

GS-2016 (Chemistry)**TATA INSTITUTE OF FUNDAMENTAL RESEARCH**Written Test in **CHEMISTRY - December 13, 2015**

Duration : Three hours (3 hours)

Name : _____ Ref. Code : _____

Please read all instructions carefully before you attempt the questions.

1. Please fill-in details about name, reference code etc. on the answer sheet. The Answer Sheet is machine-readable. Use only Blue/Black ball point pen to fill-in the answer sheet.
2. Indicate your ANSWER ON THE ANSWER SHEET by blackening the appropriate circle for each question. Do not mark more than one circle for any question : this will be treated as a wrong answer.
3. This is a multiple choice question paper with **ONE** section having a total of 40 questions. Each correct answer will get you 3 marks. Every wrong answer will get you -1 mark. Marks are not awarded or deducted when a question is not attempted. It is better not to answer a question if you are not sure.
4. We advise you to first mark the correct answers on the QUESTION PAPER and then to TRANSFER these to the ANSWER SHEET only when you are sure of your choice.
5. Rough work may be done on blank pages of the question paper. If needed, you may ask for extra rough sheets from an invigilator.
6. **Use of calculators is permitted. Calculator which plots graphs is NOT allowed. Multiple-use devices such as cell phones, smart phones etc., CANNOT be used for this purpose.**
7. Do NOT ask for clarifications from the invigilators regarding the questions. They have been instructed not to respond to any such inquiries from candidates. In case a correction/clarification is deemed necessary, the invigilator(s) will announce it publicly.

SOME USEFUL DATA

Avogadro number = $6.02 \times 10^{23} \text{ mol}^{-1}$

$RT/F = 0.0257 \text{ V}$ at 25°C

Faraday constant = 96500 C/mol

Boltzmann constant $k = 1.38 \times 10^{-23} \text{ J K}^{-1}$

$E_n = -\frac{Z^2}{2n^2}$ a.u. for hydrogen-like atoms

Mass of an electron = $9.109 \times 10^{-31} \text{ kg}$

Average velocity = $\sqrt{\frac{8kT}{\pi m}}$

$e = 1.6 \times 10^{-19} \text{ C}$

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

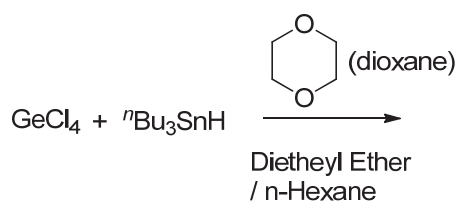
$c = 3 \times 10^8 \text{ m s}^{-1}$

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

1) In a 1 g diamond crystal, a scientist wants to replace a few of the carbon atoms with nitrogen atoms. Which of the following statements best describes the resulting material?

- A) This is not possible as nitrogen has a coordination number of 3 and carbon has a coordination number of 4
- B) The resulting material will NOT have a cubic diamond structure
- C) The resulting material will be a defective diamond as it will be *p*-doped
- D) The resulting material can be characterized as *n*-doped diamond ✓

2) What is the product of the following reaction?



(A) HGeCl_3

(B) $\text{Cl}_2\text{Ge:Dioxane}$ ✓

(C) $\text{Cl}_3\text{Ge-Sn}^n\text{Bu}_3$

(D) none of the above

3) A long column of water in any transparent bottle appears slightly blue. However if we replace water with heavy water (D₂O) it will look more transparent. This effect is due to:

- A) Rayleigh Scattering
- B) Kinetic Isotope effects
- C) Absorption spectra of H₂O and D₂O are different ✓
- D) None of the above

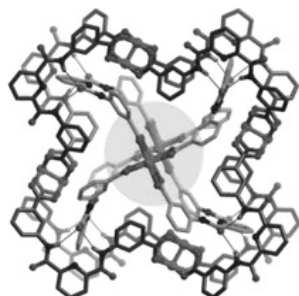
4) The integral $\int_{-a}^a \cos(x) \sin(x) dx$

- A) Equals to zero for any value of a , and $\cos(x)$ is symmetric in the range of the integral ✓
- B) Is not equal to zero except for certain values of a , and $\sin(x)$ is antisymmetric in the range of the integral
- C) Is not equal to zero except for certain values of a , and $\cos(x)$ is symmetric in the range of the integral
- D) Has a non-zero value depending on a

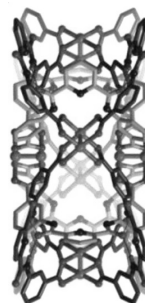
5) Which of the following statements is the best definition of the **base peak** in a mass spectrum?

- A) The molecular ion peak
- B) The lowest m/z peak
- C) The highest mass rearrangement ion
- D) The ion peak of greatest intensity ✓

6) Shown below are the front and side views of the structure a molybdenum-based metal organic polyon. What is the symmetry of the molecule?



Front view



Side view

- A) D_{4h}
- B) C_{4h} ✓
- C) C_{2v}
- D) C₄

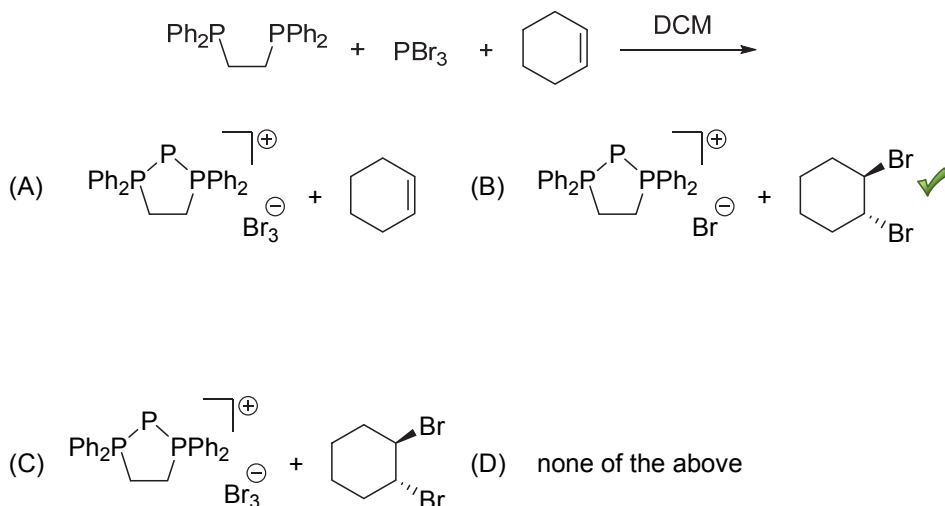
7) Which of the following is/are implied by the second law of thermodynamics?

- A) $\Delta S > \int_A^B dq(\text{irreversible})/T$ for an irreversible process $A \rightarrow B$ at temperature T
- B) $\Delta S > 0$ for an isolated system in the course of a spontaneous change
- C) Entropy of the universe always tends to maximum
- D) All of the above ✓

- 8) A protein has three folded states F_1, F_2, F_3 and three unfolded states U_1, U_2, U_3 . Consider transitions between configurations $T_{i \rightarrow f}$ where the initial (i) and final (f) configurations each comprise of simple additive combinations of purely folded (e.g. $F_1, F_1+F_2, F_1+F_2+F_3$) or unfolded states (e.g. $U_1, U_1+U_2, U_1+U_2+U_3$). Transitions between folded (or unfolded) configurations are also allowed unless a state is part of both the initial and final configurations. Assuming $T_{i \rightarrow f} = T_{f \rightarrow i}$ the total number of distinct transitions are:

- A) 61 ✓ B) 49 C) 73 D) 9

- 9) What is the product of the following reaction?



- 10) The specific heat of a certain material monotonically increases with temperature. Two identical blocks of this material are kept at 50°C and 100°C , respectively. The two blocks are now brought in contact with each other. Assume that no heat is lost to the surrounding. When thermal equilibrium is reached after the two blocks are kept in contact, what would be the final temperature of the two blocks?

- A) 75°C B) $> 75^\circ\text{C}$ ✓ (C) $< 75^\circ\text{C}$
 D) T_f can be either more than or less than 75°C , depending upon the precise variation of the specific heat with temperature

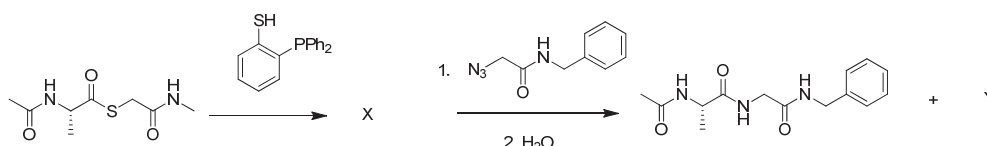
- 11) A carpenter claims to have made a rectangular parallelepiped (cuboid), the length of whose three face diagonals are 33, 56 and 65 meters. You are required to determine the length the main diagonal joining a pair of opposite corners of this parallelepiped.

- A) $65\sqrt{2}$ meters B) $65/\sqrt{2}$ meters C) 65 meters
 D) It is not possible to make a rectangular parallelepiped with the claimed dimensions of the three faces ✓

12) For a canonical ensemble where each system has N , V , T fixed, which of the following statements regarding energy hold(s) true:

- A) Energy of the system does not fluctuate
- B) At thermodynamic limit (large N) the fluctuation in energy is extremely narrow ✓
- C) At thermodynamic limit (large N), the fluctuation in energy is extremely broad
- D) All of the above

13) Predict the products X and Y of the following peptide ligation reaction.



- | | X | Y |
|----|---|---|
| A) | | |
| B) | | |
| C) | | |
| D) | | |

14) Neopentyl chloride, $(\text{CH}_3)_3\text{CCH}_2\text{Cl}$, reacts with a strong base (sodium amide) to produce a new compound. This compound has two ^1H NMR singlets at δ 0.20 ppm & δ 1.05 ppm (intensity ratio = 2:3). What is the most probable structure of this compound?

- A) 2-methyl-2-butene
- B) 1,1-dimethylcyclopropane ✓
- C) methylcyclobutane
- D) cyclopentane

15) The ^1H NMR of 1,1-dibromoethane consists of two well-separated signals, one large and another one small. Which one of the following statements is correct?

- A) The large signal is a quartet and the small signal is a doublet
- B) The large signal is a triplet and the small signal is a singlet
- C) The large signal is a singlet and the small signal is a triplet
- D) The large signal is a doublet and the small signal is a quartet ✓

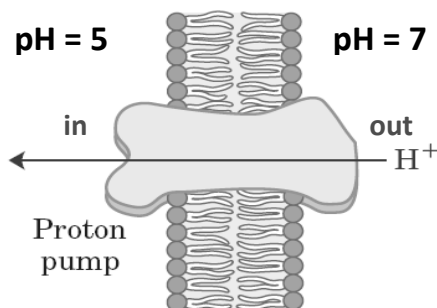
16) For an ideal gas in a closed system at constant temperature T , what are the values of $\frac{\partial U}{\partial V}$ and $\frac{\partial H}{\partial p}$?

- A) $\frac{\partial U}{\partial V} = 0$ and $\frac{\partial H}{\partial p} = 0$ ✓
- B) $\frac{\partial U}{\partial V} > 0$ and $\frac{\partial H}{\partial p} < 0$
- C) $\frac{\partial U}{\partial V} < 0$ and $\frac{\partial H}{\partial p} > 0$
- D) $\frac{\partial U}{\partial V} > 0$ and $\frac{\partial H}{\partial p} > 0$

17) The reaction of nitric oxide with oxygen gas is given by $\text{NO} + \text{O}_2 \rightarrow \text{NO}_2$. When 25 g of NO is allowed to react with 12 g of oxygen gas, the maximum amount of NO_2 formed will be

- A) 38.3 g
- B) 17.3 g
- C) 34.5 g ✓
- D) None of these

18) Proton pumps are ubiquitous in living organisms. They (shown in below figure) serve as an important regulator of pH gradients across membranes, which lead to ATP synthesis. Calculate the amount of CHEMICAL work done at temperature T by such a pump to maintain $\text{pH} = 5$ inside the cellular compartment against a neutral pH outside the membrane?



- A) $2 RT$
- B) $2.303 RT$
- C) $4.606 RT$ ✓
- D) $23.03 RT$

19) Which of following observations reflect colligative properties?

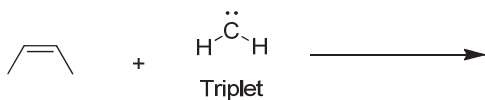
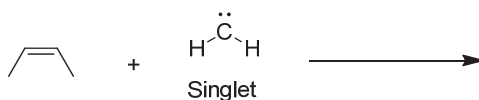
- i. A 0.5 M NaCl solution has a higher vapor pressure than a 0.5 M BaCl₂ solution.
- ii. A 0.5 M NaOH solution freezes at a lower temperature than pure water.
- iii. Pure water freezes at a higher temperature than pure methanol.

- A) i and ii only ✓
- B) i and iii only
- C) ii and iii only
- D) i, ii and iii

20) $ABCD$ is a rectangle of area 50 m^2 . The mid-points AB , BC and AD are E , F and G , respectively. When EF is extended, it meets extended DC at H . Similarly, when EG is extended, it meets extended CD at J . What is the area of the triangle EHJ ?

- A) 50 m^2 ✓
- B) 100 m^2
- C) 200 m^2
- D) The area cannot be determined without knowing the length and breadth of the rectangle

21) Predict the products of the following reactions between *cis*-2-butene and singlet and triplet methylenes.



Singlet

Triplet

A)



B)



C)



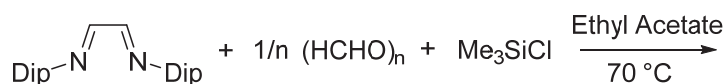
D)



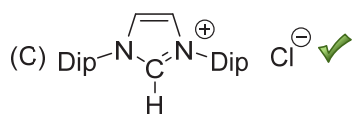
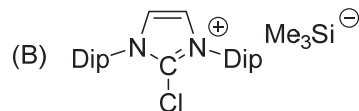
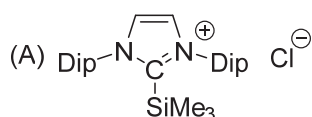
22) Consider an electron with energy E and mass M tunneling through a barrier of height $V > E$ and width W . The total time the electron spends inside the barrier is:

- A) $\frac{\hbar}{V-E}$ ✓ B) $W \times \sqrt{\frac{2M}{E}}$ C) $\sqrt{\frac{2M(V-E)}{\hbar}}$ D) $\sqrt{\frac{4M^2(V-E)}{\hbar E}}$

23) What is the product of the following reaction?



Dip = 2,6-diisopropylphenyl



(D) none of the above

24) A doubly ionized lithium atom in an excited state ($n = 6$) emits a photon of energy 4.25 eV. What are the quantum number (n) and the energy (E) of the final state?

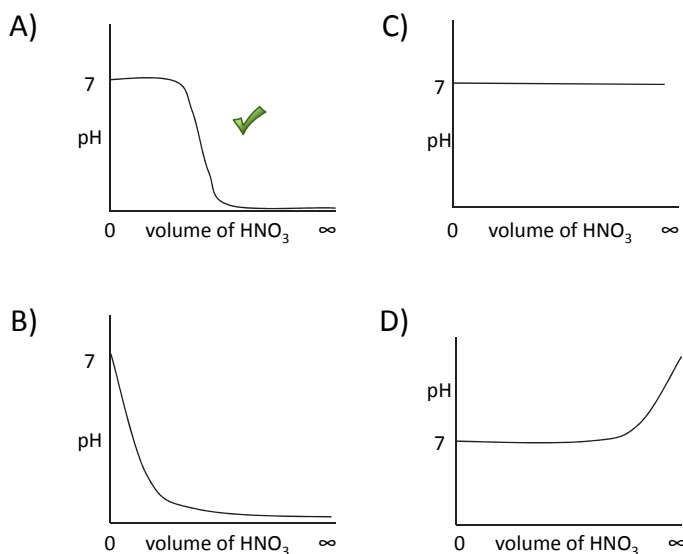
- A) $n = 2, E = -30.6 \text{ eV}$
 B) $n = 3, E = -13.6 \text{ eV}$
 C) $n = 4, E = -7.65 \text{ eV}$ ✓
 D) $n = 5, E = -4.90 \text{ eV}$

25) Which of the following can be labelled as a colloid?

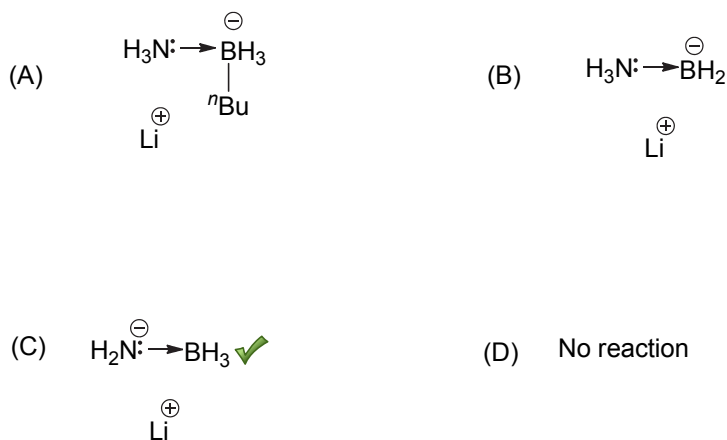
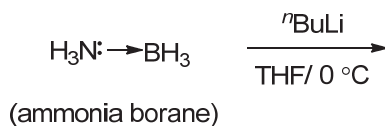
- i. A mixture of water and ethanol
- ii. Milk
- iii. Clouds
- iv. Gemstones

- A) (i), (ii) and (iii) only
 B) (ii) and (iii) only
 C) (ii), (iii) and (iv) only ✓
 D) All of the above

26) A beaker contains 10 mL of dilute buffer solution of pH 7. To this, dilute solution of HNO_3 is added continuously and the pH is measured. Which of the following graphs will be representative to show how the pH varies on addition of HNO_3 ?



27) What is the product of the following reaction?



28) Equal volumes of two metals of densities d_1 and d_2 are mixed together. The density of the resulting alloy is given by:



- 29) A $C_5H_{12}O_2$ compound has strong infrared absorption at 3300 to 3400 cm^{-1} . The 1H NMR spectrum has three singlets at δ 0.9, δ 3.45 and δ 3.2 ppm with relative areas 3:2:1. Addition of D_2O to the sample eliminates the lower field signal. The ^{13}C NMR spectrum shows three signals all at higher field than δ 100 ppm. Which of the following compounds best fits this data?
- A) 1,5-pentanediol
 - B) 1,3-dimethoxypropane
 - C) 2,2-dimethyl-1,3-propanediol ✓
 - D) 2,4-pentanediol
- 30) The 1H NMR spectrum of a compound A shows a doublet and a septet. Which one of the following statements is true?
- A) The spectrum is consistent with A containing a $CH_3CH_2CH_2$ group
 - B) The spectrum is consistent with A being $(CH_3)_2CHCl$ ✓
 - C) The spectrum is consistent with A containing a CH_3CH_2 group
 - D) The spectrum is consistent with A being $(CH_3)_2CCl_2$
- 31) What is the molecular mass (M) of a compound that has a concentration $w = 1.2$ g/L and an osmotic pressure of $\Pi = 0.20$ atm at $T = 300$ K?
- A) $M = 576$ g/mol
 - B) $M = 3876$ g/mol
 - C) $M = 147$ g/mol ✓
 - D) $M = 9818$ g/mol
- 32) In a face centered arrangement of A and B atoms. Where A atoms are at the corners of the unit cell and B atoms are at the face centers. For each unit cell, one A atom is missing from a corner position and one B atom is missing from one face position. The simplest formula of the resulting compound will be:
- A) $A_{14}B_{40}$
 - B) A_7B_{20} ✓
 - C) $A_{1-x}B_{3-x}$
 - D) AB_2
- 33) For a binary mixture of ideal gas, free energy of mixing is given by $\Delta G_{mix} = nRT(x \ln x + (1 - x) \ln(1 - x))$, where x is the mole fraction of one of the components. What are the enthalpy and entropy of mixing of this system?
- A) $\Delta H_{mix} > 0$ and $\Delta S_{mix} > 0$
 - B) $\Delta H_{mix} < 0$ and $\Delta S_{mix} < 0$
 - C) $\Delta H_{mix} = 0$ and $\Delta S_{mix} > 0$ ✓
 - D) $\Delta H_{mix} > 0$ and $\Delta S_{mix} = 0$

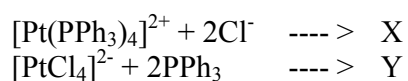
34) Far infrared and microwave radiation is useful in studying the following process

- A) Transition of inner electrons of atoms
- B) Transitions of outer (or valence) electrons in atoms or molecules
- C) Changes in vibrational-rotational states of molecules
- D) Changes in molecular rotational states only ✓

35) A compound of formula C_5H_{12} gives one signal in the 1H NMR and two signals in the ^{13}C NMR spectra. The compound is

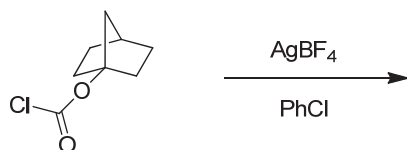
- A) pentane
- B) 2-methylbutane
- C) 2,2-dimethylpropane ✓
- D) cannot tell without more information

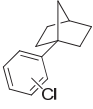

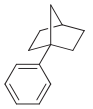
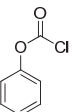
36) Predict the products of the following reactions:



- A) X = *trans*-[PtCl₂(PPh₃)₂] and Y = *cis*-[PtCl₂(PPh₃)₂]
- B) X = *cis*-[PtCl₂(PPh₃)₂] and Y = *trans*-[PtCl₂(PPh₃)₂] ✓
- C) X = Y = *cis*-[PtCl₂(PPh₃)₂]
- D) X = Y = *trans*-[PtCl₂(PPh₃)₂]

37) Predict the products of the following reaction.



- A)  + CO₂ ✓
- B)  + AgCl
- C)  + BF₃
- D)  + HF

- 38) A set of N vectors $\mathbf{X}_1, \mathbf{X}_2, \dots, \mathbf{X}_N$ satisfy the eigenvalue equation for an operator A with scalar eigenvalues $\lambda_1, \lambda_2, \dots, \lambda_N$ (i.e., $A \mathbf{X}_k = \lambda_k \mathbf{X}_k$). The linear combination vector $\mathbf{X} = \sum_{k=1}^N C_k \mathbf{X}_k$, where C_k 's are non-zero scalar coefficients
- A) is not an eigenvector of A
 - B) is an eigenvector of A only if the λ_k 's are all distinct (no two eigenvalues are equal)
 - C) is an eigenvector of A only if the λ_k 's are all equal ✓
 - D) is an eigenvector of only if C_k 's are equal
- 39) What is the value of $i^{(i+2)}$, where $i = \sqrt{-1}$
- A) Real number ✓
 - B) Complex number
 - C) Cannot be calculated
 - D) None of the above
- 40) Chemical oxidation of water to produce O_2 gas is an energy demanding reaction, done routinely by plants using the process called photosynthesis. By how many eV will it be uphill if the water oxidation reaction be carried out at $\text{pH} = 0$ versus at $\text{pH} = 7.0$?
- A) 0.41 eV ✓
 - B) -1.6 eV
 - C) -0.41 eV
 - D) Cannot be calculated based on the data given

The following question does NOT carry any marks and is given to collect information only:

- 41) How much time did you take to complete this chemistry exam?
- A) Less than 1 hour
 - B) Between 1 to 2 hours
 - C) Between 2 to 3 hours
 - D) Insufficient time was given