

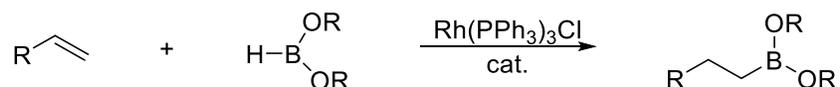
Recommended Reading: 24, 27.1-27.7 (3rd edition); 24, 25.1-25.7 (4th edition)

Ch 102 – Problem Set 8

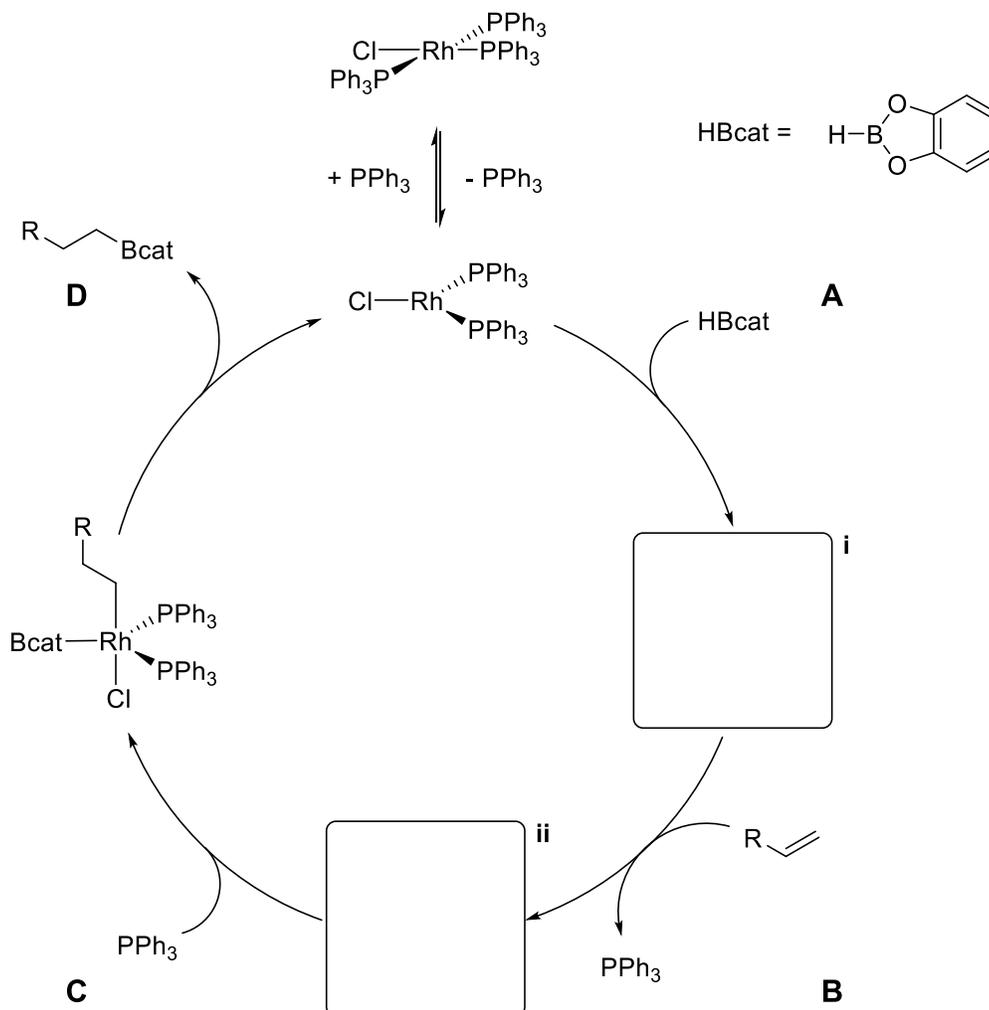
Due: Thursday, June 2 – Before Class

Problem 1 (3 points)

As discussed in class, Wilkinson's catalyst ($\text{Rh}(\text{PPh}_3)_3\text{Cl}$) is capable of catalyzing the hydrogenation of alkenes. This compound has been found to be a catalyst for the hydroboration of alkenes as well. The overall chemical reaction is shown below:



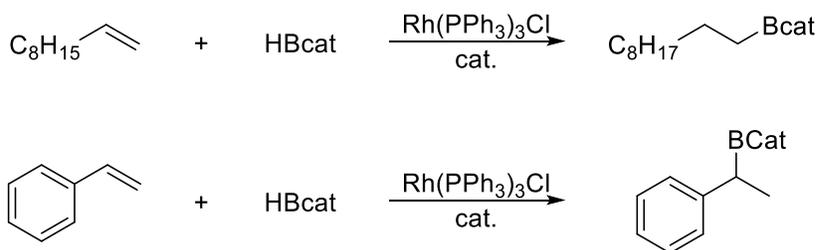
a) The cycle for the Rh-catalyzed hydroboration of alkenes with catecholborane (HBcat) is shown. Draw the missing intermediates **i** and **ii**. For every intermediate, give the oxidation state of Rh, the d-electron count, and the overall valence electron count. Finally, name all elementary steps **A-D** of the catalytic cycle.



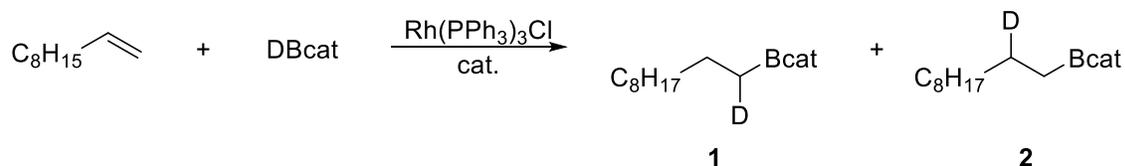
Two potential products can be envisioned from the catalytic cycle - the terminal boronate ester (anti-Markovnikov product) or the secondary boronate ester (Markovnikov product).



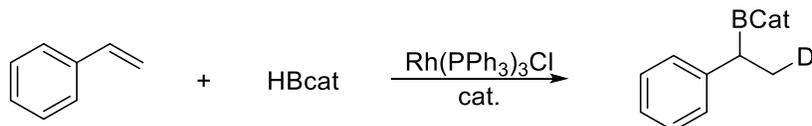
b) The uncatalyzed addition of HBcat to alkenes selectively produces the anti-Markovnikov product whether the R group is an alkyl or aryl moiety. In the Rh-catalyzed system, when 1-decene (R = alkyl) is used, the anti-Markovnikov product is selectively produced. However, when substrates such as styrene (R = aryl) are used, the Markovnikov product is formed preferentially. Given the mechanistic picture from part a, propose a reason for this contrast in regioselectivity. Hint: Involve the aryl pi-system in coordination to metal.



d) When deuterium-labeled catecholborane (DBcat) is employed in the hydroboration of 1-decene, deuterium incorporation is observed in both the C-1 (**1**) and C-2 (**2**) positions. Propose two pathways that would lead from intermediate **ii** in the cycle and result in the formation of products **1** and **2**, respectively, under the deuterium-labeled conditions. Draw each intermediate in the path and name the elementary steps involved.



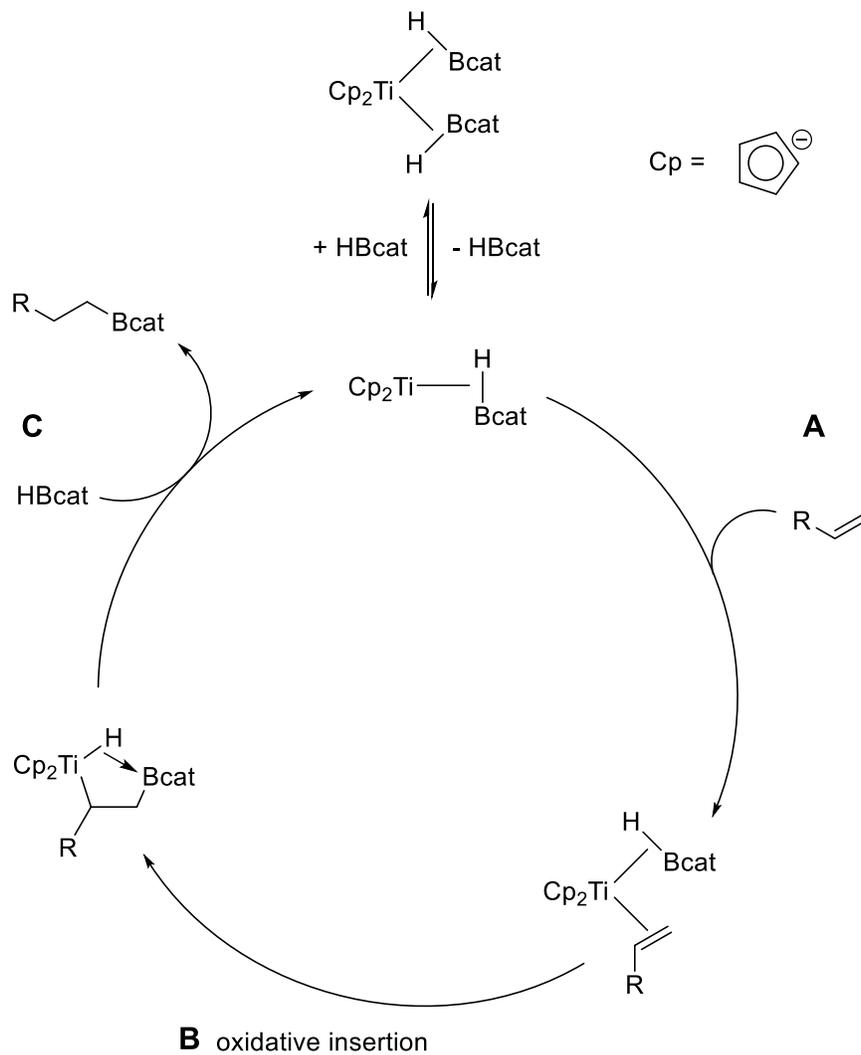
When DBcat is used in the hydroboration of styrene, deuterium incorporation is *only* observed on the primary carbon.



e) What do the deuterium-labeling studies suggest about the reversibility of step C for 1-decene and styrene respectively? What step in the cycle (A, B, C, or D) determines the regioselectivity of the reaction with 1-decene? What step determines the regioselectivity of the reaction with styrene.

Other transition metals are capable of catalyzing the hydroboration of alkenes as well. Cp_2TiMe_2 has been reported to act as a pre-catalyst for addition of HBcat across olefins by first generating $\text{Cp}_2\text{Ti}(\text{HBcat})_2$. The catalytic cycle is shown below.

f) For each intermediate, provide the Ti oxidation state, d-electron count, and total valence electron count. Provide the names of the elementary steps for **A** and **C**.



g) Given that steps **B** and **C** are relatively irreversible, what would be the product(s) of the addition of DBcat to 1-decene under the Ti-catalyzed conditions?

c) If isotopically labeled dioxygen were used in the catalytic reaction, indicate where those ^{18}O atoms would appear in the products.

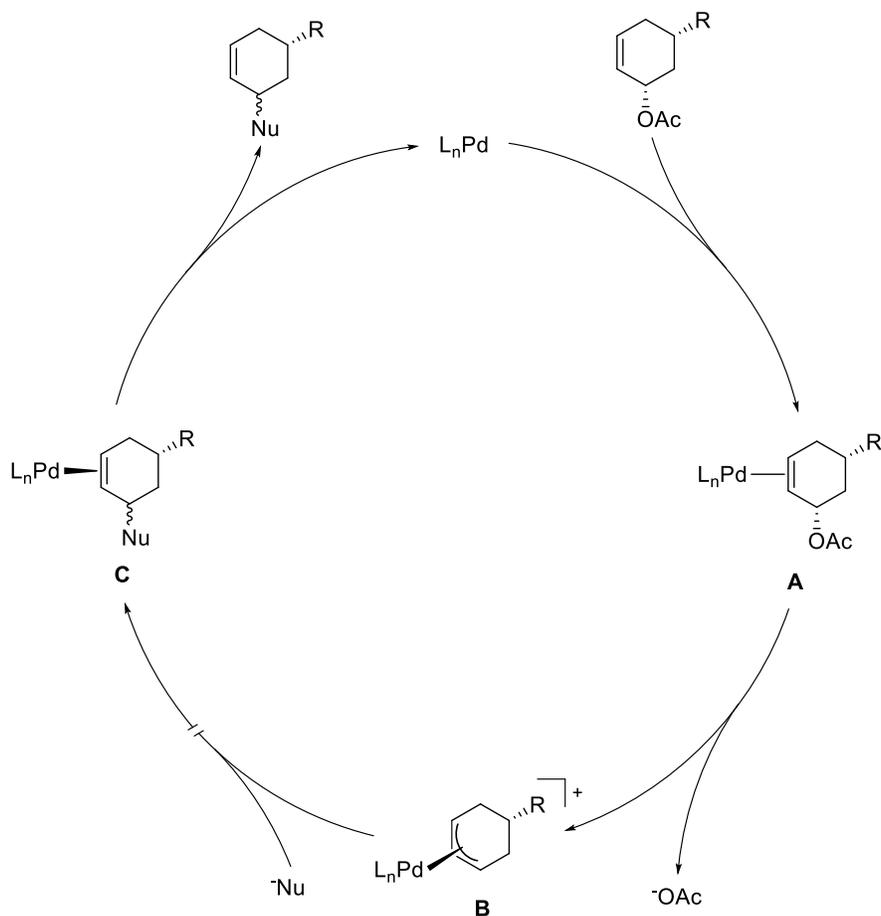
d) Indicate if the above conversion corresponds to oxidase vs oxygenase reactivity.

Problem 3 (2 points)

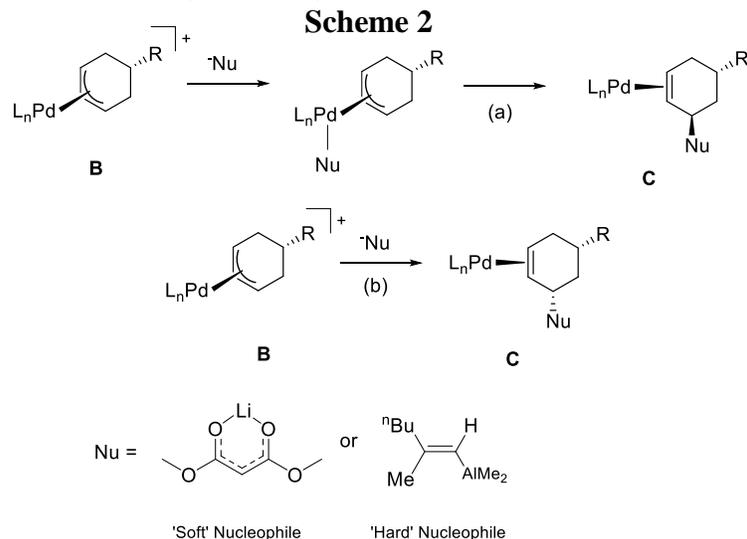
Part I

Reactions with allylic electrophiles can suffer from unpredictable regio- and stereo-selectivities. A common example of selective additions to allylic organic fragments include Michael addition to α,β -unsaturated ketones. The Tsuji-Trost reaction is an example of a transition-metal catalyzed allylic addition reaction which can occur with predictable regio- and stereospecificity (Scheme 1). In this reaction, a palladium (0) catalyst forms an η^3 - π -allyl complex with an olefin adjacent to a leaving group (either halogens, carbonates, or, shown below, esters). Nucleophilic addition (often a carbon nucleophile, but sulfur, nitrogen, and phosphorous nucleophiles are also reported) is accomplished to afford substitution at the allylic position.

Scheme 1



In the case of the substrate above, the nature of the nucleophile determines which face the ring is substituted on. Nucleophiles either substitute via direct attack on the allylic fragment, or through initial binding of the metal center (Scheme 2).



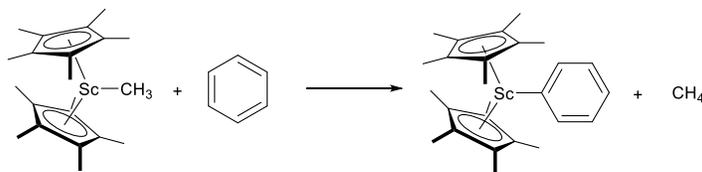
a) For metal complexes **A**, **B**, and **C**, assign valence electron count, metal oxidation state, and d electron counts. Assume L = phosphine and n = 2.

b) For the two possible mechanisms of nucleophile addition (Scheme 2), provide the type of organometallic elementary transformation in steps (a) and (b).

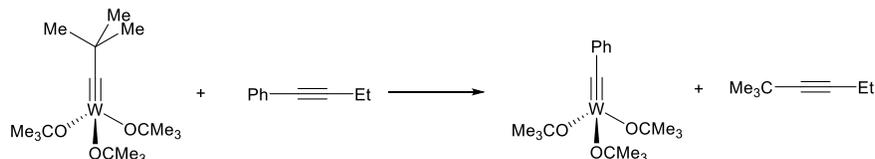
Part II

For the reactions given below, name the type of elementary organometallic transformation, and provide a mechanism of the reaction including any transition states as discussed in lecture. Provide the valence electron count, metal oxidation state, and d electron count of the metal-containing starting materials.

a)



b)



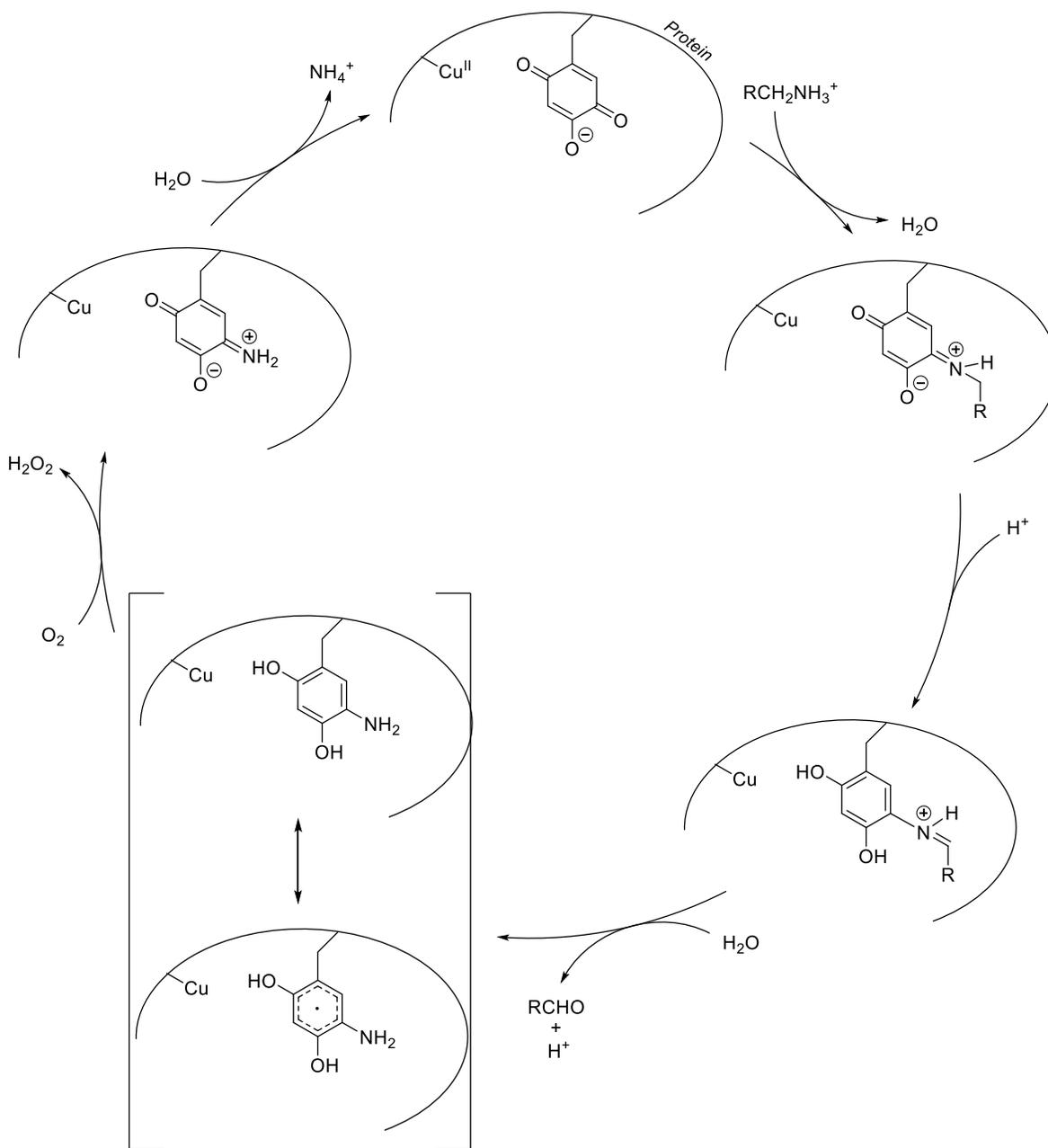
c)



Problem 4 (2 points)

Part I

The copper-containing enzyme *AO* catalyzes the oxidation of primary amines to aldehydes, producing NH_4^+ and H_2O_2 . The active site contains a unique cofactor covalently bound to the protein, topaquinone. This cofactor neighbors a Cu^{II} ion, which is bound to the protein in a square pyramidal geometry by three histidine residues, with two bound water molecules. The mechanism of this enzyme is shown below. *AO* enzymes have a variety of functions that are implicated in cell differentiation and growth, wound healing, detoxification, and signaling.



a) Write a balanced chemical reaction for the overall catalytic reaction. How many protons and electrons are formally transferred in this reaction? For the steps of the mechanism up to aldehyde release, what is the oxidant and reductant? For the remaining part of the mechanism, what is the oxidant and reductant?

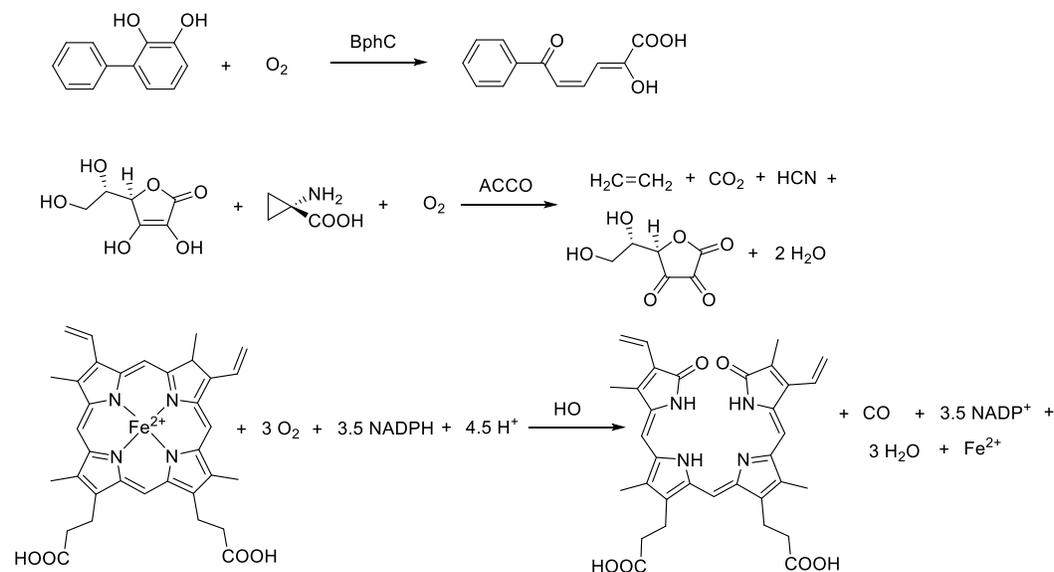
b) Give the oxidation state of Cu where missing.

c) How many redox processes (count both electron transfer and hydrogen atom transfer) take place throughout the catalytic cycle?

d) Does *AO* act as an oxygenase or oxidase?

Part II

For each of the enzyme-catalyzed reactions listed below: (1) label the oxidizing agents and reducing agents, (2) give the oxidation state of all atoms that have experienced a change in oxidation state, (3) identify the reaction as being carried out by an oxygenase or oxidase enzyme.



Problem 5 (2 points)

Pick a topic of interest from the recommended reading (descriptive chemistry) in bold at the beginning of this problem set. Prepare two power point slides including relevant *descriptive chemistry* (background on synthesis, applications, reactivity, properties, trend, etc, as applicable), some concepts presented in class (oxidation states, electron count, symmetry, MO theory, vibrational spectroscopy, etc.) and some application of the provided software (since MO theory and vibrational spectroscopy were covered in class, *you are now expected to include some molecular orbital pictures / MO diagram analysis / IR/Raman analysis using the provided software*). Email the slides in pdf format to the TAs by 12:00 noon (Thursday, June 2, 2016), and turn in a printout of the slides with your problem set.