



2001 U. S. NATIONAL CHEMISTRY OLYMPIAD

NATIONAL EXAM—PART I



Prepared by the American Chemical Society Olympiad Examinations Task Force

OLYMPIAD EXAMINATIONS TASK FORCE

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DIRECTIONS TO THE EXAMINER—PART I

Part I of this test is designed to be taken with a Scantron® answer sheet on which the student records his or her responses. Only this Scantron sheet is graded for a score on **Part I**. Testing materials, scratch paper, and the Scantron sheet should be made available to the student *only* during the examination period. All testing materials including scratch paper should be turned in and kept secure until April 22, 2001, after which tests can be returned to students and their teachers for further study.

Allow time for the student to read the directions, ask questions, and fill in the requested information on the Scantron sheet. The answer sheet must be completed using a pencil, not pen. When the student has completed **Part I**, or after **one hour and thirty minutes** has elapsed, the student must turn in the Scantron sheet, **Part I** of the testing materials, and all scratch paper.

There are three parts to the National Olympiad Examination. You have the option of administering the three parts in any order, and you are free to schedule rest-breaks between parts.

Part I	60 questions	single-answer multiple-choice	1 hour, 30 minutes
Part II	8 questions	problem-solving, explanations	1 hour, 45 minutes
Part III	2 lab problems	laboratory practical	1 hour, 30 minutes

A periodic table and other useful information are provided on page 2 for student reference. Students should be permitted to use non-programmable calculators.

DIRECTIONS TO THE EXAMINEE—PART I

DO NOT TURN THE PAGE UNTIL DIRECTED TO DO SO. Answers to questions in **Part I** must be entered on a Scantron answer sheet to be scored. Be sure to write your name on the answer sheet; an ID number is already entered for you. **Make a record of this ID number because you will use the same number on both Parts II and III.** Each item in **Part I** consists of a question or an incomplete statement that is followed by four possible choices. Select the single choice that best answers the question or completes the statement. Then use a pencil to blacken the space on your answer sheet next to the same letter as your choice. You may write on the examination, but the test booklet will not be used for grading. Scores are based on the number of correct responses. When you complete **Part I** (or at the end of one hour and 30 minutes), you *must* turn in all testing materials, scratch paper, and your Scantron answer sheet. Do not forget to turn in your U.S. citizenship statement before leaving the testing site today.

Not valid for use as an USNCO National Exam after April 22, 2001.

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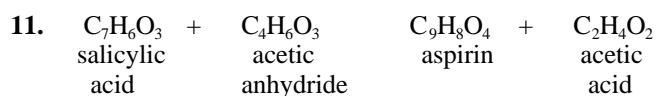
ABBREVIATIONS AND SYMBOLS			
amount of substance	<i>n</i>	equilibrium constant	<i>K</i>
ampere	<i>A</i>	Faraday constant	<i>F</i>
atmosphere	atm	formula molar mass	<i>M</i>
atomic mass unit	u	free energy	<i>G</i>
atomic molar mass	<i>A</i>	frequency	
Avogadro constant	<i>N_A</i>	gas constant	<i>R</i>
Celsius temperature	°C	gram	g
centi- prefix	<i>c</i>	heat capacity	<i>C_p</i>
coulomb	<i>C</i>	hour	h
electromotive force	<i>E</i>	joule	J
energy of activation	<i>E_a</i>	kelvin	K
enthalpy	<i>H</i>	kilo- prefix	k
entropy	<i>S</i>	liter	L
		measure of pressure	mmHg
		milli- prefix	m
		molar	<i>m</i>
		molar	M
		mole	mol
		Planck's constant	<i>h</i>
		pressure	<i>P</i>
		rate constant	<i>k</i>
		retention factor	<i>R_f</i>
		second	s
		speed of light	<i>c</i>
		temperature, K	<i>T</i>
		time	<i>t</i>
		volt	V

CONSTANTS
$R = 8.314 \text{ J}\cdot\text{mol}^{-1}\cdot\text{K}^{-1}$
$R = 0.0821 \text{ L}\cdot\text{atm}\cdot\text{mol}^{-1}\cdot\text{K}^{-1}$
$1 F = 96,500 \text{ C}\cdot\text{mol}^{-1}$
$1 F = 96,500 \text{ J}\cdot\text{V}^{-1}\cdot\text{mol}^{-1}$
$N_A = 6.022 \times 10^{23} \text{ mol}^{-1}$
$h = 6.626 \times 10^{-34} \text{ J}\cdot\text{s}$
$c = 2.998 \times 10^8 \text{ m}\cdot\text{s}^{-1}$

USEFUL EQUATIONS		
$E = E^\circ - \frac{RT}{nF} \ln Q$	$\ln K = \frac{-H}{R} \frac{1}{T} + c$	$\ln \frac{k_2}{k_1} = \frac{E_a}{R} \left(\frac{1}{T_1} - \frac{1}{T_2} \right)$

PERIODIC TABLE OF THE ELEMENTS

1 H 1.008																	2 He 4.003
3 Li 6.941	4 Be 9.012											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 24.31											13 Al 26.98	14 Si 28.09	15 P 30.97	16 S 32.07	17 Cl 35.45	18 Ar 39.95
19 K 39.10	20 Ca 40.08	21 Sc 44.96	22 Ti 47.88	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 72.61	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 102.9	46 Pd 106.4	47 Ag 107.9	48 Cd 112.4	49 In 114.8	50 Sn 118.7	51 Sb 121.8	52 Te 127.6	53 I 126.9	54 Xe 131.3
55 Cs 132.9	56 Ba 137.3	57 La 138.9	72 Hf 178.5	73 Ta 181.0	74 W 183.8	75 Re 186.2	76 Os 190.2	77 Ir 192.2	78 Pt 195.1	79 Au 197.0	80 Hg 200.6	81 Tl 204.4	82 Pb 207.2	83 Bi 209.0	84 Po (209)	85 At (210)	86 Rn (222)
87 Fr (223)	88 Ra 226.0	89 Ac 227.0	104 Rf (261)	105 Db (262)	106 Sg (263)	107 Bh (262)	108 Hs (265)	109 Mt (266)	110 (269)	111 (272)	112 (277)		114 (289)		116 (289)		118 (293)
58 Ce 140.1	59 Pr 140.9	60 Nd 144.2	61 Pm (145)	62 Sm 150.4	63 Eu 152.0	64 Gd 157.3	65 Tb 158.9	66 Dy 162.5	67 Ho 164.9	68 Er 167.3	69 Tm 168.9	70 Yb 173.0	71 Lu 175.0				
90 Th 232.0	91 Pa 231.0	92 U 238.0	93 Np 237.0	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 (260)				



What is the percent yield if 0.85 g of aspirin is formed in the reaction of 1.00 g of salicylic acid with excess acetic anhydride?

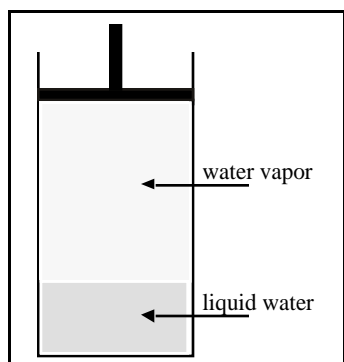
Substance	Molar Mass
$C_7H_6O_3$	138.12 g·mol ⁻¹
$C_4H_6O_3$	102.09 g·mol ⁻¹
$C_9H_8O_4$	180.15 g·mol ⁻¹
$C_2H_4O_2$	60.05 g·mol ⁻¹

- (A) 65 % (B) 77 % (C) 85 % (D) 91 %

12. The triple point of CO₂ occurs at 5.1 atm and -56 °C. Its critical temperature is 31 °C. Solid CO₂ is more dense than liquid CO₂. Under which combination of pressure and temperature is liquid CO₂ stable at equilibrium?

- (A) 10 atm and -25 °C (B) 5.1 atm and -25 °C
 (C) 10 atm and 33 °C (D) 5.1 atm and -100 °C

13. The vapor pressure of water at 20 °C is 17.54 mmHg. What will be the vapor pressure of the water in the apparatus shown after the piston is lowered, decreasing the volume of the gas above the liquid to one half of its initial volume? (Assume no temperature change.)



- (A) 8.77 mmHg
 (B) 17.54 mmHg
 (C) 35.08 mmHg
 (D) between 8.77 and 17.54 mmHg

14. What is the density of propane, C₃H₈, at 25 °C and 740. mmHg?

- (A) 0.509 g·L⁻¹ (B) 0.570 g·L⁻¹
 (C) 1.75 g·L⁻¹ (D) 1.96 g·L⁻¹

15. An unknown gas effuses through a small hole one half as fast as methane, CH₄, under the same conditions. What is the molar mass of the unknown gas?

- (A) 4 g·mol⁻¹ (B) 8 g·mol⁻¹
 (C) 32 g·mol⁻¹ (D) 64 g·mol⁻¹

16. What is the average velocity of H₂ molecules at 100 K relative to their velocity at 50 K?

- (A) 2.00 times the velocity at 50 K
 (B) 1.41 times the velocity at 50 K
 (C) 0.71 times the velocity at 50 K
 (D) 0.50 times the velocity at 50 K

17. What type of semiconductor results when highly purified silicon is doped with arsenic?

- (A) *n*-type (B) *p*-type
 (C) *q*-type (D) *s*-type

18. The heat of formation of NO from its elements is +90 kJ·mol⁻¹. What is the approximate bond dissociation energy of the bond in NO?

Bond	Bond Energy
N=N	941 kJ·mol ⁻¹
O=O	499 kJ·mol ⁻¹

- (A) 630 kJ·mol⁻¹ (B) 720 kJ·mol⁻¹
 (C) 765 kJ·mol⁻¹ (D) 810 kJ·mol⁻¹

19. How much energy must be supplied to change 36 g of ice at 0 °C to water at room temperature, 25 °C?

Data for Water, H ₂ O	
$H^{\circ}_{\text{fusion}}$	6.01 kJ·mol ⁻¹
$C_{P, \text{liquid}}$	4.18 J·K ⁻¹ ·g ⁻¹

- (A) 12 kJ (B) 16 kJ
 (C) 19 kJ (D) 22 kJ

20. For a process that is both endothermic and spontaneous,

- (A) $H < 0$ (B) $G > 0$
 (C) $E = 0$ (D) $S > 0$

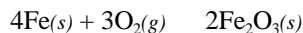
21. Consider the values for H° (in kJ·mol⁻¹) and for S° (in J·mol⁻¹·K⁻¹) given for four different reactions. For which reaction will G° increase the most (becoming more positive) when the temperature is increased from 0 °C to 25 °C?

- (A) $H^{\circ} = 50$, $S^{\circ} = 50$
 (B) $H^{\circ} = 90$, $S^{\circ} = 20$
 (C) $H^{\circ} = -20$, $S^{\circ} = -50$
 (D) $H^{\circ} = -90$, $S^{\circ} = -20$

22. A certain reaction is exothermic by 220 kJ and does 10 kJ of work. What is the change in the internal energy of the system at constant temperature?

(A) +230 kJ (B) +210 kJ
(C) -210 kJ (D) -230 kJ

23. $\text{Fe}_2\text{O}_3(s) + 3/2\text{C}(s) \rightarrow 3/2\text{CO}_2(g) + 2\text{Fe}(s) \quad H^\circ = +234.1 \text{ kJ}$
 $\text{C}(s) + \text{O}_2(g) \rightarrow \text{CO}_2(g) \quad H^\circ = -393.5 \text{ kJ}$
 Use these equations and H° values to calculate H° for this reaction.

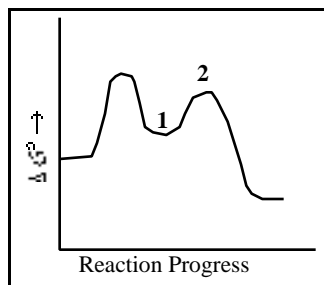


(A) -1648.7 kJ (B) -1255.3 kJ
(C) -1021.2 kJ (D) -129.4 kJ

24. A large positive value of G° corresponds to which of these?

(A) small positive K (B) small negative K
(C) large positive K (D) large negative K

25. What names apply to chemical species corresponding to locations 1 and 2 on this reaction coordinate diagram?



Location 1

Location 2

(A) activated complex activated complex
(B) reaction intermediate activated complex
(C) activated complex reaction intermediate
(D) reaction intermediate reaction intermediate

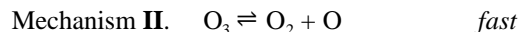
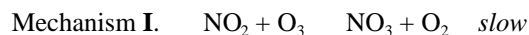
26. Gadolinium-153, which is used to detect osteoporosis, has a half-life of 242 days. Which value is closest to the percentage of the Gd-153 left in a patient's system after 2 years (730 days)?

(A) 33.0 % (B) 25.0 %
(C) 12.5 % (D) 6.25 %

27. Consider this reaction.



The reaction of nitrogen dioxide and ozone represented is first order in $\text{NO}_2(g)$ and in $\text{O}_3(g)$. Which of these possible reaction mechanisms is consistent with the rate law?



(A) I only (B) II only
(C) both I and II (D) neither I nor II

28. When the temperature of a reaction is raised from 300 K to 310 K, the reaction rate doubles. Determine the activation energy, E_a , associated with the reaction.

(A) 6.45 kJ·mol⁻¹ (B) 23.3 kJ·mol⁻¹
(C) 53.6 kJ·mol⁻¹ (D) 178 kJ·mol⁻¹

29. Use the experimental data in the table to determine the rate law for this reaction.



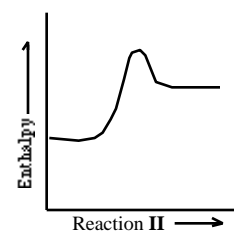
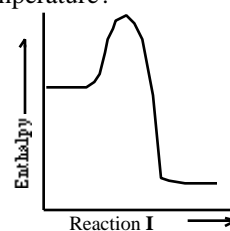
These data were obtained when the reaction was studied.

[A], M	[B], M	$\frac{[\text{AB}]}{t} \text{ mol}\cdot\text{L}^{-1}\cdot\text{s}^{-1}$
0.100	0.100	2.0×10^{-4}
0.200	0.100	2.0×10^{-4}
0.300	0.300	1.8×10^{-3}

What is the rate equation for the reaction?

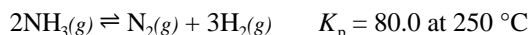
(A) rate = $k [\text{A}] [\text{B}]$ (B) rate = $k [\text{A}]^2$
(C) rate = $k [\text{B}]$ (D) rate = $k [\text{B}]^2$

30. Which of the reactions represented in these diagrams will show the greatest increase in rate for a given increase in temperature?

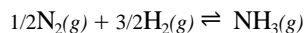


(A) Reaction I forward (B) Reaction I reversed
(C) Reaction II forward (D) Reaction II reversed

Questions 31 and 32 should both be answered with reference to this equilibrium system.

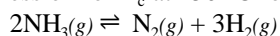


31. What is K_p for this reaction?



- (A) 0.0125 (B) 0.112
(C) 8.94 (D) 40.0

32. What is the expression for K_c at 250 °C for this reaction?



- (A) $K_c = \frac{K_p}{(RT)^2}$ (B) $K_c = \frac{K_p}{RT}$
(C) $K_c = K_p (RT)^2$ (D) $K_c = K_p RT$

33. $\text{HCOOH}(aq) \rightleftharpoons \text{H}^+(aq) + \text{HCOO}^-(aq)$ $K_a = 1.7 \times 10^{-4}$

The ionization of formic acid is represented. Calculate $[\text{H}^+]$ of a solution initially containing 0.10 M HCOOH and 0.050 M HCOONa.

- (A) 8.5×10^{-5} M (B) 3.4×10^{-4} M
(C) 4.1×10^{-3} M (D) 1.8×10^{-2} M

34. Which are strong acids?



- (A) I only (B) III only
(C) I and III only (D) II and III only

35. Carbonic acid, H_2CO_3 , is a diprotic acid for which $K_1 = 4.2 \times 10^{-7}$ and $K_2 = 4.7 \times 10^{-11}$. Which solution will produce a pH closest to 9?

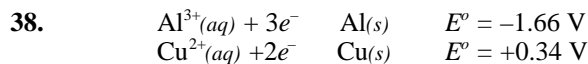
- (A) 0.1 M H_2CO_3 (B) 0.1 M Na_2CO_3
(C) 0.1 M NaHCO_3 (D) 0.1 M NaHCO_3 and
0.1 M Na_2CO_3

36. What is the pH of a saturated solution of magnesium hydroxide, $\text{Mg}(\text{OH})_2$ at 25 °C? ($K_{sp} = 6.0 \times 10^{-12}$ at 25 °C)

- (A) 10.56 (B) 10.36
(C) 10.26 (D) 10.05

37. $\text{P}_4(s) + 3\text{OH}^-(aq) + 3\text{H}_2\text{O}(l) \rightleftharpoons \text{PH}_3(g) + 3\text{H}_2\text{PO}_2^-(aq)$
For this reaction, the oxidizing and reducing agents are, respectively,

- (A) P_4 and OH^- (B) OH^- and P_4
(C) P_4 and H_2O (D) P_4 and P_4



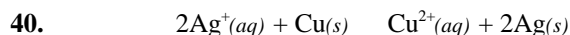
What voltage is produced under standard conditions by combining the half-reactions with these Standard Electrode Potentials?

- (A) 1.32 V (B) 2.00 V (C) 2.30 V (D) 4.34 V

39. For which of these oxidation/reduction pairs will the reduction potential vary with pH?

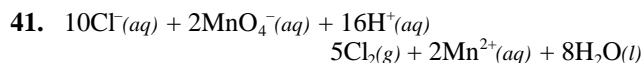


- (A) I only (B) II only
(C) I and II only (D) I, II, and III



The standard potential for this reaction is 0.46 V. Which change will increase the potential the most?

- (A) doubling the $[\text{Ag}^+]$
(B) halving the $[\text{Cu}^{2+}]$
(C) doubling the size of the $\text{Cu}(s)$ electrode
(D) decreasing the size of the Ag electrode by one half



The value of E° for this reaction at 25 °C is 0.15 V. What is the value of K for this reaction?

- (A) 2.4×10^{25} (B) 4.9×10^{12}
(C) 1.2×10^5 (D) 3.4×10^2

42. When water is electrolyzed, hydrogen and oxygen gas are produced. If 1.008 g of H_2 is liberated at the cathode, what mass of O_2 is formed at the anode?

- (A) 32.0 g (B) 16.0 g
(C) 8.00 g (D) 4.00 g

43. Which property of an element is most dependent on the shielding effect?

- (A) atomic number
(B) atomic mass
(C) atomic radius
(D) number of stable isotopes

44. How many unpaired electrons are present in a ground state gaseous Ni^{2+} ion?
 (A) 0 (B) 2 (C) 4 (D) 6
45. When the elements carbon, nitrogen and oxygen are arranged in order of increasing ionization energies, what is the correct order?
 (A) C, N, O (B) O, N, C
 (C) N, C, O (D) C, O, N
46. Given this set of quantum numbers for a multi-electron atom: 2, 0, 0, $1/2$ and 2, 0, 0, $-1/2$. What is the next higher allowed set of n and l quantum numbers for this atom in its ground state?
 (A) $n = 2, l = 0$ (B) $n = 2, l = 1$
 (C) $n = 3, l = 0$ (D) $n = 3, l = 1$
47. Which element will exhibit the photoelectric effect with light of the longest wavelength?
 (A) K (B) Rb (C) Mg (D) Ca
48. All these elements have common allotropes *except*
 (A) C (B) O (C) Kr (D) S
49. How many sigma and pi bonds are shown in this compound?
- $$\begin{array}{ccccccc} & & \text{H} & \text{H} & \text{O} & & \\ & & | & | & || & & \\ \text{H}-\text{N} & = & \text{C} & - & \text{C} & - & \text{C} & = & \text{C} & - & \text{H} \\ & & & & | & & & & & & \\ & & & & \text{H} & & & & & & \end{array}$$
- (A) 8 sigma and 7 pi (B) 8 sigma and 3 pi
 (C) 11 sigma and 3 pi (D) 11 sigma and 4 pi
50. Which reaction involves a change in the electron-pair geometry for the underlined atom?
 (A) $\underline{\text{B}}\text{F}_3 + \text{F}^- \rightarrow \underline{\text{B}}\text{F}_4^-$ (B) $\underline{\text{N}}\text{H}_3 + \text{H}^+ \rightarrow \underline{\text{N}}\text{H}_4^+$
 (C) $2\underline{\text{S}}\text{O}_2 + \text{O}_2 \rightarrow 2\underline{\text{S}}\text{O}_3$ (D) $\text{H}_2\underline{\text{O}} + \text{H}^+ \rightarrow \text{H}_3\underline{\text{O}}^+$
51. Which compound has the largest lattice energy?
 (A) NaF (B) CsI (C) MgO (D) CaS
52. Which is the best description of a covalent bond?
 (A) Electrons are simultaneously attracted by more than one nucleus.
 (B) Filled orbitals of two or more atoms overlap one another.
 (C) Unoccupied orbitals of two or more atoms overlap one another.
 (D) Oppositely-charged ions attract one another.
53. What is the formal charge on the chlorine atom in the oxyacid HOClO_2 if it contains only single bonds?
 (A) -2 (B) -1 (C) +1 (D) +2
54. Which of these compounds is not adequately represented by a valence bond model?
 I. CO_2 II. SO_2 III. SiO_2
 (A) I only (B) II only
 (C) I and III only (D) II and III only
55. Which compound is not correctly matched with its class name?
 (A) HCOOH , acid
 (B) $\text{C}_6\text{H}_5\text{CHO}$, aldehyde
 (C) $\text{C}_2\text{H}_5\text{COCH}_3$, ether
 (D) $\text{CH}_3\text{CHOHCH}_3$, secondary alcohol
56. How many toluene derivatives have the formula $\text{C}_7\text{H}_7\text{Cl}$?
 (A) 1 (B) 2 (C) 3 (D) 4
57. When the compounds CH_3COOH , $\text{C}_2\text{H}_5\text{OH}$ and $\text{C}_6\text{H}_5\text{OH}$ are arranged in order of increasing acidity in aqueous solution, which order is correct?
 (A) $\text{C}_2\text{H}_5\text{OH} < \text{CH}_3\text{COOH} < \text{C}_6\text{H}_5\text{OH}$
 (B) $\text{C}_6\text{H}_5\text{OH} < \text{CH}_3\text{COOH} < \text{C}_2\text{H}_5\text{OH}$
 (C) $\text{CH}_3\text{COOH} < \text{C}_6\text{H}_5\text{OH} < \text{C}_2\text{H}_5\text{OH}$
 (D) $\text{C}_2\text{H}_5\text{OH} < \text{C}_6\text{H}_5\text{OH} < \text{CH}_3\text{COOH}$
58. Which can be used as a catalyst in an esterification reaction?
 I. NaOH II. H_2SO_4
 (A) I only (B) II only
 (C) both I and II (D) neither I nor II

59. Which term best describes a carbocation?

- (A) electrophilic (B) free radical
(C) hydrophobic (D) nucleophilic

60. A racemic mixture has equal amounts of

- (A) alkanes and alkenes.
(B) *cis* and *trans* isomers.
(C) functional group isomers.
(D) enantiomers.

END OF TEST

U. S. National Chemistry Olympiad – 2001
National Examination—Part I
SCORING KEY

Number	Answer	Number	Answer	Number	Answer
1.	C	21.	C	41.	A
2.	D	22.	D	42.	C
3.	B	23.	A	43.	C
4.	B	24.	A	44.	B
5.	D	25.	B	45.	D
6.	B	26.	C	46.	B
7.	C	27.	C	47.	B
8.	C	28.	C	48.	C
9.	D	29.	D	49.	D
10.	A	30.	B	50.	A
11.	A	31.	B	51.	C
12.	A	32.	A	52.	A
13.	B	33.	B	53.	D
14.	C	34.	A	54.	B
15.	D	35.	C	55.	C
16.	B	36.	B	56.	D
17.	A	37.	D	57.	D
18.	A	38.	B	58.	B
19.	B	39.	B	59.	A
20.	D	40.	A	60.	D