1) What is CRDS and IRMS?

CRDS = Cavity Ring Down Spectroscopy
IRM = Isotope Ratio Mass Spectrometry

2) How many CO₂ molecule/cm³ are represented in each of the three peaks of Figure 3?

\[ n = \frac{100 \text{ torr}}{760 \text{ torr}} \times 0.001 \text{ L} = 0.001 \times 5.2 \times 10^{-6} \text{ mole/L} = 2.6 \times 10^{-5} \text{ mole/L} \]

\[ 298 - 8.31 \text{ K} \]

\[ N = \frac{2.6 \times 10^{-5} \text{ mole/L}}{298 - 8.31 \text{ K}} \times 6.02 \times 10^{23} \text{ mole}^{-1} = 3.3 \times 10^{18} \text{ molecules/cm}^3 \]

79.7 ppm \[ \rightarrow 3.3 \times 10^{18} \text{ molecules/cm}^3 \times 79.7 \times 10^{-6} \text{ cm} = 2.63 \times 10^{14} \text{ molecules CO}_2 \]

41.2 ppm \[ \rightarrow 3.3 \times 10^{18} \text{ molecules/cm}^3 \times 41.2 \times 10^{-6} \text{ cm} = 1.36 \times 10^{14} \text{ molecules CO}_2 \]

18.3 ppm \[ \rightarrow 3.3 \times 10^{18} \text{ molecules/cm}^3 \times 18.3 \times 10^{-6} \text{ cm} = 6.04 \times 10^{13} \text{ molecules CO}_2 \]

3) Estimate the signal to noise for each CO₂ mixing ratio.

79.7 ppm signal = 100 \[ \rightarrow \frac{1}{3} \]

41.2 ppm signal = 50 \[ \rightarrow \frac{1}{3} \]

18.3 ppm signal = 20 \[ \rightarrow \frac{1}{3} \]

Noise = 3

4) How would pressure impact the shape of the peak?

Collisions shorten radiative lifetime, increasing uncertainty, thus broadening the peak. High p = broad peak.

5) Explain why regulating the temperature would improve the precision of the CRDS.

Changes in temperature cause changes in thermal Doppler broadening. Broadening can cause reduced signal to noise and may cause overlap with adjacent absorption features.

6) What does the cm⁻¹ unit on the y-axis referring to if Figure 3?

Effect pathlength of the reflective chamber.
7) Identify the P, Q, and R branch of the CO₂ spectra above.

8) Draw a simple schematic that shows the energy transitions and selection rule that generate the P, Q, and R branch in CO₂.

9) Label the terminus of the X axis in terms high and low energy, and explain why energies are different.

10) Sketch the features that are produced by \(^{13}\text{CO}_2\) and \(^{12}\text{CO}_2\).
11) What is the energy difference in joules between the $^{13}$CO$_2$ and $^{12}$CO$_2$ in 4b?

$$\Delta E = \frac{1}{1.6 \text{ cm}^{-1}}$$

$$v = \frac{3 \times 10^{-8}}{0.00625 \text{ m}} = 4.8 \times 10^3 \text{ cm}^{-1}$$

$$E = \hbar v = 6.626 \times 10^{-34} \times 4.8 \times 10^3 \text{ J}$$

$$= 3.2 \times 10^{-13} \text{ J/molecule}$$

12) What is the wavelength of light in nm of $^{13}$CO$_2$ and $^{12}$CO$_2$ peaks in 4b?

$$^{13}\text{CO}_2: \frac{1}{\lambda} = 6261.8 \text{ cm}^{-1} \rightarrow 1.597 \times 10^{-4} \text{ cm} = 1.597 \times 10^{-3} \text{ nm}$$

$$^{12}\text{CO}_2: \frac{1}{\lambda} = 6262.2 \text{ cm}^{-1} \rightarrow 1.5968 \times 10^{-4} \text{ cm} = 1.5968 \times 10^{-3} \text{ nm}$$

13) What type of light is this (VUV, UV, Vis, IR, MW, RW)?

IR light in micron range
14) The abundance fraction of $^{16}\text{O}$ and $^{18}\text{O}$ is .9976 and .0024 respectively. What is the probability of forming $^{16}\text{O}^{16}\text{O}$, $^{16}\text{O}^{18}\text{O}$, and $^{18}\text{O}^{18}\text{O}$?

\[
\begin{align*}
16\text{O}16\text{O} &= (.9976)^2 = .9952 \\
18\text{O}16\text{O} &= (.9976)(.0024)x2 = .00399 \\
18\text{O}18\text{O} &= (.0024)^2 = 4\times10^{-6}
\end{align*}
\]

15) The paper states that human breath is 2% CO$_2$. What would the other 4 most abundant gases be and justify their percentage, including the effect of respiration of glucose.

Air: 79% N$_2$, 21% O$_2$, 1% Ar, There CO$_2$, H$_2$O

Breath: 3% CO$_2$, 3% H$_2$O, 78% N$_2$, 1% Ar, 15% O$_2$

(roughly)

16) The paper notes that $^{13}\text{C}^{16}\text{O}^{17}\text{O}$ and $^{12}\text{C}^{16}\text{O}^{18}\text{O}$ are difficult to measure using an IRMS. What mass resolving power would you need to resolve these isotopologues?

\[
\begin{align*}
M_{RP} &= M/\Delta M \\
\Delta M &= (^{13}\text{C}^{16}\text{O}^{17}\text{O} - ^{12}\text{C}^{16}\text{O}^{18}\text{O}) = ^{12}\text{C}^{16}\text{O} - ^{12}\text{C}^{16}\text{O} \\
&= (13.00335 + 16.9991) - (12.0000 + 17.9996) \\
&= 3.29 \times 10^{-3} \\
M &= 13 + 16 + 17 = 46 \\
M_{RP} &= \frac{46}{3.29 \times 10^{-3}} = 14,000
\end{align*}
\]
17) The paper notes that “The test is based on the absence of urease in the healthy human gastrointestinal tract. Urea ingested orally by a healthy human is therefore excreted unmodified. *H. pylori*, however, has a high urease activity, and converts urea (CO(NH₂)₂) into HCO₃⁻ and NH₄⁺. The HCO₃⁻ finds its way through the bloodstream to the lungs and is exhaled as CO₂.”

18) Write out the double equilibrium of the acidic gas CO₂ when it dissolves in water $K_{a1} = 4.5 \times 10^{-5}$, $K_{a2} = 4.7 \times 10^{-11}$.

$$CO₂ + H₂O ⇌ HCO₃⁻ + H⁺ \quad K_{a1} \quad H⁺ + CO₃^{2-} \quad K_{a2}$$

19) What is the oxidation state in the 3 C compounds in the equilibrium?

- $C_{\text{O}}$: $C + 2(-2) = 0$, $C = +4$
- $HCO₃⁻$: $C + 3(-2) + (1)(+1) + (-1) = 0$, $C = +4$
- $CO₃^{2-}$: $C + 3(-2) + (-2) = 0$, $C = +4$

Acid base no net change

20) Blood has a pH of about 7.35, what would the $[\text{H}⁺]$, $[\text{HCO₃}⁻]/[\text{CO₂}]$ and $[\text{CO₃}^{2-}]/[\text{HCO₃}⁻]$ be in the blood?

- $[\text{H}⁺] = 10^{-7.35} = 4.47 \times 10^{-8}$ M

$$K_{a1} = \frac{[\text{HCO₃}⁻][\text{H}⁺]}{[\text{CO₂}⁻]}$$
- $[\text{HCO₃}⁻]/[\text{CO₂}⁻] = \frac{4.5 \times 10^{-5}}{4.47 \times 10^{-8}} = 1000$

$$K_{a2} = \frac{[\text{CO₃}^{2-}][\text{H}⁺]}{[\text{HCO₃}⁻]}$$
- $[\text{CO₃}^{2-}]/[\text{HCO₃}⁻] = \frac{4.7 \times 10^{-11}}{4.47 \times 10^{-8}} = 1 \times 10^{-3}$

$$\frac{[\text{CO₂}⁻]}{[\text{CO₃}^{2-}]} = \frac{1000}{1 \times 10^{-3}} = 1$$
1. (25 points) Binding affinity and specificity.
   a. The dissociation constants ($K_D$) for many binding interactions are often in the
      same ballpark with the *in vivo* ligand concentration. Explain these observations.
      (10 points)
      It is mostly due to evolitional selection. When $K_D$ is close to the ligand
      concentration, about half of the target protein will be in complex with ligand.
      Increase or decrease of the ligand concentration will be able to significantly change
      the ratio of binding and thus regulate the protein function.
   
   b. For an effective drug with minimal side effects, it is often necessary to improve
      its binding affinity to targets to achieve very high specificity ($K_D$ is the range of
      nanomolar to picomolar). Explain this need. (10 points)
      When the $K_D$ for target is that low, the affinity for targets will be orders' better than
      the affinity for non-specific binding. A concentration of the drug between the two $K_D$
      numbers can then be easily found to nearly saturate the target while it is still low
      enough to only cause insignificant non-specific binding.
   
   c. Many proteins have multiple binding domains. Explain why multiple binding
      domains are needed. (5 points)
      Multiple binding domains will help improve binding affinity and specificity

2. (20 points) Light scattering can be used to measure the sizes of macromolecules in
   solutions. Answer the following questions about light scattering.
   a. What is static light scattering? What is the principle for static scattering to
      measure protein sizes? (10 points)
      Static light scattering measures the angular dependence of scattered lights. From
      the rate of decay the average size of the protein particles can be calculated.
   
   b. What is dynamic light scattering? What is the principle for dynamic light
      scattering to measure protein sizes? (10 points)
      Dynamic light scattering measures the time dependent fluctuation of the scattered
      light. The rate of fluctuation is inversely related the diffusion rate and thus
      molecular size. From the time correlation of the scattering, the average size of
      the protein particles can be calculated.

3. (20 points) The discovery of the DNA double helix structure is one the greatest
   discoveries in last century. Answer the following questions about the double helix:
   a. Describe at least five major structural features of the DNA double helix. (5
      points)
      • Right-handed
      • Anti-parallel around common axis
      • Phosphate-sugar groups are outside
      • Base pairs via H-bonds
      • Base pairs are inside
      • Strict complementary: A-T and C-G
      • ~20 Angstrom in diameter
b. What are the major factors in the formation of DNA double helix? (5 points)
   Base pairing via H-bonding

c. What are the major forces in the stability of DNA? (5 points)
   Base stacking

d. What is the famous experimental evidence leading to the discovery of double helix? (5 points)
   X-ray fiber diffraction of DNA by Rosalind Franklin. The X-shaped diffraction pattern is characteristic of helical structure. Watson and Crick saw the image and then came up with the double helix model of DNA.

4. (20 points) If you were asked to determine the 3-D structure of an icosahedral virus, which one of the three major structural methods would you choose: NMR, Cryo-EM or X-ray crystallography? (5 points) Use all three methods in your arguments to support your choice. Contrast the advantages and disadvantages of each technique. (15 points)

Cryo-EM will be the best choice. Cryo-EM can use just a small amount samples, image the virus particles in near-native environment, and obtain atomic structure through 3-D computational reconstruction from 2-D image. Cryo-EM has advanced to a level in recent years that it is now considered a better method for virus structures than X-ray crystallography. X-ray crystallography has traditionally been the only method that can determine atomic structures of viruses. However, it requires well-ordered crystals that can be challenging or infeasible for many viruses. NMR can also determine 3-D structure in solution without need of crystal. However, it is only suitable for small structures and virus structures are too large for NMR.

5. (15 points) From the following image of ribosome, what insights can you get for protein synthesis? Justify your points using features in this image.

- Protein synthesis by ribosome starts from the arrow and then progressively proceeds to the other end along mRNA.
- Multiple ribosomes can work on the same mRNA but independently.
- The nascent peptide extrudes from ribosome and extends away from mRNA
March 7 \underline{Cume Answers} \hspace{1cm} \underline{INORGANIC}

**Question #1.**
- 20 e.u. \(\rightarrow\) associative mechanism

\[
\text{Indene} \xrightarrow{\text{rh slip}} \left[ \begin{array}{c} \text{OC} \\ \text{OC} \end{array} \right] \xrightarrow{\text{slip}} \text{back} \rightarrow \text{Rh}_{\text{complex}}
\]

Indenes have a fast rate because the ring slip induces aromaticity in the benzo substituent. Unsubstituted rings have faster rates because they are less sterically hindered \(\rightarrow\) makes assoc. mech go faster. Also, the groups make Rh more e-rich - disthioavored in assoc. mechs.

**Question #2.**
\[
\text{MLn} \xrightarrow{\text{bond rotation}} \text{reflect}
\]

**Question #3.**

A. \[
\text{p}^+\text{Bu}_2 \hspace{1cm} \text{Rh} \hspace{1cm} \text{Cl} \hspace{1cm} \text{p}^+\text{Bu}_2
\]

B. \[
\text{p}^+\text{Bu}_2 \hspace{1cm} \text{Rh} \hspace{1cm} \text{CH}_3 \hspace{1cm} \text{Cl} \hspace{1cm} \text{p}^+\text{Bu}_2
\]
Question #4.  
5 > 3 > 2 > 1 > 4
5: π→π transition, π-accepting ligand
3: 
2: 
1: 
4: σ*→σ* transition, σ-donor ligand

Question #5.

\[ \text{dissociative pathway: } \frac{k_1 k_2 [Co][P(OEt)\text{$_3$}]}{k_{-1} [PPh\text{$_3$}] + k_2 [P(OEt)\text{$_3$}]} \]

Question #6.
6a. CpW(CO)$_3$(C$_2$H$_5$)$_2$ + I$^-$
6b. 2 Mn(CO)$_5$H
6c. CpFe(\text{C}_6H$_5$)$_2$(CO)(PPh$_3$)
6d. Cp$_2$HfMe$_2$

Question #7.
A = CpFe(CO)$_2$H
B = CO
C = H$_2$
No Organic crib available
March 7, 2015
Written by Professor Dai
Ph# 67898
1) \[ \frac{d[A^*]}{dt} = k_1 [A][P] \]

2) \[ \int_0^t d[A^*] = \int_0^t k_1 [A][P] dt \]
   \[ [A^*] = k_1 [A][P] t \]

3) \[ \frac{d[A^*]}{dt} = k_1 [A][P] - k_1 [A^*] - k_2 [A^*][P] \]

4) If \( \frac{d[A^*]}{dt} = 0 \) (steady-state approximation)
   then \( (k_1 [A] - k_2 [A^*])[P] - k_1 [A^*] = 0 \)
   \[ [P] = \frac{k_1 [A^*]}{k_1 [A] - k_2 [A^*]} = \frac{k_1 [A^*]}{k_1 [A^*] - k_2} \]

5) Stimulated emission rate
   \[ \frac{d[P]}{dt} = - \frac{d[A^*]}{dt} = - k_2 [A^*][P] \]
   \[ = - k_1 k_2 [A^*] \]
   \[ \frac{k_1 [A]}{k_1 [A^*] - k_2} - k_2 \]