

GS-2017 (Chemistry)

TATA INSTITUTE OF FUNDAMENTAL RESEARCHWritten Test in **CHEMISTRY - December 11, 2016**

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. In answering the questions, please choose the option that best describes the solution to the problem.
8. 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 $k = 1.38 \times 10^{-23} \text{ J K}^{-1}$

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

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

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

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

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

1) For a hydrogen atom, which of the following orbital(s) have the lowest energy:

A) $4s$

B) $4p$

C) $4d$

✓ D) All of the above have same energy

2) Given an operator A and a set of vectors \mathbf{X} which obey the following relationship

$$A\mathbf{X} = \lambda\mathbf{X},$$

where λ is the set of scalars. If A commutes with B and $B \neq A$, which of the following is correct:

A) \mathbf{X} are eigenvectors of A only if the λ are all distinct (no two eigenvalues are equal)

✓ B) \mathbf{X} are eigenvectors of B

C) \mathbf{X} are eigenvectors of B with set of eigenvalues λ

D) \mathbf{X} need not be eigenvectors of A

3) The non-bonded interactions between two molecules consist of electrostatic (El) and van der Waals (vdW) forces. Which of the following is a correct description of the distance dependence intermolecular interactions between two molecules?

A) At large distances, El interactions decay faster than the vdW interactions

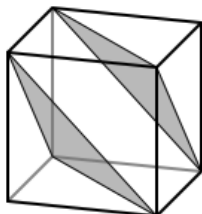
✓ B) At large distances, vdW interactions decrease faster than the El interactions

C) Which force drops faster depends on the net charge of the molecules

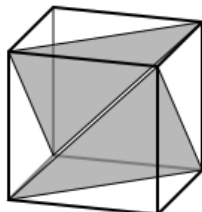
D) Both interactions have same distance dependence

4) In a cubic unit cell, identify the Miller plane (111)

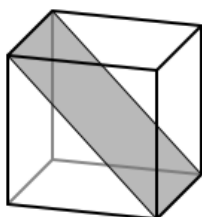
✓ A)



B)

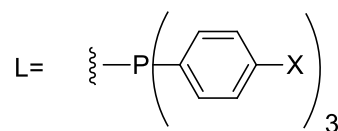
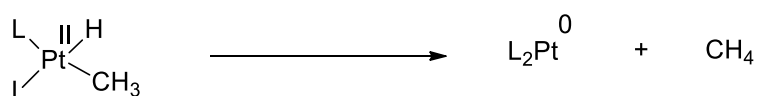


C)



D) None of the above

5) Predict the relative rates for the following reductive elimination for X = H, Cl, CH₃, OCH₃



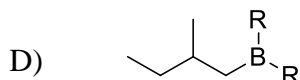
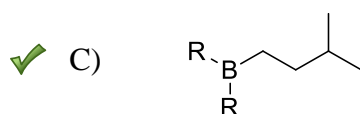
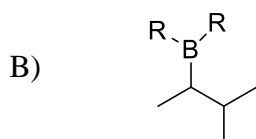
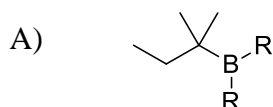
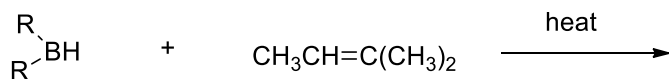
✓ A) Cl > H > CH₃ > OCH₃

B) H > Cl > OCH₃ > CH₃

C) OCH₃ > CH₃ > H > Cl

D) CH₃ > H > Cl > OCH₃

6) Predict the major product of the following hydroboration reaction:



7) Predict the multiplicities for hydrogens on C1, C3, and C4 of butanone associated with the spin-spin coupling in its ^1H NMR spectrum.

A) H's on C1: *Singlet*; H's on C3: *Doublet*; H's on C4: *Triplet*

B) H's on C1: *Singlet*; H's on C3: *Triplet*; H's on C4: *Quartet*

✓ C) H's on C1: *Singlet*; H's on C3: *Quartet*; H's on C4: *Triplet*

D) H's on C1: *Triplet*; H's on C3: *Doublet*; H's on C4: *Triplet*

8) All natural amino acids, except one, react with cold nitrous acid and produce nitrogen gas. Which one of the following is that odd amino acid?

A) Tryptophan

B) Glycine

✓ C) Proline

D) Histidine

9) Zinc solid has hcp (hexagonal close packed) structure. In a unit cell of solid Zinc, the Zinc atoms occupy

✓ A) 74% of volume of unit cell.

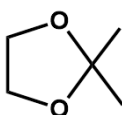
B) 80% of volume of unit cell.

C) 68% of volume of unit cell.

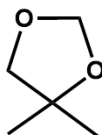
D) 90% of volume of unit cell.

10) An organic compound has the following spectroscopic properties: Mass Spectrometry: m/z 102 (very small), 87 & 43 are the largest ions; ^1H NMR: δ 1.4 & 3.9 ppm (both singlets, intensity ratio 3:2); ^{13}C NMR: δ 108, 64 & 25 ppm; Infrared spectroscopy: several strong absorptions in the 1000 to 1300 cm^{-1} region. Which of the following is the most likely formula of this compound?

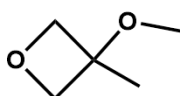
✓ A)



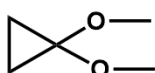
B)



C)



D)



11) An electron tunnels through a square barrier of width d and height h . If h is fixed and d is normally distributed, then the electron transfer probability distribution is:

A) a normal distribution

B) a delta function

✓ C) a log normal distribution

D) a poisson distribution

12) In a rotational microwave spectrum of $C^{12}O^{16}$ lines were equally spaced by 3.863 cm^{-1} . In a rotational Raman spectrum of N_2 (normal isotope) the lines were equally spaced by 8.04 cm^{-1} . Assuming that the force constant for the two molecules is inversely proportional to their bond lengths, the ratio of the vibrational frequency of CO to that of N_2 will be:

A) 0.8368

✓ B) 0.9952

C) 1.0258

D) 1.2198

13) If standard potential of the reaction $2H_2O(l) = O_2(g, 1\text{bar}) + 4H^+(aq) + 4e^-$ is $E^0 = -1.23\text{ V}$. At 25°C and $\text{pH} = 7$, what is the oxidation potential of pure water according to this reaction?

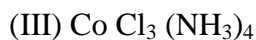
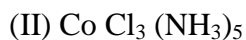
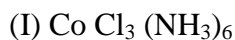
A) +0.410 V

B) -2.620 V

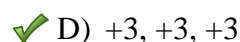
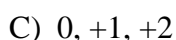
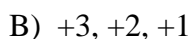
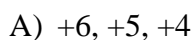
✓ C) -0.817 V

D) -0.410 V

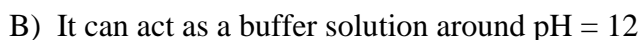
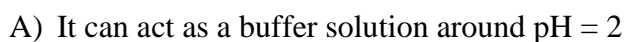
14) Given the molecular formula of the hexa-coordinated complexes



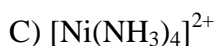
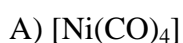
If the number of coordinated NH_3 molecules in (I), (II), and (III) respectively are 6, 5 and 4 then the oxidation state of Co in (I), (II) and (III) are respectively:



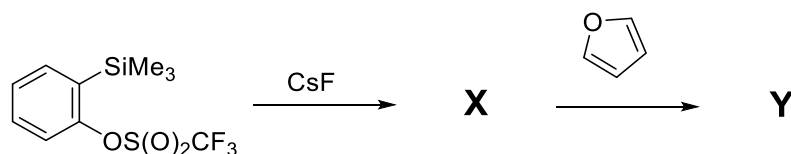
15) An aqueous solution contains $0.300 \text{ mole L}^{-1}$ of KH_2PO_4 and $0.015 \text{ mole L}^{-1}$ of K_2HPO_4 . Which of the following statements is true about this solution? [Data: For H_3PO_4 , $\text{p}K_1 = 2.16$, $\text{p}K_2 = 7.21$, $\text{p}K_3 = 12.32$]


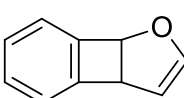

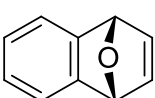

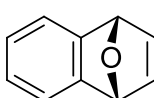

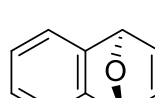


16) The complex showing a spin-only magnetic moment of 2.82 B.M. is



17) What are **X** and **Y** in the following reaction?



- A)  **X**  **Y**
- B)  **X**  **Y**
- ✓ C)  **X**  **Y**
- D)  **X**  **Y**

18) What is the value of $i \log_{10} i^2$, where $i = \sqrt{-1}$?

- A) Real and positive number
- ✓ B) Real and negative number
- C) Complex number
- D) Purely imaginary

19) Cyclooctatetraene is

- A) aromatic, because it is planar and it follows Hückel's rule
- B) antiaromatic, because it is not planar and it does not follow Hückel's rule
- C) antiaromatic, because it is planar and it does not follow Hückel's rule
- ✓ D) nonaromatic, because it is not planar and it does not follow Hückel's rule

20) What are the products of the following reaction?



- A) $\text{H}_2 + \text{Et}_3\text{N} + \text{LiCl} + \text{AlH}_3$
- B) $\text{LiH} + \text{Et}_3\text{N} + \text{HCl} + 0.5 \text{Al}_2\text{H}_6$
- ✓ C) $\text{LiCl} + \text{H}_3\text{Al}:\text{NEt}_3 + \text{H}_2$
- D) $\text{LiCl} + \text{NEt}_3 + \text{H}_2 + 0.5 \text{Al}_2\text{H}_6$

21) What is the value of the continued fraction given below?

$$1 + \frac{2000}{2 + \frac{2000}{2 + \frac{2000}{2 + \dots}}}$$

- A) 1999 B) $\sqrt{2000}$ ✓ C) $\sqrt{2001}$ D) None of them

22) A compound with molecular formula $\text{C}_5\text{H}_{12}\text{O}_2$, has strong infrared absorption at 3300 to 3400 cm^{-1} . The ^1H NMR spectrum showed three singlets at δ 0.90, δ 3.45 and δ 3.20 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 higher 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

23) For angular momentum vector operator \vec{L} , which of the following relation is true:

A) $\vec{L} \times \vec{L} = i\hbar \vec{L}^2$

✓ B) $\vec{L} \times \vec{L} = i\hbar \vec{L}$

C) $\vec{L} \times \vec{L} = -i\hbar \vec{L}$

D) $\vec{L} \times \vec{L} = 0$

24) Isotopic substitution is an often-used procedure in assigning vibrational spectroscopic features but the difference in isotopic masses of the vibrating atoms has to be sufficiently large to make the vibrational shift observable. In a double isotopic replacement experiment, a proline with a $^{13}\text{C}=\text{}^{18}\text{O}$ carbonyl group is inserted in the middle of the polypeptide using molecular recombinant techniques. Given that in the naturally found proline the $^{12}\text{C}=\text{}^{16}\text{O}$ group exhibits a narrow vibrational feature at $1,711\text{ cm}^{-1}$, what is the shift of the carbonyl stretching vibration for the $^{13}\text{C}=\text{}^{18}\text{O}$ proline isotopomer.

Assume:

- a) The force constant for different isotopes can be considered identical.
- b) The isotopic changes in the carbonyl group will have little effect on the vibrations of other atoms in proline.

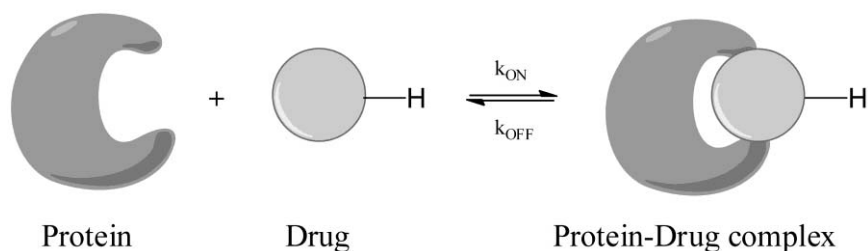
✓ A) 80 cm^{-1}

B) 165 cm^{-1}

C) 85 cm^{-1}

D) 42.5 cm^{-1}

25)



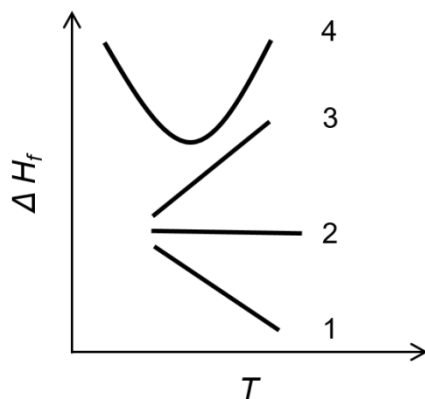
NMR spectroscopy can be used to assay for drug binding to certain protein targets. One of the primary objectives of any binding assay is the quantification of the free and the bound forms of a drug molecule at a certain concentration of the protein target. Let us assume that the fully bound drug exhibits a ^1H chemical shift of δ_A while that of the free form resonates at δ_B for the same proton (see figure above). If the exchange timescale (i.e.; proportional to k_{OFF} as k_{ON} is diffusion limited) between the free form of the drug and its bound form is in microseconds, which of the following statements cannot be true assuming that the drug is only 50% bound with its protein target?

- A) The NMR linewidth of the observed transition(s) will be different from the free form of the drug.
- ✓ B) There will be two resonances obtained in the NMR spectrum of the Protein-Drug complex: one for the free form while other for the bound form.
- C) We will see a single resonance at a position δ_{eff} which is in between δ_A and δ_B .
- D) Varying the concentration of the drug molecule while observing the NMR signatures will provide an estimate of the binding constant.

26) At 25 $^{\circ}\text{C}$, if the pK_a value for a weak acid is smaller than its aqueous solution pH by 2, what is the fraction of the acid in dissociated form?

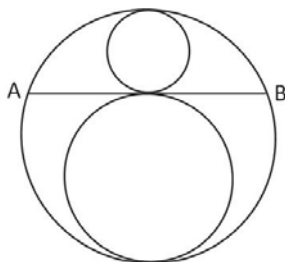
- A) 1.10 %
- ✓ B) 99.01 %
- C) 0.99%
- D) More information is needed

27) The heat of formation (ΔH_f) for the reaction $2\text{Cu}(s) + \text{O}_2(g) \rightarrow 2\text{CuO}(s)$ is measured and plotted as a function of temperature (T). Of the 4 possible graphs shown below, which one would most likely represent the observed trend?



- A) 1
- B) 2
- ✓ C) 3
- D) 4

28) If the outer circle radius is 'Z', in the diagram given below, then what is the line segment AB? The ratio of inner circles' diameters is 2.



- ✓ A) $\frac{4\sqrt{2}}{3} Z$
- B) close to $2 Z$
- C) $\frac{\sqrt{5}}{\sqrt{2}} Z$
- D) $\frac{2\sqrt{5}}{3} Z$

29) Assume that the temperature (T) dependence of ΔG for a chemical reaction can be represented by an equation of the form

$$\Delta G = x + yT + zT^2$$

What is the expression for the heat capacity change at constant pressure, ΔC_p ?

- A) x/T
- B) $-y$
- ✓ C) $-2zT$
- D) Insufficient information

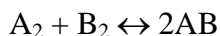
30) During isothermal expansion of an ideal gas which of the following happen:

- (i) Temperature does not change
 - (ii) Process is spontaneous
 - (iii) The energy of the system does not change
 - (iv) Entropy increases
- A) i and iii only
 - B) i, ii, and iv only
 - C) i, iii, and iv only
 - ✓ D) i, ii, iii and iv

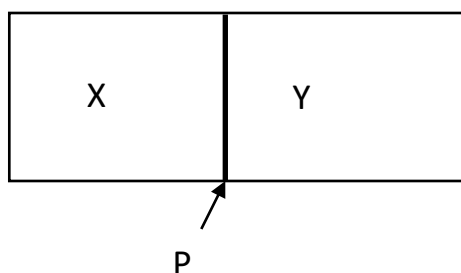
31) In an experiment measuring the weight of the object, 100 repeats were performed by one student. He found the mean weight of 332 grams with standard error of the mean as 5 grams. A lazier student only performs 10 measurements on the same object. Which of the following values will her result be closest to?

- A) 330 ± 50 grams
- B) 400 ± 15 grams
- ✓ C) 330 ± 15 grams
- D) 330 ± 5 grams

- 32) Two compartments X and Y are separated by an impermeable partition P. In the compartment X, the following reaction is going on in a solvent S, while the compartment Y contains only the solvent S:



Contents of both the compartments are continuously and vigorously stirred. After the reaction in the compartment X has reached equilibrium, the concentrations of A_2 , B_2 and AB are measured and the equilibrium constant calculated. Then the partition is quickly removed. After waiting for a very long time, all the concentrations are measured again, and the new value of the equilibrium constant calculated. What is the most appropriate statement you can make about the result of this experiment? Assume that the chemicals are behaving ideally and the temperature is kept constant.



- A) The concentrations of all the chemicals and the equilibrium constant will be less than their values before the partition was removed.
- B) After removing the partition, the concentrations of A_2 and B_2 will increase, and that of AB will decrease.
- C) After removing the partition, the concentrations of A_2 and B_2 will decrease, and that of AB will increase.
- ✓ D) After removing the partition, the concentrations of all the chemicals will decrease.
- 33) A kid has been playing with an inflated balloon. Suddenly, a reaction happens inside the balloon. This causes the inside surface of the balloon to become sticky, so that some of the air molecules inside which collide against the surface get stuck to it. As a result, immediately after the reaction, the balloon will
- A) Inflate
- ✓ B) Deflate
- C) Remain unaltered
- D) Will change its shape without changing its volume

34) “Doping” and “Alloying” are two common terms used to describe the presence of two different elements in one material. Which one of the following statements is false?

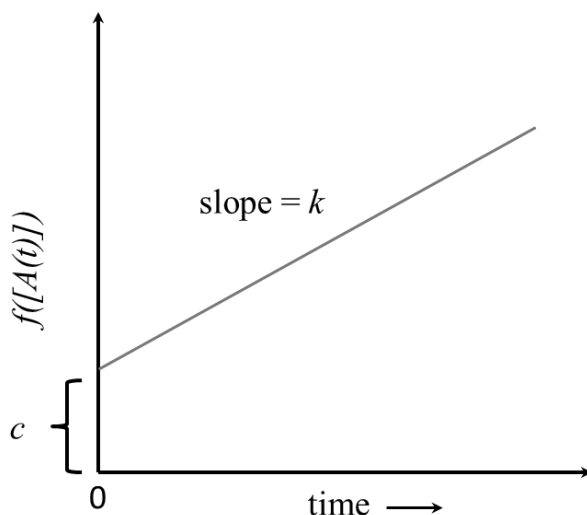
A) Doping is the process of intentionally introducing impurities into an semiconductor in order to change its electrical properties.

✓ B) Doping means making one solid solution.

C) Alloying is a homogeneous mixture of two or more elements, at least one of which is a metal.

D) In an alloy, the combined mixture has different properties from those of its component elements.

35) The graph below plots the progress of a dimerization reaction involving species A. It depicts a straight line with slope k (the rate constant). What is the value of the intercept, c in the graph?



A) $[A(0)]$

B) $[A(0)]^2$

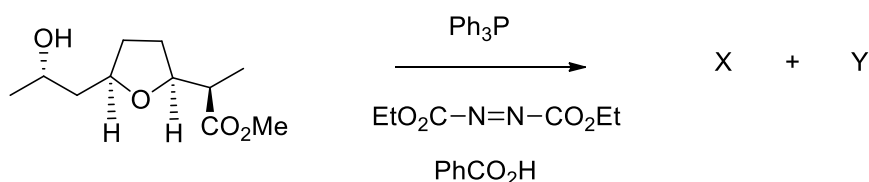
✓ C) $[A(0)]^{-1}$

D) $k \times [A(0)]^2$

36) A particle in a 1-D box of length L has eigenstates $\psi_n(x)$ with energies E_n . Consider two initial states of the particle at time $t = 0$: case 1) $\Psi(x, t = 0) = \psi_n$ (arbitrary n), and case 2) $\Psi(x, t = 0) = \psi_n + \psi_m$ (arbitrary n and m ; $n \neq m$). The probability to find the particle at a specific position within the box:

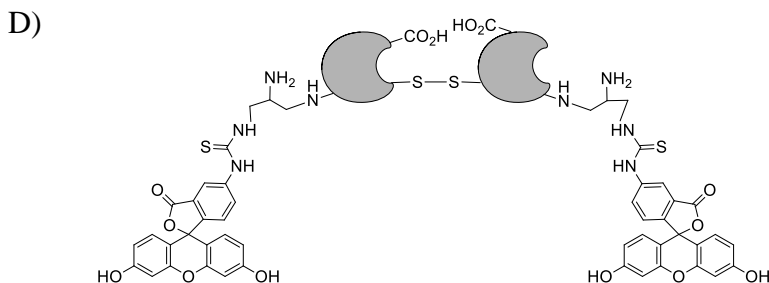
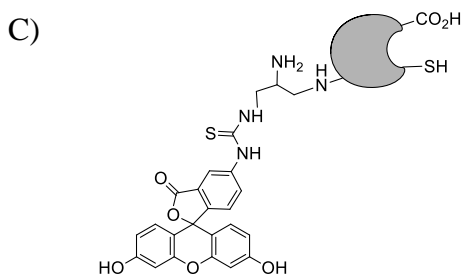
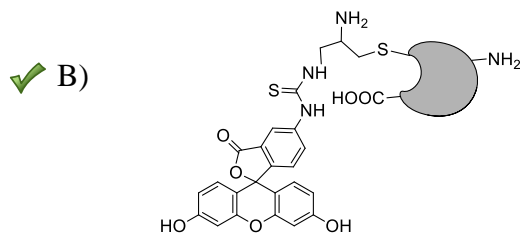
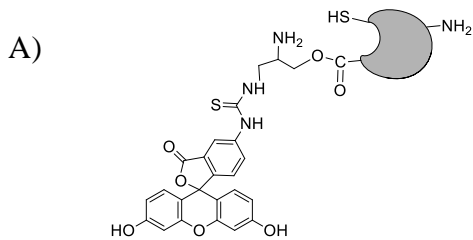
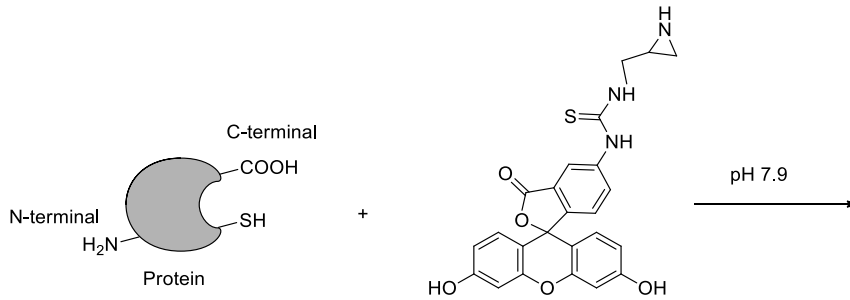
- A) Varies with time for case 1 but not for case 2
- B) Is time dependent for both cases
- C) Is time independent for both cases
- ✓ D) Varies with time for case 2 but not for case 1

37) What major products are obtained in the following Mitsunobu reaction?



- A) and $\text{Ph}_3\text{P}=\text{O}$
- ✓ B) and $\text{Ph}_3\text{P}=\text{O}$
- C) and $\text{Ph}_3\text{P}=\text{O}$
- D) and $\text{Ph}_3\text{P}=\text{O}$

38) A bio-conjugation reaction can be used to modify a specific residue on a protein to attach therapeutics and diagnostic agents. Predict the major product of the following bio-conjugation reaction with Fluorescein.



39) The acidity of molecules is usually measured by a parameter called the pK_a . Metal ions (M^{n+}) solubilized in water form solvated aqua complexes commonly denoted by $[M(H_2O)_m]^{n+}$ or M_{aq}^{n+} . It is known that the pK_a of coordinated water in such metal-aqua complexes will be different from that of bulk water. For the following set of metal-aqua complexes: Ca_{aq}^{2+} , Fe_{aq}^{2+} , Mn_{aq}^{2+} , Fe_{aq}^{3+} ; arrange the complexes with decreasing value of expected pK_a of the coordinated water molecule:

- A) $Fe_{aq}^{2+} > Mn_{aq}^{2+} > Ca_{aq}^{2+} > Fe_{aq}^{3+}$
- ✓ B) $Ca_{aq}^{2+} > Mn_{aq}^{2+} > Fe_{aq}^{2+} > Fe_{aq}^{3+}$
- C) $Fe_{aq}^{2+} > Fe_{aq}^{3+} > Mn_{aq}^{2+} > Ca_{aq}^{2+}$
- D) $Mn_{aq}^{2+} > Ca_{aq}^{2+} > Fe_{aq}^{2+} > Fe_{aq}^{3+}$

40) Solid inorganic materials are commonly classified as conductors, semi-conductors or insulators as determined by their bandgap. Carbon has many allotropes such as diamond, graphite, carbon nanotubes and graphene with distinct bandgaps. Considering the properties of diamond, what should be its bandgap:

- ✓ A) 7.0 eV
- B) 1.0 eV
- C) 0.01 eV
- D) 0 eV

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