2001 U. S. NATIONAL CHEMISTRY OLYMPIAD

LOCAL SECTION EXAM

Prepared by the American Chemical Society Olympiad Examinations Task Force

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DIRECTIONS TO THE EXAMINER

This test is designed to be taken with an answer sheet on which the student records his or her responses. All answers are to be marked on that sheet, not written in the booklet. Each student should be provided with an answer sheet and scratch paper, both of which must be turned in with the test booklet at the end of the examination. Local Sections may use an answer sheet of their own choice.

The full examination consists of 60 multiple-choice questions representing a fairly wide range of difficulty. Students should be permitted to use non-programmable calculators. A periodic table and other useful information are provided on page two of this exam booklet for student reference.

Suggested Time: 60 questions—110 minutes

DIRECTIONS TO THE EXAMINEE

DO NOT WRITE IN THIS BOOKLET. DO NOT TURN THE PAGE UNTIL DIRECTED TO DO SO.

This is a multiple-choice examination with four choices for each question. There is only *one* correct or best answer to each question. When you select your choice, blacken the corresponding space on the answer sheet with your pencil. Make a heavy full mark, but no stray marks. If you decide to change your answer, be certain to erase your original answer completely.

Any question for which more than one response has been blackened will NOT BE COUNTED. Your score is based on the number of questions you answer correctly. It is to your advantage to answer every question. A periodic table and other useful information are provided on page two of this exam booklet for your reference.

ABBREVIATIONS AND SYMBOLS

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

CONSTANTS

$R = 8.314 \ \text{J·mol}^{-1}\text{·K}^{-1}$

$R = 0.0821 \ \text{L·atm·mol}^{-1}\text{·K}^{-1}$

$1 \ F = 96,500 \ \text{C·mol}^{-1}$

$1 \ F = 96,500 \ \text{J·V}^{-1}\text{·mol}^{-1}$

$N_A = 6.022 \times 10^{23} \ \text{mol}^{-1}$

$h = 6.626 \times 10^{-34} \ \text{J·s}$

$c = 2.998 \times 10^8 \ \text{m·s}^{-1}$

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)

Not for use as a USNCO Local Section Exam after April 22, 2001.

• When you have selected your answer, blacken the corresponding space on the answer sheet with a soft, black #2 pencil. Make a heavy, full mark, but no stray marks. If you decide to change an answer, erase the unwanted mark very carefully.
• Make no marks in the test booklet. Do all calculations on scratch paper provided by your examiner.
• There is only one correct answer to each question. Any questions for which more than one response has been blackened will not be counted.
• Your score is based solely on the number of questions you answer correctly. It is to your advantage to answer every question.
• The best strategy is to arrive at your own answer to a question before looking at the choices. Otherwise, you may be misled by plausible, but incorrect, responses.

1. Which metal reacts most vigorously with water?

   (A) Al (B) Ca (C) Fe (D) K

2. Which are strong acids?
      I. HI   **II.** HNO_3 **III.** H_2SO_3

   (A) **II** only   (B) **I** and **II** only

   (C) **II** and **III** only   (D) **I**, **II** and **III**

3. What products result when aqueous solutions of $CuCl_2$ and $(NH_4)_2S$ are mixed?

   (A) CuS*(aq)* and NH_4Cl*(s)* (B) CuS*(s)* and NH_4Cl*(aq)*

   (C) CuS*(aq)* and NH_4Cl*(g)* (D) CuS*(s)* and NH_4Cl*(s)*

4. Which element has the highest electrical conductivity?

   (A) Ga (B) Ge (C) As (D) Si

5. The molar mass of a volatile liquid (bp < 90°C) is to be determined by measuring the density of its vapor in an Erlenmeyer flask capped with Al foil with a pinhole to allow the vapor to escape. A sample of the liquid is added to the pre-weighed flask that is heated in a water bath until the liquid has evaporated, after which the flask is dried and reweighed. Which piece of information is *not* required to determine the molar mass of the liquid?

   (A) barometric pressure (B) mass of liquid sample

   (C) temperature of water (D) volume of the flask

6. Which set of reactants produces a gaseous product?
      I. 6 M HNO_3*(aq)* + Cu*(s)*   **II.** 6 M HCl*(aq)* + $CaCO_3$*(s)*

   (A) **I** only   (B) **II** only

   (C) Both **I** and **II**   (D) Neither **I** nor **II**

7. Which metal, when exposed to air, forms an oxide coating that protects the metal from further reaction?

   (A) Al (B) Cu (C) Fe (D) Zn

8. The principal reason that solid sodium hydroxide is *not* used as a primary standard for acid-base titrations is that it

   (A) absorbs water from air.

   (B) has a low molar mass.

   (C) reacts slowly with many acids.

   (D) ionizes in water.

9. A chloride salt of rhenium contains 63.6% Re by mass. What is its empirical formula?

   (A) ReCl   (B) $ReCl_2$

   (C) $ReCl_3$ (D) $ReCl_5$

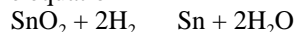10. The amount of chloride ion in a water sample is to be determined by adding excess silver nitrate. If

Molar Mass, g·mol^{-1}	
$AgNO_3$	169.91
AgCl	143.25

    1.0 g of silver chloride is precipitated, what mass of chloride ion is in the original sample?

    (A) 0.25 g   (B) 0.34 g

    (C) 0.50 g   (D) 0.75 g

11. __Sn^{2+}*(aq)* + __MnO_4^-*(aq)* + __H^+*(aq)*
       __Sn^{4+}*(aq)* + __Mn^{2+}*(aq)* + __H_2O*(l)*

    When this equation for the reaction of Sn^{2+}*(aq)* and MnO_4^-*(aq)* is balanced correctly, what is the ratio, Sn^{2+} / MnO_4^-?

    (A) 1/1 (B) 1/2 (C) 2/1 (D) 5/2

12. How many millimoles of methane, CH_4, are present in 6.4 g of this gas?

    (A) 0.40   (B) 4.0

    (C) 40.   (D) 4.0×10^2

13. A 1.50 mL sample of a sulfuric acid solution from an automobile storage battery is titrated with 1.47 M sodium hydroxide solution to a phenolphthalein endpoint, requiring 23.70 mL. What is the molarity of the sulfuric acid solution?

(A) 23.2 M   (B) 11.6 M

(C) 6.30 M   (D) 0.181 M

14. According to the equation
$$SnO_2 + 2H_2 \quad Sn + 2H_2O$$
What volume of hydrogen, measured at 1 atm and 273 K, is required to react with 2.00 g of SnO_2?

(A) 0.00133 L   (B) 0.00265 L

(C) 0.297 L   (D) 0.595 L

15. Which terms are matched correctly?

(A) high vapor pressures   high H_{vap} values

(B) high H_{vap} values   low boiling points

(C) low vapor pressure   high boiling points

(D) low boiling points   low vaporization rates

16. Three balloons are filled with the same number of atoms of He, Ar, and Xe, respectively. Which statement is true under the same conditions of temperature and pressure?

(A) The balloons contain the same mass of gas.

(B) All balloons have the same volume.

(C) The densities of the three gases are the same.

(D) The average speed of the different types of atoms is the same.

17. A 0.239 g sample of a gas in a 100-mL flask exerts a pressure of 600 mmHg at 14 °C. What is the gas?

(A) chlorine   (B) nitrogen

(C) krypton   (D) xenon

18. Which parameter affects the vapor pressure of a liquid?

(A) volume of the liquid

(B) surface area of the liquid

(C) volume of space above the liquid

(D) temperature of the liquid

19. Which points in this phase diagram represent conditions of temperature and pressure where liquid will be present?
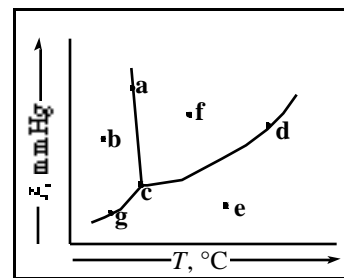
(A) **a**, **b**, and **g** only   (B) **a**, **c**, **d** and **g** only

(C) **a**, **c**, **d** and **f** only   (D) **c**, **d**, **e** and **g** only

20. Which compound is expected to be the most soluble in water at 25 °C?

(A) $N_{2(g)}$ (B) $O_{2(g)}$

(C) $(C_2H_5)_2NH_{(l)}$ (D) $C_2H_5OC_2H_{5(l)}$

21. A hard, crystalline solid with a high melting point does not conduct electricity in any phase. This solid is most likely

(A) an ionic solid.

(B) a metallic solid.

(C) a molecular solid.

(D) a network covalent solid.

22. For the formation of one mole of each of these gases from their elements, which reaction is most endothermic?

(A) CO   ($H_f^o = -110.5$ kJ·mol^{-1})

(B) NO_2 ($H_f^o = +33.9$ kJ·mol^{-1})

(C) O_3 ($H_f^o = +142.2$ kJ·mol^{-1})

(D) SO_2 ($H_f^o = -300.4$ kJ·mol^{-1})

23. The specific heats of several metals are given in the table. If the same number of Joules were applied to the same mass of each metal, which metal would show the greatest temperature change?

Specific Heat, J·g^{-1}·°C^{-1}	
Al	0.900
Au	0.129
Cu	0.385
Hg	0.139

(A) Al   (B) Au   (C) Cu   (D) Hg

24. $4Li(s) + O_2(g) \rightarrow 2Li_2O(s)$

At 25 °C, H^o for this reaction is –598.8 kilojoules per mole of $Li_2O(s)$ formed. What mass of Li should be reacted with excess $O_2(g)$ in order to release 150. kJ?

(A) 0.874 g   (B) 1.74 g

(C) 3.48 g   (D) 6.98 g

25. When these substances are arranged in order of increasing $S°$ values at 25 ˚C, what is the correct order?

(A) $Na(s)$, $Cl_2(g)$, $NaCl(s)$ (B) $NaCl(s)$, $Cl_2(g)$, $Na(s)$

(C) $Cl_2(g)$, $NaCl(s)$, $Na(s)$ (D) $Na(s)$, $NaCl(s)$, $Cl_2(g)$

26. The H^o and S^o values for a particular reaction are –60.0 kJ and –0.200 kJ·K^{-1} respectively. Under what conditions is this reaction spontaneous?

(A) all conditions   (B) $T < 300$ K

(C) $T = 300$ K   (D) $T > 300$ K

27. For the reaction;
$$2NO_2(g) \rightarrow 2NO(g) + O_2(g)$$
at a certain temperature, the initial rate of decomposition of NO_2 is 0.0036 mol·L^{-1}·s^{-1}. What is the initial rate of formation of $O_2(g)$ in mol·L^{-1}·s^{-1}?

(A) 0.0018   (B) 0.0036

(C) 0.0054   (D) 0.0072

28. The reaction $A + B \rightarrow AB$ has an enthalpy of reaction of –85.0 kJ·mol^{-1}. If the activation enthalpy for the forward reaction is 120.0 kJ·mol^{-1}, what is the activation energy for the reverse reaction $AB \rightarrow A + B$?

(A) 35.0 kJ·mol^{-1} (B) 85.0 kJ·mol^{-1}

(C) 120.0 kJ·mol^{-1} (D) 205.0 kJ·mol^{-1}

29. Use the experimental data in this table to determine the rate law for the reaction of hydrogen iodide, HI, with ethyl iodide, C_2H_5I, to form ethane, C_2H_6, and iodine, I_2.

[HI], M	[C_2H_5I], M	$\dfrac{[I_2]}{t}$, mol·L^{-1}·s^{-1}
0.010	0.010	1.2×10^{-5}
0.010	0.020	2.4×10^{-5}
0.020	0.020	4.8×10^{-5}

(A) rate = k [HI]   (B) rate = k [C_2H_5I]

(C) rate = k [HI] [C_2H_5I]   (D) rate = k [HI]^2 [C_2H_5I]^2

30. Which equation indicates the presence of a catalyst in the reaction?

(A) $A + B \rightarrow D + B$ (B) $A + B \rightarrow C + D$

(C) $A + A \rightarrow D$ (D) $A \rightarrow B + C$

31. The reaction $A \rightarrow B + C$ obeys the rate law: rate = k[A]. Which graph will produce a straight line?

(A) [A] vs time   (B) ln[A] vs time

(C) 1/[A] vs time   (D) [A] vs 1/time

Questions **32** and **33** should both be answered with reference to this system.
$$H_2(g) + I_2(s) \rightleftharpoons 2HI(g) \qquad H = +51.8 \text{ kJ}$$

32. Which would increase the equilibrium quantity of HI(g)? Assume the system has reached equilibrium with all three components present.

   I. increasing pressure   **II.** increasing temperature

(A) **I** only   (B) **II** only

(C) Both **I** and **II**   (D) Neither **I** nor **II**

33. What is the equilibrium constant expression for this system?

(A) $K = \dfrac{[HI]^2}{[H_2][I_2]}$ (B) $K = \dfrac{[H_2][I_2]}{[HI]^2}$

(C) $K = \dfrac{2[HI]}{[H_2][I_2]}$ (D) $K = \dfrac{[HI]^2}{[H_2]}$

34. The ionization of benzoic acid is represented by this equation.
$$C_6H_5COOH(aq) \rightleftharpoons H^+(aq) + C_6H_5COO^-(aq)$$
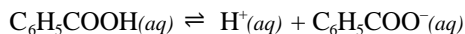
If a 0.045 M solution of benzoic acid has an [H$^+$] = 1.7×10^{-3}, what is the K_a of benzoic acid?

(A) 7.7×10^{-5} (B) 6.4×10^{-5}

(C) 3.8×10^{-2} (D) 8.4×10^{-1}

**35.** $$C_6H_5OH(aq) + CN^-(aq) \rightleftharpoons HCN(aq) + C_6H_5O^-(aq)$$

The equilibrium constant for this reaction is less than 1. What is the strongest base in this system?

(A) $C_6H_5OH(aq)$ (B) $CN^-(aq)$

(C) $HCN(aq)$ (D) $C_6H_5O^-(aq)$

36.

$$HOCl(aq) \rightleftharpoons H^+(aq) + OCl^-(aq)$$

The ionization of hypochlorous acid represented above has $K = 3.0 \times 10^{-8}$ at 25°C. What is K for this reaction?

$$OCl^-(aq) + H_2O(l) \rightleftharpoons HOCl(aq) + OH^-(aq)$$

(A) 3.3×10^{-7}
(B) 3.0×10^{-8}
(C) 3.0×10^{6}
(D) 3.3×10^{7}

37. Lead(II) fluoride (PbF_2), lead(II) chloride ($PbCl_2$), lead(II) bromide ($PbBr_2$), and lead(II) iodide (PbI_2) are all slightly soluble in water. Which lead salt will *increase* in solubility when its saturated solution is acidified?

(A) PbF_2
(B) $PbCl_2$
(C) $PbBr_2$
(D) PbI_2

38. In which process does the nitrogen undergo oxidation?

(A) $N_2 \quad 2NH_3$
(B) $N_2O_4 \quad 2NO_2$
(C) $2NO_3^- \quad N_2O_5$
(D) $NO_2^- \quad NO_3^-$

39. Which statement is *not* true about the electrolysis of a 1 M solution of KI to which phenolphthalein has been added?

(A) Potassium metal is formed.
(B) A yellow color appears at the anode.
(C) A pink color appears at the cathode.
(D) A gas is produced at the cathode.

Questions **40** and **41** should be answered with reference to these half-reactions and their standard reduction potentials.

$$Al^{3+}(aq) + 3e^- \quad Al(s) \quad E^o = -1.66 \text{ V}$$
$$Mn^{2+}(aq) + 2e^- \quad Mn(s) \quad E^o = -1.18 \text{ V}$$
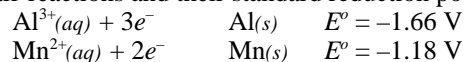
40. What process occurs at the anode of a voltaic cell utilizing these two half-reactions?

(A) $Al(s) \quad Al^{3+}(aq) + 3e^-$
(B) $Al^{3+}(aq) + 3e^- \quad Al(s)$
(C) $Mn(s) \quad Mn^{2+}(aq) + 2e^-$
(D) $Mn^{2+}(aq) + 2e^- \quad Mn(s)$

41. What is the standard potential of a voltaic cell produced by using these two half-reactions?

(A) 0.04 V
(B) 0.48 V
(C) 2.84 V
(D) 6.68 V

42.

$$Ni(s) + Cu^{2+}(aq) \quad Ni^{2+}(aq) + Cu(s)$$

The voltaic cell based on this reaction has a voltage of 0.59 V under standard conditions. Which of these changes will produce a higher voltage?

I.   increasing $[Cu^{2+}]$
II. increasing the size of the $Ni(s)$ electrode

(A) **I** only
(B) **II** only
(C) Both **I** and **II**
(D) Neither **I** nor **II**

43. When a phosphorus atom is converted to a phosphide ion, what happens to the number of unpaired electrons and the total number of electrons around the phosphorus?

	unpaired electrons	total electrons
(A)	increases	increases
(B)	decreases	increases
(C)	increases	remains the same
(D)	decreases	remains the same

44. Which list includes species with the same number of electrons?

(A) Mg, Ca, Sr
(B) Li^+, Na^+, K^+
(C) K^+, Cl^-, S^{2-}
(D) Fe^{2+}, Co^{2+}, Ni^{2+}

45. Which pair of symbols represents nuclei with the same number of neutrons?

(A) ^{56}Co and ^{58}Co
(B) ^{57}Mn and ^{57}Fe
(C) ^{57}Fe and ^{58}Ni
(D) ^{57}Co and ^{58}Ni

46. Which list includes elements in order of *increasing* metallic character?

(A) Si, P, S
(B) As, P, N
(C) Al, Ge, Sb
(D) Br, Se, As

47. How many unpaired electrons are in an iron atom in its ground state?

(A) 6
(B) 4
(C) 2
(D) 0

48. How do the energy gaps between successive electron energy levels in an atom vary from low to high n values?

(A) All energy gaps are the same.
(B) The energy gap decreases as n increases.
(C) The energy gap increases as n increases.
(D) The energy gap changes unpredictably as n increases.

49. Which bond is expected to be the *least* polar?

(A) O–F

(B) P–F

(C) Si–N

(D) B–Cl

50. For which element would XH_3 be a stable species?

(A) C

(B) Cl

(C) P

(D) S

51. Which species has a Lewis diagram and structure most like that of the carbonate ion, CO_3^{2-}?

(A) NO_3^-

(B) CH_3^+

(C) SO_3^{2-}

(D) PO_4^{3-}

52. Which compounds contain both ionic and covalent bonds?

I. $BaSO_4$ **II.** $Ca(NO_3)_2$ **III.** NH_4Cl

(A) **I** only

(B) **I** and **III** only

(C) **II** and **III** only

(D) **I**, **II** and **III**

53. When the species NH_4^+, H_3O^+, and H_2F^+ are arranged in order of increasing H–**X**–H bond angles, what is the correct order?

(A) $H_3O^+ < NH_4^+ < H_2F^+$

(B) $H_2F^+ < H_3O^+ < NH_4^+$

(C) $NH_4^+ < H_2F^+ < H_3O^+$

(D) $NH_4^+ < H_3O^+ < H_2F^+$

54. The nitrite ion, NO_2^-, may be represented by two major resonance forms. The lengths of the nitrogen-to-oxygen bonds in this ion are expected to be

(A) the same as the length of nitrogen-to-oxygen double bonds.

(B) the same as the length of nitrogen-to-oxygen triple bonds.

(C) between the lengths of a nitrogen-to-oxygen single bond and a nitrogen-to-oxygen double bond.

(D) between the lengths of a nitrogen-to-oxygen double bond and a nitrogen-to-oxygen triple bond.

55. Which of these compounds contains a carboxyl group?

(A) propanol

(B) propanal

(C) propanone

(D) propanoic acid

56. Which class of compounds consists exclusively of saturated hydrocarbons?

(A) alkanes

(B) alkenes

(C) alkynes

(D) aromatics

57. How many different alcohols (not including optical isomers) have the molecular formula $C_4H_{10}O$?

(A) 2

(B) 3

(C) 4

(D) 5

58. What is the position of the bromine atom relative to the methyl group in 3-bromotoluene?

(A) meta

(B) ortho

(C) para

(D) trans

59. Which of these compounds have *cis-* and *trans-* isomers?

(A) dichlorobenzene

(B) 1-chloropropene

(C) 1,2-dichloropropane

(D) dichloroethyne

60. If a certain polymer has the formula $(-CH_2CCl_2CH_2CCl_2-)_n$, from which monomer is it made?

(A) $HC\equiv CCl$

(B) $ClHC=CClH$

(C) $Cl_2C=CH_2$

(D) $H_2C=CClH$

END OF TEST

U.S. NATIONAL CHEMISTRY OLYMPIAD
2001 LOCAL SECTION EXAM — KEY

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