No credit for a simple answer. You should provide a detail discussion on each question.

Part I. N-Heterocyclic carbenes (50)
1. Please write an article to describe the chemistry of N-Heterocyclic carbenes (including the structure, preparation, reactions and applications).
2. Provide a reasonable mechanism for each of the following transformation (with explanation) and show how to support the proposed mechanism.
   (A) N-Heterocyclic carbene (NHC) catalyzed direct carbonylation of dimethylamine with CO leading to the formation of N,N-dimethylformamide.

   (B)

   ![Diagram]

Part II. Acid-Base (50)
1. Please describe Bronsted-Lowry acid-base theory and the importance of this concept in chemistry. (Please write an article to describe it)
2. How to determine the concentration of an unknown hexane solution of n-butyllithium? Rationalize your answer.
3. What kind of base is (are) suitable for the following transformation? Rationalize your answer in detail.

   (A)

   ![Diagram]

   (B)

4. Treatment of a hydroxamic acid with a strong acid can form three different mono-protonated species. What kind of strong acids would be suitable for this protonation? Which of the three protonated species is the most favorable one? Rationalize your answer.

5. Compare the difference between “Kinetic acidity” and “Thermodynamic acidity”.
Cumulative Examination: Inorganic Chemistry. Date: 2013.03.23

From organometallic papers in *Angew. Chem. Int. Ed.* 2012

1. The title of the article published in *Angew. Chem. Int. Ed.* 2012, 51, 12250 –12253 is “Tandem Heck/Decarboxylation/Heck Strategy is used for the Protecting-Group-Free Synthesis of Symmetric and Unsymmetric Hydroxylated Stilbenoids”. (a) Use the following paragraph to draw the chemical formula of the main reaction and (b) give the plausible mechanism for the reaction. “The cross-coupling of 4-halophenols with acrylic acid to yield unprecedented symmetric or unsymmetric hydroxylated stilbenoids (C6-C2-C6 unit) or distyrylbenzene (C6-C2-C6-C2-C6 unit) in a protecting-group free manner is catalyzed by Pd. Coupling of two equivalents of 4-iodophenol and one equivalent of acrylic acid was carried out using Pd(OAc)₂, PPh₃, and piperidine/sodium formate under microwave irradiation, thus providing the product. The method allows tuning of the concentration of the coupling partners, and CO₂ is the only by-product with respect to the acrylic acid; conventional coupling of 4-halophenols and acrylic acid are known to provide 4-hydroxy cinnamic acid (C6-C3 unit)”. Pd complexes are commonly used for the Heck reaction, Sonogashira coupling and Suzuki coupling (c) Describe the Heck reaction, Sonogashira coupling and Suzuki coupling. (d) Give mechanism for any two reactions. 40%

2. A direct access to a wide range of fully substituted carbon centers bearing amines by a three components coupling was reported in *Angew. Chem. Int. Ed.* 2012, 51, 12289 –12292. (a) Predict the product from the reaction of heating cyclohexanone, benzylamine, and 1-octyne in with 5 mol% CuCl₂. The combination of 2-butanone, benzylamine, and 1-octyne is, however, unreactive unless 50 mol% Lewis acid additives are added. (b) Among species of Fe, Al, Ti, Au, which is the most effective Lewis acid? (c) Describe briefly the role of the catalyst and the Lewis acid. 10%

3. Pd(0) [Pd(dba)₂]-catalyzed enantioselective C-H arylation of cyclopropanes for the compound drawn below to yield functionalized tetrahydroquinolines was reported in *Angew. Chem. Int. Ed.* 2012, 51, 12842 –12845. (a) Draw the structure of the product from intramolecular cyclization retaining the cyclopropane group in the first step. (b) When the trityl (Tf) group on the nitrogen of this product was removed under reductive conditions with Red-Al (NaAlH₂(OC₂H₅OCH₃))₂, what is the product? (c) Furthermore, the cyclopropyl moiety is amenable to modifications. Treatment of the product in the first step with H₂ and 10% Pd/C in ethyl acetate selectively reduces the highest-substituted C-C bond of the cyclopropane to give the ring-enlarged product. Draw the structure of the product. 10%

4. The first catalyst capable of promoting not only the efficient metathesis of a wide variety of terminal alkynes, but also the unprecedented terminal ring-closing alkyne metathesis (TRAM) of α,ω-diacetylenes was reported in *Angew. Chem. Int. Ed.* 2012, 51, 13019 –13022. The catalyst was
prepared in many steps. The first step involved the reaction of M(CO)$_6$ (M = Mo or W) with MesLi followed by addition of aqueous NMe$_4$Br solution to give A. (a) Draw the structure of this product A. Treatment of product A with oxalyl bromide at -90°C gave a neutral carbyne product B (b) Draw the structure of B. Reaction of B with bromine and DME (1,2-dimethoxyethane) which could serve as a bidentate ligand at -90°C produce a carbyne product C with mer-tribromides and DME ligand as crystalline solids in 80% overall yield. (c) Draw the structure of C. The catalyst used for metathesis is prepared by treating C (Mo complex) with KOC(CF$_3$)$_2$Me to yield a tetrahedral complex. (d) Draw the structure of the catalyst. (e) Give product of the following two starting materials drawn below. Olefin metathesis can be catalyzed by Ru catalyst. (f) Give a common catalyst for this olefinic reaction. (g) Give a reasonable mechanism for olefin metathesis, 20%

5. Rh-catalyzed regio-, diastereo-, and enantioselective [2+2+2] cycloaddition of 1,6-enynes with acrylamides was reported in Angew. Chem. Int. Ed. 2012, 51, 13031 –13035, because [2+2+2] cycloadditions involving two alkene units have been largely limited to the intramolecular reactions of dienynes. The authors reported the reaction using the first two starting materials drawn below in the presence of the cationic rhodium(I)/chiral bisphosphine catalysts. (a) Give all possible products of the reaction. Which regioselectivity was observed? (b) Give a plausible mechanism. 20%
Physical Chemistry Cumulative Exam (March 23, 2013)  Thermodynamics and Statistical Mechanics

Range: Silbey/Alberty/Bawendi, 4th edition, 2005, examples and problems of Ch. 1-6 and 16

R = 8.314 J/mol-K = 0.082 atm-L/mol-K
1 cal = 4.184 J
1 atm-L = 101 J
k_B T (at 298 K) = 4.11 x 10^{-21} J

\( P + \frac{a}{V^2} ) (V - b) = RT \)

1). (20 pt)
An ideal gas at 300 K expands isothermally and reversibly from 10 bar to 1 bar.
Calculate the molar quantities of (1a) q, (1b) w, (1c) \( \Delta U \), (1d) \( \Delta H \), (1e) \( \Delta G \) (1f) \( \overline{\Delta A} \), and (1g) \( \overline{\Delta S} \).

2). (20 pt)
Derive the expression for the vibrational contribution to the internal energy is \( U_v = \frac{RTx}{e^x - 1} \), where \( x = \frac{hv}{kT} \)

What is the limit of the vibrational contribution at high temperature?

3). (20 pt)
Show that \( q_{rev} \) is not a state function for a gas obeying the van der Waals equation of state, but \( (q_{rev}/T) \) is.

4). (20 pt)
At low pressures the compressibility factor for a van der Waals gas is given by

\[ Z = \frac{RT}{P} = 1 + \left( b - \frac{a}{RT} \right) \frac{P}{RT} \]

Derive the expression for \( \overline{\Delta G} \) for a change in pressure from \( P_1 \) to \( P_2 \).

5). (20 pt)
Show that equations for the bubble line and dew line for non-ideal solutions are given by

\[ x_i = \frac{P - \gamma_i P_i^*}{\gamma_1 P_1^* - \gamma_2 P_2^*} \quad y_i = \frac{P \gamma_1 P_1^* - \gamma_i \gamma_2 P_1^* P_2^*}{P \gamma_1 P_1^* - \gamma_2 P_2^*} \]

Where \( \gamma \) is the activity coefficient, \( P_i^* \) is the vapor pressure of component \( i \).

--- End of Exam ---

Page 1/1
Analytical Cumulative Examination
March 23, 2013

I. You are asked to deliver two 20-min talks covering (A) absorption and fluorescence, and (B) metal nanodots. Write down your teaching material. (40%, each 20%)

II. Describe this work based on the following scheme. (20%)

III. Describe two nanoparticles based sensing systems (can not be similar to that shown in Question II). (40%, each 20%)
1. Using the provided reaction diagram, please illustrate how enzyme convert the substrate to enzyme-bound products and then release the products (15pt)

![Reaction Diagram]

2. Please draw the reaction (binding) coordinate-energy diagram and explain (a) the differences between chemical reaction with and without enzymes and (b) how transition state analog inhibitors work. (20pt)

3. Please EXPLAIN why transition state binds tightly to the enzyme using the provided thermodynamic box. What is the $K_d/K_d'$ equal to? (10pt)

![Thermodynamic Box]

4. Why are spectroscopic or static techniques incapable of characterizing enzymatic transition state complexes? Hint: life-time and population (5pt)

5. The features of enzymatic transition state can be characterized experimentally by the measurement of intrinsic kinetic isotope effects at every atomic position of substrate molecules. What is kinetic isotope effect? Please illustrate it by simplified bond vibrational basis. (14pt)

6. What are the normal, unity and inverse isotope effects in term of the value and bond environment? (6pt)
7. What are forward and reverse committee factors? Why committee factors are important for the measurement of V/K? (10pt)

8. Why value of kinetic isotope effect for hydrogen is larger than that for carbon? (5pt)

9. What are the primary, secondary, remote and solvent isotope effects (5pt)?

10. After Kinetic isotope effects are measured, how the transition state structure is obtained? After knowing the transition state structure, what features of model should be matched for the design of transition-state analogs? (5pt)

11. What are good target candidates for transition-state analog design should have? (5pt)