase diatomic molecule?

(A) $\frac{3}{2}R$

(B) $2R$

(C) $\frac{5}{2}R$

(D) $3R$

(E) $\frac{7}{2}R$
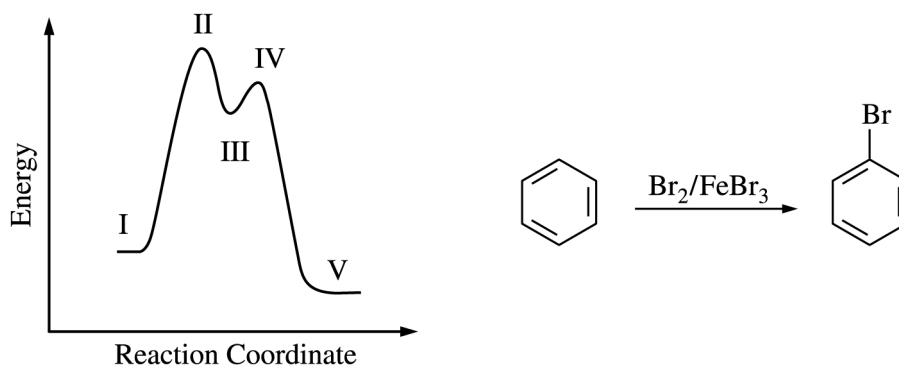
128. The reaction energy diagram for the electrophilic bromination of benzene with Br_2 and $FeBr_3$ is shown above. Which position on the diagram corresponds to the species shown below?
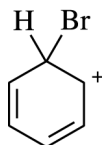
(A) I
(B) II
(C) III
(D) IV
(E) V

GO ON TO THE NEXT PAGE.

129. Of the following atoms, which has the lowest electron affinity?

(A) F
(B) Si
(C) O
(D) Ca
(E) Br

130. Which of the following is a primary standard for use in standardizing bases?

(A) Ammonium hydroxide
(B) Sulfuric acid
(C) Acetic acid
(D) Potassium hydrogen phthalate
(E) Silver nitrate

If you finish before time is called, you may check your work on this test.

I

NOTE: To ensure prompt processing of test results, it is important that you fill in the blanks exactly as directed.

SUBJECT TEST

A. Print and sign your full name in this box:

PRINT: _____
       (LAST)   (FIRST)   (MIDDLE)

SIGN: _____

Copy this code in box 6 on your answer sheet. Then fill in the corresponding ovals exactly as shown.

6. TITLE CODE

2 7 1 2 0

Copy the Test Name and Form Code in box 7 on your answer sheet.

TEST NAME   *Chemistry*

FORM CODE   GR1727

GRADUATE RECORD EXAMINATIONS SUBJECT TEST

B. The Subject Tests are intended to measure your achievement in a specialized field of study. Most of the questions are concerned with subject matter that is probably familiar to you, but some of the questions may refer to areas that you have not studied.

Your score will be determined by the number of questions you answer correctly. Questions you answer incorrectly or for which you mark no answer or more than one answer are counted as incorrect. Nothing is subtracted from a score if you answer a question incorrectly. Therefore, to maximize your score, it is better for you to guess at an answer than not to respond at all.

You are advised to use your time effectively and to work as rapidly as you can without losing accuracy. Do not spend too much time on questions that are too difficult for you. Go on to the other questions and come back to the difficult ones later if you can.

YOU MUST INDICATE ALL YOUR ANSWERS ON THE SEPARATE ANSWER SHEET. No credit will be given for anything written in this examination book, but you may write in the book as much as you wish to work out your answers. After you have decided on your response to a question, fill in the corresponding oval on the answer sheet. BE SURE THAT EACH MARK IS DARK AND COMPLETELY FILLS THE OVAL. Mark only one answer to each question. No credit will be given for multiple answers. Erase all stray marks. If you change an answer, be sure that all previous marks are erased completely. Incomplete erasures may be read as intended answers. Do not be concerned that the answer sheet provides spaces for more answers than there are questions in the test.

Example:

What city is the capital of France?

(A) Rome
(B) Paris
(C) London
(D) Cairo
(E) Oslo

Sample Answer

Ⓐ ● Ⓒ Ⓓ Ⓔ   CORRECT ANSWER PROPERLY MARKED

Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ
Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ
Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ   IMPROPER MARKS
Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ

DO NOT OPEN YOUR TEST BOOK UNTIL YOU ARE TOLD TO DO SO.

Worksheet for the GRE Chemistry Test, Form GR1727
Answer Key and Percentages* of Test Takers Answering Each Question Correctly

QUESTION Number	Answer	P+	CORRECT RESPONSE	QUESTION Number	Answer	P+	CORRECT RESPONSE	QUESTION Number	Answer	P+	CORRECT RESPONSE
1	D	74		46	A	67		91	B	37	
2	E	45		47	E	48		92	D	47	
3	C	71		48	A	72		93	D	52	
4	D	40		49	E	34		94	A	67	
5	A	81		50	D	68		95	E	54	
6	D	46		51	E	37		96	C	79	
7	C	62		52	A	63		97	A	65	
8	B	41		53	E	40		98	C	55	
9	C	47		54	E	54		99	E	39	
10	D	62		55	C	65		100	A	30	
11	B	86		56	A	61		101	D	25	
12	B	92		57	D	56		102	A	49	
13	E	49		58	C	61		103	E	66	
14	D	82		59	A	58		104	D	29	
15	E	30		60	E	65		105	E	70	
16	E	71		61	C	65		106	C	46	
17	A	98		62	E	73		107	C	46	
18	E	87		63	D	41		108	B	76	
19	D	68		64	A	82		109	B	63	
20	C	39		65	D	90		110	E	54	
21	E	52		66	A	84		111	D	36	
22	B	73		67	D	54		112	E	44	
23	A	45		68	E	77		113	B	76	
24	D	19		69	E	19		114	E	61	
25	C	95		70	C	68		115	E	53	
26	B	53		71	D	42		116	D	43	
27	E	26		72	B	69		117	A	43	
28	D	78		73	A	37		118	E	76	
29	E	80		74	B	59		119	E	47	
30	B	93		75	C	86		120	A	54	
31	C	53		76	A	56		121	D	36	
32	D	40		77	E	63		122	B	40	
33	A	40		78	D	52		123	E	36	
34	E	55		79	B	66		124	D	76	
35	C	39		80	A	62		125	A	58	
36	D	36		81	B	72		126	C	70	
37	A	35		82	A	67		127	E	14	
38	A	68		83	A	56		128	C	58	
39	B	52		84	E	45		129	D	86	
40	B	59		85	E	74		130	D	45	
41	E	90		86	A	89					
42	A	66		87	A	28					
43	D	53		88	B	72					
44	B	73		89	A	72					
45	B	46		90	B	70					

Total Correct: _____

Total Scaled: _____

* The numbers in the P+ column indicate the percentages of test takers in the United States who answer each question correctly.

Total Score			
Total Correct	**Scaled Score**	**Total Correct**	**Scaled Score**
		74	640
130	980	72-73	630
128-129	970	70-71	620
127	960	68-69	610
126	950	66-67	600
125	940	64-65	590
123-124	930	62-63	580
122	920	60-61	570
120-121	910	58-59	560
118-119	900	56-57	550
117	890	53-55	540
115-116	880	51-52	530
113-114	870	49-50	520
112	860	47-48	510
110-111	850	44-46	500
108-109	840	42-43	490
107	830	39-41	480
105-106	820	37-38	470
103-104	810	34-36	460
102	800	32-33	450
100-101	790	29-31	440
98-99	780	26-28	430
96-97	770	23-25	420
95	760	20-22	410
93-94	750	18-19	400
91-92	740	15-17	390
90	730	12-14	380
88-89	720	10-11	370
86-87	710	7-9	360
84-85	700	6	350
83	690	4-5	340
81-82	680	2-3	330
79-80	670	1	310
77-78	660	0	300
75-76	650		

GRADUATE RECORD EXAMINATIONS® - (ETS) GRE® - SUBJECT TEST

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1   2   3   4

1. NAME
Enter your last name, first name initial (given name), and middle initial if you have one.
Omit spaces, apostrophes, Jr., II., etc.

Last Name only (Family Name or Surname) - First 15 Letters

First Name Initial **Middle Initial**

2. YOUR NAME:
(Print)

Last Name (Family or Surname)   First Name (Given)   M.I.

MAILING ADDRESS:
(Print)

P.O. Box or Street Address

City   State or Province

Country   ZIP or Postal Code

CENTER:

City   State or Province

Country   Center Number   Room Number

SIGNATURE:

DO NOT USE INK

Use only a pencil with soft, black lead (No. 2 or HB) to complete this answer sheet.
Be sure to fill in completely the space that corresponds to your answer choice.
Completely erase any errors or stray marks.

BE SURE EACH MARK IS DARK AND COMPLETELY FILLS THE INTENDED SPACE AS ILLUSTRATED HERE: ●
YOU MAY FIND MORE RESPONSE SPACES THAN YOU NEED. IF SO, PLEASE LEAVE THEM BLANK.

Item responses continued on reverse side.

3. DATE OF BIRTH
Month   Day   Year

Jan. Feb. Mar. April May June July Aug. Sept. Oct. Nov. Dec.

4. LAST FOUR DIGITS OF SOCIAL SECURITY NUMBER
(U.S.A. only)

5. REGISTRATION NUMBER
(from your admission ticket)

6. TITLE CODE
(on back cover of your test book)

7. TEST NAME (on back cover of your test book)

FORM CODE (on back cover of your test book)

8. TEST BOOK SERIAL NUMBER
(number in upper right corner of front cover of your test book)

SHADED AREA FOR ETS USE ONLY

53

SIDE 2

SUBJECT TEST

COMPLETE THE CERTIFICATION STATEMENT, THEN TURN ANSWER SHEET OVER TO SIDE 1.

BE SURE EACH MARK IS DARK AND COMPLETELY FILLS THE INTENDED SPACE AS ILLUSTRATED HERE: ●.
YOU MAY FIND MORE RESPONSE SPACES THAN YOU NEED. IF SO, PLEASE LEAVE THEM BLANK.

116 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	148 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	180 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	212 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ
117 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	149 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	181 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	213 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ
118 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	150 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	182 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	214 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ
119 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	151 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	183 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	215 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ
120 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	152 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	184 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	216 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ
121 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	153 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	185 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	217 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ
122 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	154 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	186 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	218 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ
123 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	155 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	187 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	219 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ
124 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	156 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	188 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	220 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ
125 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	157 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	189 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	221 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ
126 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	158 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	190 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	222 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ
127 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	159 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	191 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	223 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ
128 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	160 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	192 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	224 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ
129 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	161 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	193 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	225 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ
130 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	162 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	194 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	226 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ
131 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	163 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	195 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	227 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ
132 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	164 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	196 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	228 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ
133 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	165 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	197 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	229 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ
134 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	166 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	198 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	230 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ
135 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	167 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	199 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	231 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ
136 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	168 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	200 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	232 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ
137 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	169 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	201 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	233 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ
138 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	170 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	202 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	234 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ
139 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	171 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	203 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	235 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ
140 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	172 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	204 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	236 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ
141 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	173 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	205 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	237 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ
142 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	174 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	206 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	238 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ
143 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	175 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	207 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	239 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ
144 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	176 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	208 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	240 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ
145 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	177 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	209 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	241 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ
146 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	178 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	210 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ	242 Ⓐ Ⓑ Ⓒ Ⓓ Ⓔ
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