Answers for the Analytical Chemistry Cumulative Exam Oct. 19, 2002

(15)(a) EDTA = ethylenediaminetetraacetate ion or protonated derivatives which first go to N's.

\[
\begin{align*}
\text{EDTA}^{-4} & = \left(\begin{array}{c}
-\text{OOCCH}_2 \\
\text{N-C}_2\text{H}_5\text{-N} \\
-\text{OOCCH}_2 \\
\end{array}\right) + 4\text{H}^+
\end{align*}
\]

\[
\begin{align*}
\text{OY}^{-3} & = \left(\begin{array}{c}
-\text{OOCCH}_2 \\
\text{HN-C}_2\text{H}_5\text{-NH} \\
-\text{OOCCH}_2 \\
\end{array}\right) + 3\text{H}^+
\end{align*}
\]

\[
\begin{align*}
\text{OH}^{-2} & = \left(\begin{array}{c}
-\text{OOCCH}_2 \\
\text{HN-C}_2\text{H}_5\text{-NH} \\
-\text{OOCCH}_2 \\
\end{array}\right) + 2\text{H}^+
\end{align*}
\]

\[
\begin{align*}
\text{Cu(II)Y}^{2-} & \text{ is a 1:1 complex with 5-6 groups from EDTA coordinated to Cu}^{II}.
\end{align*}
\]

One of these dentate arms might be free with a Cu-OH$_2$ in its place.
EDTA has six donor groups that can form electron-pair bonds to Cu(II) (coordinate covalent bonding) and to other metal ions. These reactions release up to six coordinated water molecules. In general, very strong 1:1 complexes form as a result for the favorable enthalpy change (\(-\Delta H\)) from six groups and the favorable entropy change (\(\Delta S\)) as a result of two species reacting to give seven species:

\[
M(H_2O)_6^{2+} + Y^{4-} \rightarrow MY^{2-} + 6H_2O
\]

as well as the additional entropy release caused by charge neutralization (i.e. outer-sphere water associated with the metal ion and with the charged ligand are also released).

(a) 0.6472 g sample of Chromel (an alloy of Ni, Fe, and Cr) is dissolved and diluted to 250 mL. Each 50.00 mL aliquot therefore has \(\frac{0.6472}{5} = 0.12944\) g 

\[50\text{ mL} \times 0.05182\text{ M EDTA} = 2.5910 \text{ mmol EDTA mixed with an equal volume of diluted sample (i.e. 50.00 mL) and back titrated with 5.11 mL of 0.06241 M Cu(II) = 0.3189 \text{ mmol Cu(II)}. Therefore, 2.5910 - 0.3189 = 2.2721 \text{ mmol of EDTA were needed to complex the metals in the sample = mmol Ni + Fe + Cr in 50.00 mL.}

Cr masked, \(\text{Ni + Fe} = 36.28 \text{ mL} \times 0.05182\text{ M EDTA} = 1.8700 \text{ mmol/50 mL}

Fe + Cr masked, \(\text{Ni} = 25.91 \text{ mL} \times 0.05182\text{ M EDTA} = 1.3427 \text{ mmol/50 mL}

Cr = 2.2721 \text{ mmol(Ni + Fe) - 1.8800 mmol Ni + Fe} = 3.921 \text{ mmol/50 mL}

Fe = 1.8800 \text{ mmol Ni + Fe} - 1.3427 \text{ mmol Ni} = 0.5373 \text{ mmol/50 mL.}
Each 50 mL aliquot

\[\% \text{Ni} = \frac{1.3427 \text{ mmol} \times 58.698 \text{ g/mol}}{10^2 \text{ mmol} \times 0.12944 \text{ g}} \times 100 = 60.88\%\]

\[\% \text{Cr} = \frac{3.921 \text{ mmol} \times 51.996 \text{ g/mol}}{10^3 \text{ mmol} \times 0.12944 \text{ g}} \times 100 = 15.75\%\]

\[\% \text{Fe} = \frac{0.5373 \text{ mmol} \times 55.845 \text{ g/mol}}{10^3 \text{ mmol} \times 0.12944 \text{ g}} \times 100 = 23.18\%\]

\[\text{total} = 99.81\%\]

i.e. (0.19\% impurities)

(d) Questions about procedure in (c)

(10) (1) An oxidizing acid such as HNO₃ (hot and conc.) would be needed to dissolve this alloy. This would have to be boiled to remove excess acid before dilution to 250 mL.

(10) (2) The expected oxidation states of the dissolved metal ions are Ni(II), Cr(III), and Fe(III). All three are somewhat to very sluggish in their reactions with EDTA. Hence, excess EDTA is needed to be sure all three are complexed.

The direct titration needs faster reactions. Once complexed, the back titration with a labile metal ion such as Cu(II) reacts with the excess EDTA only because the other metal-EDTA complexes are slow to react. The back titration must be done to determine the total Cr + Ni + Fe content.

(10) (3) Masking agents are ligands that react selectively with metal ions to prevent their reaction with other ligands — in this case to prevent EDTA complexation.
Hexamethylenetramine, \( \text{N(CH}_2\text{CH}_2\text{NH}_2\text{)}_3 \), reacts selectively with Cr as an all amine N donor, whereas Fe and Ni prefer the combination of amino carboxylate donors in EDTA.

Pyrophosphate, \((\text{C}_2\text{P}_2\text{O}_7\text{)}\), in moderately high concentrations will selectively form complexes with \(\text{Fe}^{III}\) and \(\text{Cr}^{III}\) and permit the \(\text{Ni}^{II}\) present to react with EDTA.

(10) Effective means of determining the equivalence point in EDTA titrations would be by use of one or more metallochromic indicators that will change color when complexed to the various metal ions. For example, Eriochrome Black T can be used to titrate \(\text{Ni}^{II}\). In the case of \(\text{Fe}^{III}\) and \(\text{Cr}^{III}\) (and \(\text{Cu}^{II}\) for its back titration) other metallochromic indicators may be needed. These indicators have iminodiacetate groups attached to dye molecules (azo or phthalein dyes of the type used for pH indicators) that change color when complexed by the metal ions.
Since all other 19 amino acids are primary amines and Pro is a secondary amine it alone reacts differently with amino group modifying reagents. In the post-column derivatization amino acid analysis the reaction with ninhydrin differs. The 16 amino acids (Glu, Asn and Trp are destroyed by hydrolysis) react with ninhydrin to form a product best observed at 570nm. Proline’s ninhydrin reaction product is best observed at 440nm. Similar difficulties arise in amino acid analyses that rely on pre-column derivatization.

In sequencing and in chemical protein synthesis optimal conditions for removal of Pro and for incorporation of Pro differ from those of other amino acids.
In protein structure X-Pro forms essentially all the cis peptide bonds observed in proteins. In most protein renaturations the slow step is in Pro cis $\leftrightarrow$ trans isomerization. Pro is strongly disfavored on the interior of a helices, it is slightly favored in the N and C termini of helices.

The denatured polypeptide chains involving pro are extremely stiff as in pro there is only one dihedral angle where rotation is allowed. Two such dihedral angles are present in other amino acid residues.

Gly is a primary amine. Its analytical chemistry is very similar to that of the other 18.

However, because it lacks a $\beta$ carbon there is much less interference to rotation than in any other residue. It is often present in places where a) unusual flexibility is required; b) a D residue is desired (gly is both D and L or simply not chiral); c) minimal side chain is desired as in every third residue in collagen. Denatured protein chain containing Gly are short and flexible.

2. a) Subtilisin and chymotrypsin are analogous but not homologous. They arose by convergent rather than divergent evolution. They are both proteinases and serine proteinases. They both employ a Asp ... His ... Ser catalytic triad. In chymotrypsin these three residues are Asp$^{102}$, His$^{57}$, and Ser$^{193}$. In subtilisin they are Asp$^{72}$, His$^{64}$ and Ser$^{221}$. As these are different orders, it seems unlikely that they diverged from a common ancestor that was also an active serine proteinase.

Another point -- the catalytic and substrate recognizing parts are quite similar but the rest of the structures and sequences is very dissimilar.

b) These proteins are paralogous. An example are the various human globing genes $\alpha$, $\beta$, $\gamma^A$, $\gamma^D$ and $\delta$ and Mb (myoglobin).

Another example are various human serine proteinases: trypsins, kallikreins, chymotrypsins, elastases, plasmin and thrombin.

c) Fibrinopeptides are the NH$_2$ terminal peptides in the $\alpha$ and $\beta$ chains of fibrinogen. Thrombin by hydrolyzing Arg$^4$ Gly bonds in these chains releases them. It appears that they evolve at the neutral mutation rate as their sequence does not greatly affect their function.

Another very rapidly evolving part is the C peptide which is released upon conversion of proinsulin to insulin. Yet another example is a loop of residues 15-25 in ribonucleases that connect the S peptide to S protein.

Slowly evolving is histone 4, a protein component of nucleosomes and ubiquitin, a protein whose attachment targets intracellular proteins for degradation.
3. a) In the coupling step the Edman reagent phenylisothiocyanate

\[ \text{N = C = S} \]

reacts with amino acid terminal R — NH₂ groups in their deprotonated form. This reaction occurs in aqueous buffer at pH 8.5 (in order to deprotonate the terminal).

In the cleavage step, the coupled NH₂ terminal residue cyclizes and breaks off from the peptide chain. This step occurs in non-aqueous acid medium. After the cyclized terminal is extracted and the conditions restored to aqueous pH 8.5 we are ready for the coupling step.

The problem with many systems of sequential release of amino acid residues from either the amino terminal end (e.g., aminopeptidases) or carboxyl terminal end (carboxypeptidases) is that it is very hard to keep track of the order of the released residues as conditions are not changed after each residue is released. A sequencer does an excellent job of keeping track of the residues as a change of conditions is required to release each residue.

b) The three assistants are Peptidyl Disulfide Isomerase, Peptidyl Prolyl Isomerase, and Chaperonins.

Of these the first two are enzymes and single globular proteins. Chaperonins, there are several kinds, are large assemblies of proteins.

As the name implies peptidyl disulfide isomerase aids in finding the most stable pairing of disulfide bonds — a common slow step in folding of disulfide containing proteins.

Peptidyl Prolyl Isomerase aids in achieving the cis \( \leftrightarrow \) trans equilibrium of X — pro peptide bonds. In native proteins some of these are trans, others cis. In denatured proteins each is at equilibrium. To fold quickly a denatured chain should have all trans, where trans is needed and all cis where cis is needed. The PPI enzyme greatly speeds folding of proteins especially those that contain cis X — Pro bonds.

The largest problem of folding is protein … protein aggregation, when folding occurs at high concentrations. Chaperonins, allow each chain to fold independently of the others by isolating them. They may also promote folding.

4. a) Nucleosome is a complex that is the first element in compaction of DNA in eukaryotes. Otherwise, our 3 × 10⁹ base pair would be excessively long even when split into 23 chromosomes. Nucleosome is an octamer of histones (four different kinds, two of each) around which DNA is wound around thus greatly shortening its advance. Several X-ray structures of nucleosomes were recently obtained confirming the surmises.
b) Prokaryotic ribosomes are 70S particles (MW 2,400,000) which readily dissociate into the large 50S and small 30S subunits. The 50S subunit consists of two ribosomal or rRNAs, 5S and 23S, and of 1 copy each of 31 different proteins. The 30S particle has a 16S rRNA and one copy of each of 21 different proteins. The working ribosome also binds the mRNA. Ribosomes are enzymes that synthesize proteins. The strong belief that most enzymes are proteins inclined workers to believe that it was one (or more) of the 52 proteins that was responsible for the enzymatic activity. The recent X-ray crystallographic studies showed this is not true. The slogan “ribosome is a ribozyme” summarizes this work. Steitz et al., Yale University, 2000.

c) Proteosomes are responsible for intracellular degradation and turnover of damaged proteins. They were also called multicatalytic proteases. X-ray structures confirmed this. The simple proteosomes are stacks of four seven-membered rings (with a seven-fold symmetry). The two inner rings contain 14 catalytic subunits. All have NH$_2$ terminal Thr, which is an important active site residue. In a prokaryote, Tetrahymena all the catalytic subunits are the same but in eukaryotes, there are several different kinds. All have NH$_2$ terminal Thr but differ in specificity. Robert Huber about 1995 for prokaryotic and 1999 for eukaryotic nucleosomes.

d) Chaperonin structures revealed that they are composed of many protein subunits. They act in folding of proteins in vivo. They act as barrels into which unfolded proteins are stuffed. These proteins emerge folded. The most popular theory is that they work as “Anfinsen cages” isolating the folding proteins from their folding neighbors. Other workers think that more is involved.

Items a) and b) are nucleoproteins in which the nucleic acid turns out to be central. Items c) and d) are pure proteins and good examples of how birth and death of proteins can be assisted by pure protein apparatus.
Inorganic Cumulative Exam

Theme: Nanotechnology
100 points total

Important note: Please do not go over the specified number of sentences to answer the question, or else only the specified number will be graded.

1. 15 points. In 5 sentences or less, define nanotechnology and indicate why nanotechnology has become an intense field of research only over the past decade or so (why not in the 1960's, for instance?).

NSTC (National Science and Technology Council) Definition:
Nanotechnology involves research and technology development at the atomic, molecular, or macromolecular levels in the dimension range of approximately 1-100 nanometers to provide fundamental understanding of phenomena and materials at the nanoscale and to create and use structures, devices, and systems that have novel properties and functions because of their small and/or intermediate size. The novel and differentiating properties and functions are developed at a critical length scale of matter typically under 100 nm. Nanotechnology research and development includes control at the nanoscale and integration of nanoscale structures into larger material components, systems, and architectures. Within these larger scale assemblies, the control and construction of their structures and components remains at the nanometer scale.

Nanotechnology has become an intense field of interest over the past decade or so because the tools needed to characterize and prepare such features have only recently been developed.

2. 30 points. Describe precisely 3 projects that would be funded by NSF or other federal funding agencies in the field of nanotechnology, not including the one described in question 3. Please use 4 sentences or less to describe each project.

Many, many answers here. You are limited only by your imagination.

3. (45 points total) One area of research that is the subject of intense research efforts is light emission from quantum dots (nanoparticles). Photoluminescence from nanoparticles may have several different origins.

Please answer each of the following questions in 4 sentences or less.

a) (10 points) Give 2 possible explanations for light emission from a nanoparticle in 3 sentences or less.
2 possible routes:

**i) Exciton recombination in the bulk nanocrystallite:** In a nanoparticle, an electron-hole pair (exciton) may be formed upon absorption of a photon of light. If the exciton is not quenched through non-radiative pathways, the electron and hole may recombine, releasing a photon of lower energy, and returning the nanoparticle back to the ground state.

**ii) Defects in a crystal lattice as radiative recombination centers:** A deficiency in the crystal lattice or in an amorphous material may absorb an incoming photon and release a second photon of lower energy. In a similar manner, certain interfacial groups (functionalities on the surface) may also lead to emission in a similar manner.

**b) (10 points) How is the electronic structure of a quantum dot different and yet similar to that of a molecule? 3 sentences or less.**

Like a molecule, a quantum dot has discrete energy levels (the conduction and valence bands) that resemble the homo and lumos of a molecule. The homo-lumo gap is, however, smaller than that of a covalent molecule and so also have band-like character of a bulk solid.

c) (10 points) What happens to the light emission when you incrementally change the size of a cadmium sulfide (or any photocmissive nanoparticle) quantum dot from ~1 nm through to ~20 nm in diameter? 3 sentences or less.

As you increase the size of the nanoparticles, the conduction-valence band gap decreases to become more 'solid-like', leading to emission of longer wavelengths. The smaller particles emit light that is closer to blue, and the larger particles colors more to the red. See for instance this figure from Mouni Bawendi's group at MIT for CdSe particles:
d) (15 points) Using simple band structure diagrams, explain the answer to 3 c. Please no more than 5 total written sentences.

4. (10 points) The Nobel Prizes were announced last week. Write down the names of at least 2 different people who have shared a Nobel Prize (for 2 different prizes in any area) over the past 5 years (from 1997-2002) and in 3 sentences, describe the research for which they merited the biggest prize in the history of chemistry.

Check out www.nobel.se
Recently (*J. Org. Chem. 2002, 67, 3231*), Huang and Chen reported the "Stereoselective Synthesis of α-Fluorosilyl Enol Ethers (eg: 1) and Their Aldol Reaction."

\[
\text{F} \quad \begin{array}{c}
\text{OCH}_2\text{CH}_3 \\
\text{H}
\end{array}
\quad \text{OSiMe}_3
\]

(a) Write a mechanism for a typical aldol reaction. (10 pts)
(b) Write the E-isomer of 1. (5 pts)
(c) Write the structure of a pair of diastereomers of the product from the aldol reaction of 1 with benzaldehyde and assign their configurations (*R, S* notation). (10 pts)

II. Tomioka and coworkers recently reported an asymmetric 1,4-addition reaction as shown below (*JACS, 2002, 124, 8932*).

\[
\begin{array}{c}
\text{O} \\
\text{PhB(OH)}_2
\end{array}
\quad \begin{array}{c}
\text{cyclohexanone} \\
\text{Rh(acac)(C}_2\text{H}_4)_2
\end{array}
\quad \begin{array}{c}
\text{dioxane-H}_2\text{O (10:1)} \\
100 \degree \text{C}
\end{array}
\quad \begin{array}{c}
\text{O} \\
\text{Ph}
\end{array}
\]

Write the catalytic cycle for an *achiral version* of this reaction. For convenience, you may use Rh(OH)L as the Rhodium catalyst. (25 pts).

**Extra credit (10 pts)** if you discuss the catalytic cycle for the enantioselection.

III. Arrange the following molecules in their decreasing order of acidity and justify their pK_a values (approximate values). (20 pts)

\[
\begin{array}{c}
\text{-} \\
\text{H}
\end{array}
\quad \begin{array}{c}
\text{H} \\
\text{C}_6\text{H}_5
\end{array}
\quad \begin{array}{c}
\text{H} \\
\text{CH}_3
\end{array}
\]

IV. Provide a typical example for the following reactions. (3x10 pts)

(a) Robinson annulation
(b) reductive amination
(c) malonic ester synthesis
1a. \[ q = 0 \] adiabatic

\[ W_{\text{tot}} = W_{\text{expansion}} + W_{\text{electrical}} \]

\[ = -\int pdV + \int I^2 R \, dt \]

\[ W_{\text{exp}} = -(2.8 \times 10^5 \text{ Pa})(0.2400 - 0.2200) \text{ m}^3 \]

\[ = -5 \times 10^3 \text{ Pa} \cdot \text{m}^2 \]

\[ = -5 \times 10^3 \text{ J} \]

\[ W_{\text{el}} = (0.5000 \text{ A})^2 (50.00 \Omega)(1600 \text{ s}) \]

\[ = 2 \times 10^4 \text{ J} \]

\[ W_{\text{tot}} = 2 \times 10^4 \text{ J} - 5 \times 10^3 \text{ J} \]

\[ W_{\text{tot}} = 1.5 \times 10^4 \text{ J} \]

\[ \Delta U = q + w \]

\[ \Delta U = 1.5 \times 10^4 \text{ J} \]

\[ \Delta H = \Delta U + \rho \Delta V \]

\[ = 1.5 \times 10^4 \text{ J} + 5 \times 10^3 \text{ J} \]

\[ \Delta H = 2 \times 10^4 \text{ J} \]

16. The process is irreversible because work is dissipated (electrical work becomes expansion work & heating of the liquid). In a reversible, adiabatic expansion, the temperature would be expected to drop (but in this process, it remained constant.)
\[ P(-v_{x_{1}}, v_{x_{1}}) = \int_{-v_{x_{1}}}^{v_{x_{1}}} f(v_{x}) \, dv_{x} \]

\[ f(-v_{x}) = f(v_{x}) \quad \text{b/c fn is even} \]

\[ P(-v_{x_{1}}, v_{x_{1}}) = 2 \int_{0}^{v_{x_{1}}} f(v_{x}) \, dv_{x} \]

Let \[ z = \sqrt{\frac{M}{2RT}} v_{x} \]

\[ dz = \sqrt{\frac{M}{2RT}} \, dv_{x} \]

\[ \sqrt{\frac{2RT}{M}} \, dz = dv_{x} \]

Rewrite:

\[ P(-v_{x_{1}}, v_{x_{1}}) = 2 \sqrt{\frac{2RT}{M}} \sqrt{\frac{M}{2RT}} \int_{0}^{v_{x_{1}}} e^{-z^2} \, dz \]

\[ P(-v_{x_{1}}, v_{x_{1}}) = \frac{2}{\sqrt{\pi}} \int_{0}^{v_{x_{1}}} e^{-z^2} \, dz \]
P. Chem 2002 - Fall '02

3. 

\[ d\ H = \left( \frac{\partial H}{\partial T} \right)_p \ dT + \left( \frac{\partial H}{\partial p} \right)_T \ dp \]

\[ \uparrow \]

\[ C_p \]

\[ d\ H = C_p \ dT + \left( \frac{\partial H}{\partial p} \right)_T \ dp \]

for \( \mu_{3T} \), holding \( H \) constant

\[ \therefore \ d\ H = 0 \]

\[ -C_p \ dT = \left( \frac{\partial H}{\partial p} \right)_T \ dp \]

\[ -C_p \ \left( \frac{\partial T}{\partial p} \right)_H = \left( \frac{\partial H}{\partial p} \right)_T \]

\[ -C_p \ \mu_{3T} = \left( \frac{\partial H}{\partial p} \right)_T \]

\[ \mu_{3T} = -\frac{\left( \frac{\partial H}{\partial p} \right)_T}{C_p} \]

\[ c. \quad \left( \frac{\partial H}{\partial p} \right)_T = V - T \left( \frac{\partial V}{\partial T} \right)_p \]

\[ = V - V = 0 \]

\[ PV = nRT \]

\[ V = \frac{nRT}{P} \]

\[ V = \frac{nRT}{P} \]

\[ T \ \frac{dV}{dT} = \frac{nRT}{P} = V \]