



2006 U. S. NATIONAL CHEMISTRY OLYMPIAD

LOCAL SECTION EXAM



Prepared by the American Chemical Society Olympiad Examinations Task Force

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 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.

Not valid for use as an ACS Olympiad Local Section Exam after March 28, 2006. **STOCK CODE OL06**

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ABBREVIATIONS AND SYMBOLS			
ampere	A	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	<i>v</i>
Avogadro constant	<i>N_A</i>	gas constant	<i>R</i>
Celsius temperature	°C	gram	g
centi- prefix	c	heat capacity	<i>C_p</i>
coulomb	C	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
equilibrium constant	<i>K</i>	milli- prefix	m
		molal	<i>m</i>
		molar	M
		molar mass	<i>M</i>
		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
		temperature, K	<i>T</i>
		time	<i>t</i>
		volt	V

CONSTANTS
$R = 8.314 \text{ J}\cdot\text{mol}^{-1}\cdot\text{K}^{-1}$
$R = 0.0821 \text{ L}\cdot\text{atm}\cdot\text{mol}^{-1}\cdot\text{K}^{-1}$
$1 F = 96,500 \text{ C}\cdot\text{mol}^{-1}$
$1 F = 96,500 \text{ J}\cdot\text{V}^{-1}\cdot\text{mol}^{-1}$
$N_A = 6.022 \times 10^{23} \text{ mol}^{-1}$
$h = 6.626 \times 10^{-34} \text{ J}\cdot\text{s}$
$c = 2.998 \times 10^8 \text{ m}\cdot\text{s}^{-1}$
$0^\circ\text{C} = 273.15 \text{ K}$
$1 \text{ atm} = 760 \text{ mmHg}$
note: the notation $\text{m}\cdot\text{s}^{-1}$ should be read meters per second

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

PERIODIC TABLE OF THE ELEMENTS

1												18							
1A												8A							
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	3 B 10.81	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 180.9	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)	89 Ac (227)	104 Rf (261)	105 Db (262)	106 Sg (263)	107 Bh (262)	108 Hs (265)	109 Mt (266)	110 Uun (269)	111 Uuu (272)	112 Uub (277)		114 Uuq (???)		116 Uuh (???)		118 Uuo (???)		
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)	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)						

DIRECTIONS

- When you have selected your answer to each question, blacken the corresponding space on the answer sheet using a soft, #2 pencil. Make a heavy, full mark, but no stray marks. If you decide to change an answer, erase the unwanted mark very carefully.
- 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.**

1. Which gas should not be collected over water because of its high solubility in water?

- (A) H_2 (B) CO (C) CH_4 (D) HCl

2. A student wishes to measure 17.3 mL of a standard solution. This can be done best using which container?

- (A) 25 mL beaker (B) 25 mL volumetric pipet
(C) 25 mL buret (D) 25 mL volumetric flask

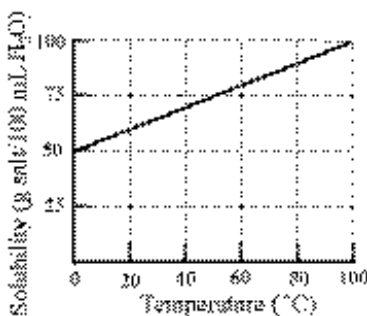
3. In a familiar classroom demonstration, concentrated H_2SO_4 is added to a beaker containing sucrose ($C_{12}H_{22}O_{11}$), to produce a column of carbon. In this reaction the H_2SO_4 is acting primarily as a

- (A) complexing agent. (B) dehydrating agent.
(C) oxidizing agent. (D) precipitating agent.

4. Aqua regia, the reagent that can be used to dissolve gold, is a 3:1 mixture of which acids?

- (A) hydrochloric and sulfuric acids
(B) hydrofluoric and nitric acids
(C) hydrochloric and nitric acids
(D) perchloric and sulfuric acids

5. The solubility of a solid in H_2O at different temperatures is indicated in the accompanying diagram. What mass of the solid will crystallize when 40. mL of a solution that is saturated at $80^\circ C$ is cooled to $20^\circ C$?



- (A) 12 g (B) 24 g (C) 30 g (D) 36 g

6. A student is asked to determine the degree of hydration of a salt by finding the mass of a clean dried crucible and lid followed by the mass of the crucible and lid containing a sample of the salt. The crucible, lid and salt are heated in a Bunsen burner flame, cooled, and weighed. If the crucible, lid and salt are heated only once instead of the recommended three times, what will be the effect on the degree of hydration compared with the actual value?

- (A) too high (B) too low
(C) unaffected (D) impossible to predict

7. Which is the net ionic equation for the reaction when 0.10 M solutions of silver nitrate and sodium sulfide are mixed?

- (A) $Ag^+(aq) + S^{2-}(aq) \rightarrow AgS(s)$
(B) $Ag^2+(aq) + S^{2-}(aq) \rightarrow AgS(s)$
(C) $Ag^2+(aq) + S^{2-}(aq) \rightarrow AgS_2(s)$
(D) $Ag^+(aq) + S^{2-}(aq) \rightarrow Ag_2S(s)$

8. Magnetite, which has the formula Fe_3O_4 , is comprised of iron(II) oxide and iron(III) oxide. What is the ratio of iron(II) ions to iron(III) ions in magnetite?

- (A) 1:1 (B) 1:2 (C) 2:3 (D) 3:2

9. $C_3H_8 + 5O_2 \rightarrow 3CO_2 + 4H_2O$
What is the total mass, in grams, of products when 2.20 g of propane is burned in excess oxygen?

- (A) 2.20 (B) 3.60 (C) 6.60 (D) 10.2

10. What volume, in mL, of concentrated sulfuric acid (18.0 M H_2SO_4) is needed to prepare 2.50 L of a 1.00 M solution?

- (A) 7.20 (B) 14.4 (C) 69.4 (D) 139

11. The bromide impurity in a 2.00 g sample of a metal nitrate is precipitated as silver bromide. If 6.40 mL of 0.200 M $AgNO_3$ solution is required, what is the mass percentage of bromide in the sample?

- (A) 1.28 (B) 2.56 (C) 5.11 (D) 9.15

12. Under which conditions is the solubility of oxygen gas in water the greatest?

Pressure Temperature

- (A) high high
 (B) high low
 (C) low high
 (D) low low
13. Which pure compounds form intermolecular hydrogen bonds?

I. HF
II. H ₂ S
III. CH ₄

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

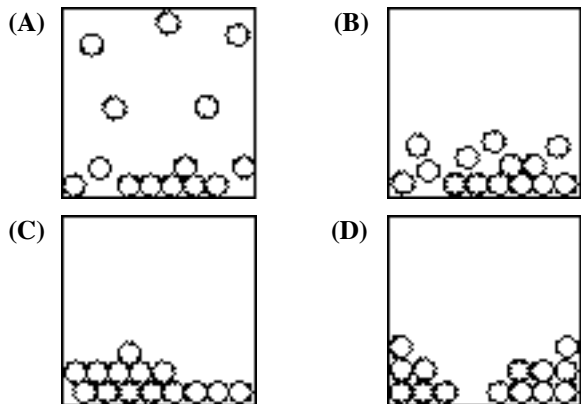
14. What is the molar mass of a gas if 10.0 grams of it occupy 4.48 liters at 273 K and 101.3 kPa (1.00 atm)?

- (A) 2.00 g/mol (B) 25.0 g/mol
 (C) 50.0 g/mol (D) 100. g/mol

15. Which process requires the greatest amount of energy for 1 mole of H₂O?

- (A) breaking the O-H bonds (B) melting
 (C) evaporating (D) subliming

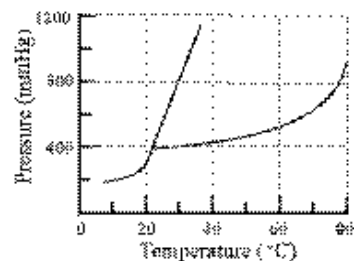
16. If the circles represent molecules, which diagram provides the best molecular level representation of a pure solid in the process of melting?



17. Which substance boils at the highest temperature?

- (A) CH₃Cl (B) CH₂Cl₂
 (C) CHCl₃ (D) CCl₄

18. What can be concluded about the substance represented by this phase diagram?



- (A) The normal boiling point of the liquid is 80 °C.
 (B) The solid is more dense than the liquid.
 (C) The solid sublimates at temperatures above 20 °C.
 (D) The vapor can be converted to liquid by compressing it at temperatures below 20 °C.

19. A chemical reaction is carried out twice with the same quantity of reactants to form the same products but the pressure is different for the two experiments. Which does not change?

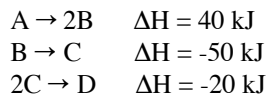
- (A) K_p (B) heat released
 (C) ΔT_{surroundings} (D) work done

20. Which of these conversions has a positive ΔS°?

I. combustion of charcoal
II. condensation of Br ₂ (g)
III. precipitation of AgCl(s)

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

21. Given these reactions:



Calculate ΔH for the reaction; D + A → 4C.

- (A) -100 kJ (B) -60 kJ
 (C) -40 kJ (D) 100 kJ

22. Hydrazine, N₂H₄, contains a N-N single bond and 4 N-H bonds. Use bond energies to calculate ΔH in kJ for the reaction;

Bond Energies (kJ·mol ⁻¹)	
H-H	436
N-H	389
N-N	159
N=N	418
N≡N	941

- N₂ + 2H₂ → N₂H₄.
 (A) -425 kJ (B) -98 kJ (C) 98 kJ (D) 425 kJ

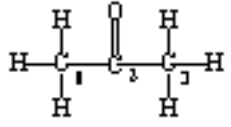
23. An ice cube of unknown mass at 0 °C is added to 265 g of H₂O at 25.00 °C in a

Properties of Water	
C _p	4.18 J·g ⁻¹ ·K ⁻¹
ΔH _{fusion}	333 J·g ⁻¹

calorimeter. If the final temperature of the resulting H₂O is 21.70 °C, what is the mass of the ice cube?

- (A) 2.47 g (B) 8.63 g (C) 10.3 g (D) 11.0 g

24. Which reaction is spontaneous at all temperatures at standard pressure and concentration?
- (A) exothermic reaction with a decrease in entropy
 (B) exothermic reaction with an increase in entropy
 (C) endothermic reaction with a decrease in entropy
 (D) endothermic reaction with an increase in entropy
25. When 100. mL of 1.0 M HCl is added to a 2.0 g piece of CaCO₃, CO₂ is produced at a certain rate. Which of the changes below will NOT increase the rate of this reaction?
- (A) adding 100. mL of 2.0 M HCl in place of 100. mL of 1.0 M HCl
 (B) heating the 100. mL of 1.0 M HCl before adding it to the CaCO₃
 (C) adding 100. mL of 1.0 M HCl to 2.0 g of powdered CaCO₃
 (D) adding 150. mL of 1.0 M HCl in place of 100. mL of 1.0 M HCl
26. $2\text{N}_2\text{H}_4(\text{g}) + \text{N}_2\text{O}_4(\text{g}) \rightarrow 3\text{N}_2(\text{g}) + 4\text{H}_2\text{O}(\text{g})$
 If N₂H₄(g) disappears at a rate of 0.12 mol·L⁻¹·min⁻¹, at what rate does N₂(g) appear?
- (A) 0.080 mol·L⁻¹·min⁻¹ (B) 0.12 mol·L⁻¹·min⁻¹
 (C) 0.18 mol·L⁻¹·min⁻¹ (D) 0.36 mol·L⁻¹·min⁻¹
27. Use the data to determine the orders of A and B in the reaction; A + B → products
- | Experiment | [A], mol·L ⁻¹ | [B], mol·L ⁻¹ | rate, mol·L ⁻¹ ·s ⁻¹ |
|------------|--------------------------|--------------------------|--|
| 1 | 0.10 | 0.10 | 0.0090 |
| 2 | 0.20 | 0.10 | 0.036 |
| 3 | 0.10 | 0.20 | 0.018 |
- (A) Rate = k[A][B] (B) Rate = k[A]²[B]
 (C) Rate = k[A][B]² (D) Rate = k[A]²[B]²
28. $2\text{NO}(\text{g}) + \text{Cl}_2(\text{g}) \rightarrow 2\text{NOCl} \quad \Delta\text{H} = -38 \text{ kJ}$
 If the activation energy for the forward reaction is 62 kJ, what is the activation energy for the reverse reaction?
- (A) 24 kJ (B) 38 kJ (C) 62 kJ (D) 100 kJ
29. What is the order of a reaction if the rate constant has the units L·mol⁻¹·s⁻¹?
- (A) zero (B) first
 (C) second (D) third
30. An iron catalyst is used in the Haber process in which gaseous N₂ and H₂ react to produce NH₃. What is the role of this catalyst?
- (A) It provides a pathway with a lower activation energy.
 (B) It increases the equilibrium constant of the reaction.
 (C) It raises the kinetic energies of the reactants.
 (D) It interacts with the NH₃.
31. $2\text{NO}_2(\text{g}) + 7\text{H}_2(\text{g}) \rightleftharpoons 2\text{NH}_3(\text{g}) + 4\text{H}_2\text{O}(\text{l})$
 What is the correct equilibrium expression for this reaction?
- (A) $K_c = \frac{[\text{NH}_3]^2}{[\text{NO}_2]^2[\text{H}_2]^7}$ (B) $K_c = \frac{[\text{NO}_2]^2[\text{H}_2]^7}{[\text{NH}_3]^2}$
 (C) $K_c = \frac{[\text{NH}_3]^2[\text{H}_2\text{O}]^4}{[\text{NO}_2]^2[\text{H}_2]^7}$ (D) $K_c = \frac{[\text{NH}_3]^2[\text{H}_2\text{O}]^4}{[\text{NO}_2]^2}$
32. $\text{N}_2\text{O}_4(\text{g}) \rightleftharpoons 2\text{NO}_2(\text{g})$
 The equilibrium reaction shown is endothermic as written. Which change will increase the amount of NO₂ at equilibrium?
- (A) adding a catalyst
 (B) decreasing the temperature
 (C) increasing the volume of the container
 (D) adding an inert gas to increase the pressure
33. Which weak acid has the strongest conjugate base?
- (A) acetic acid ($K_a = 1.8 \times 10^{-5}$)
 (B) formic acid ($K_a = 1.8 \times 10^{-4}$)
 (C) hydrofluoric acid ($K_a = 6.8 \times 10^{-4}$)
 (D) propanoic acid ($K_a = 5.5 \times 10^{-5}$)
34. What is the pH of a 0.20 M HA solution ($K_a = 1.0 \times 10^{-6}$) that contains 0.40 M NaA?
- (A) 3.15 (B) 3.35 (C) 5.70 (D) 6.30
35. A 0.1 M solution of which salt will have a pH less than 7?
- (A) NaCl (B) NH₄Br
 (C) KF (D) NaO₂CCH₃

36. What is the $[Mg^{2+}]$ in 0.10 M NaF that is saturated with MgF_2 at 25 °C?
- | | |
|----------|----------------------|
| K_{sp} | |
| MgF_2 | 6.4×10^{-9} |
- (A) 0.050 M (B) 1.9×10^{-3} M
(C) 1.2×10^{-3} M (D) 6.4×10^{-7} M
37. Which change represents an oxidation?
- (A) $NO_2^- \rightarrow N_2$ (B) $VO^{2+} \rightarrow VO_3^-$
(C) $ClO^- \rightarrow Cl^-$ (D) $CrO_4^{2-} \rightarrow Cr_2O_7^{2-}$
38. What is the oxidation number of Mo in MoO_2Cl_2 ?
- (A) 0 (B) +3 (C) +5 (D) +6
39. What is the coefficient for H^+ when the half equation is balanced with the smallest whole number coefficients?
- $$_ S^{2-} + _ H_2O \rightarrow _ SO_2 + _ H^+ + _ e^-$$
- (A) 2 (B) 4 (C) 6 (D) 8
40. What is the E° value for the voltaic cell constructed from the half-cells?
- | | |
|---------------------------------|--------|
| E° (V) | |
| $Zn^{2+} + 2e^- \rightarrow Zn$ | -0.762 |
| $Tl^+ + e^- \rightarrow Tl$ | -0.336 |
- (A) 0.090 V (B) 0.426 V
(C) 1.098 V (D) 1.434 V
41. Which is a consistent set of values for a specific redox reaction carried out under standard conditions?
- | E° | ΔG° | description |
|-----------|------------------|----------------|
| (A) + | - | spontaneous |
| (B) - | + | spontaneous |
| (C) + | + | nonspontaneous |
| (D) - | - | nonspontaneous |
42. During the electrolysis of a dilute solution of sulfuric acid, what substance is produced at the anode?
- (A) hydrogen (B) hydrogen sulfide
(C) oxygen (D) sulfur dioxide
43. Which metal is the most reactive?
- (A) silver (B) lead
(C) iron (D) cesium
44. Which element has the largest first ionization energy?
- (A) Li (B) B (C) N (D) Na
45. All of the energy levels listed are allowed EXCEPT
- (A) 3f. (B) 4d. (C) 5p. (D) 7s.
46. A sulfur atom has the electron configuration: $1s^2 2s^2 2p^6 3s^2 3p^4$. How many orbitals in this ground state atom are occupied by at least one electron?
- (A) 12 (B) 9 (C) 8 (D) 5
47. The shapes of s and p orbitals are determined by which quantum number(s)?
- | |
|---------------------|
| I. n |
| II. l |
| III. m _l |
- (A) I only (B) II only
(C) III only (D) II and III only
48. What are the elements called for which the 4f subshell is being filled?
- (A) transition metals (B) metalloids
(C) lanthanides (D) actinides
49. Which ionic compound has the smallest lattice energy?
- (A) NaF (B) MgO (C) AlN (D) $MgCl_2$
50. Which species have one or more atoms that violate the octet rule?
- | |
|---------------|
| I. NO |
| II. SF_2 |
| III. PF_4^+ |
- (A) I only (B) III only
(C) I and II only (D) II and III only
51. In which species is the carbon-nitrogen bond the shortest?
- (A) CH_3NH_2 (B) CH_2NH
(C) $(CH_3)_4N^+$ (D) CH_3CN
52. In which species is resonance most useful in explaining the observed bond lengths?
- (A) NF_3 (B) NH_4^+ (C) NO_2^+ (D) NO_2^-
53. Which description best represents the hybridization of the C_1 and C_2 atoms?
- 
- (A) $C_1 - sp^2, C_2 - sp^2$
(B) $C_1 - sp^3, C_2 - sp^3$
(C) $C_1 - sp^3, C_2 - sp^2$
(D) $C_1 - sp^2, C_2 - sp$

-
-
54. Polar molecules include which of those listed?
- | |
|--------------------------------------|
| I. CO_2 |
| II. COCl_2 |
| III. CH_2Cl_2 |
- (A) **I** only (B) **I** and **II** only
(C) **I** and **III** only (D) **II** and **III** only

55. Which is an example of an aromatic compound?
- (A) acetylene (B) benzene
(C) polyethylene (D) propanone

56. Which can exist as geometric isomers?
- (A) 1,1-dichloroethane (B) 1,1-dichloroethene
(C) 1,2-dichloroethane (D) 1,2-dichloroethene

57. Which substance is formed when $\text{K}_2\text{Cr}_2\text{O}_7$ is added to $\text{C}_2\text{H}_5\text{OH}$ in acid solution?
- (A) C_2H_6 (B) CH_3COOH
(C) $\text{K}^+\text{C}_2\text{H}_5\text{O}^-$ (D) $\text{C}_2\text{H}_5\text{OC}_2\text{H}_5$

58. Which functional group, present in simple sugars, is responsible for their high solubility in water?
- (A) $-\text{OH}$ (B) $-\text{COOH}$
(C) $-\text{CONH}_2$ (D) $-\text{NH}_2$

59. Which family of compounds is used most frequently as flavoring agents?
- (A) acids (B) alkenes
(C) esters (D) ethers

60. In addition to carbon, hydrogen and oxygen, which element is found in all amino acids?
- (A) chlorine (B) nitrogen
(C) phosphorus (D) sulfur

END OF TEST

**National Chemistry Olympiad
LOCAL SECTION EXAM 2006
KEY**

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