Exam 1, Chem 4A, Fall 2005

September 23, 2005
Professor Cohen

Name______________________________

SID______________________________

Lab GSI Name______________________________

Lab day and time______________________________

Problems

1. (20 pts) __________

2. (10 pts) __________

3. (30 pts) __________

4. (20 pts) __________

5. (20 pts) __________

Total (100 pts)_______________

<u>Rules:</u>

- Work all problems to 3 significant figures
- No lecture notes or books permitted
- No calculators with wireless access
- Time limit is 50 min
- Show all work to get partial credit
- **Box your answers**

Equations and Constants

Coulomb's Law
$E = \frac{q_1 q_2}{4\pi\epsilon_o r}$ — ϵ_o: Permittivity of vacuum; q_n: particle charges; r: distance between particles 1 and 2

Beer's Law
$A = \varepsilon c l$ — A: absorbance; ε: molar absorptivity; c: concentration; l: pathlength

Transmission
$\%T = \frac{I}{I_0} \times 100\%$ — T: Transmission; I: output intensity; I_0: input intensity

Absorption
$A = -log_{10}(T)$ — A: Absorbance; T: Transmission

Energy of Light
$E = h\nu = \frac{hc}{\lambda}$ — c: speed of light; h: Planck's constant; ν: frequency of light; λ: wavelength of light

Kinetic Energy of a Particle
$E = \frac{1}{2}m\mathrm{v}^2$ — v: velocity; m: mass

Photoelectric Effect
$E = h\nu - \Phi$ — h: Planck's constant; ν: frequency of light; Φ: material workfunction

Mean and Standard Deviation

$$\bar{x} = \frac{\sum_i x_i}{n} \qquad s = \sqrt{\frac{\sum_i (x_i - \bar{x})^2}{n-1}}$$

x_i: measurement i; $\bar{x}$: mean; n: number of measurements

Gaussian
$y = \frac{1}{\sigma\sqrt{2\pi}} e^{-(x-\mu)^2/2\sigma^2}$ — μ: Gaussian mean; σ: gaussian standard deviation

Confidence Interval
$\mu = \bar{x} \pm \frac{ts}{\sqrt{n}}$ — μ: Gaussian mean; σ: gaussian standard deviation

F-test
$F_{calc} = \frac{s_1^2}{s_2^2}$ — if $F_{calc} > F_{table}$ s_1 and s_2 are statistically different

t-test- where standard deviations are statistically equal

$$t_{calc} = \frac{|\bar{x}_1 - \bar{x}_2|}{s_{pooled}} \sqrt{\frac{n_1 n_2}{n_1 + n_2}} \qquad s_{pooled} = \sqrt{\frac{s_1^2(n_1-1) + s_2^2(n_2-1)}{n_1 + n_2 - 2}}$$

$DOF = n_2 + n_3 - 2$ — DOF: degrees of freedom

t-test- where standard deviations are statistically different

$$t_{calc} = \frac{|\bar{x}_1 - \bar{x}_2|}{\sqrt{s_1^2/n_1 + s_2^2/n_2}} \qquad DOF = \frac{(s_1^2/n_1 + s_2^2/n_2)^2}{\frac{(s_1^2/n_1)^2}{n_1+1} + \frac{(s_2^2/n_2)^2}{n_2+1}} - 2$$

$N_o = 6.022 \times 10^{23}$ molec/mol	Avogadro's number	$a_o = 5.292 \times 10^{-11}$ m	Bohr radius
$k_B = 1.381 \times 10^{-23}$ JK^{-1}	Boltzmanns constant	$e = 1.602 \times 10^{-19}$ C	Electron Charge
$m_e = 9.109 \times 10^{-31}$ kg	Electron mass	$m_p = 1.673 \times 10^{-27}$ kg	Proton mass
$m_n = 1.675 \times 10^{-27}$ kg	Neutron mass	$\epsilon_o = 8.854 \times 10^{-12}$ $C^2J^{-1}m^{-1}$	Permittivity of vacuum
$h = 6.626 \times 10^{-34}$ Js	Planck's constant	$c = 3 \times 10^8$ ms^{-1}	Speed of light
$R = 8.314$ J $mol^{-1}K^{-1}$	Gas constant	$R = 8.206 \times 10^{-2}$ atm $mol^{-1}K^{-1}$	Gas constant

F-Table

DOF for s_2	DOF for s_1: 2	3	4	5	6	7	8	9	10	12	15	20	30	∞
2	19.00	19.16	19.25	19.30	19.33	19.35	19.37	19.38	19.40	19.41	19.43	19.45	19.46	19.50
3	9.55	9.28	9.12	9.01	8.94	8.89	8.85	8.81	8.79	8.74	8.70	8.66	8.62	8.53
4	6.94	6.59	6.39	6.26	6.16	6.09	6.04	6.00	5.96	5.91	5.86	5.80	5.75	5.63
5	5.79	5.41	5.19	5.05	4.95	4.88	4.82	4.77	4.74	4.68	4.62	4.56	4.50	4.36
6	5.14	4.76	4.53	4.39	4.28	4.21	4.15	4.10	4.06	4.00	3.94	3.87	3.81	3.67
7	4.74	4.35	4.12	3.97	3.87	3.79	3.73	3.68	3.64	3.57	3.51	3.44	3.38	3.23
8	4.46	4.07	3.84	3.69	3.58	3.50	3.44	3.39	3.35	3.28	3.22	3.15	3.08	2.93
9	4.26	3.86	3.63	3.48	3.37	3.29	3.23	3.18	3.14	3.07	3.01	2.94	2.86	2.71
10	4.10	3.71	3.48	3.33	3.22	3.14	3.07	3.02	2.98	2.91	2.85	2.77	2.70	2.54
11	3.98	3.59	3.36	3.20	3.09	3.01	2.95	2.90	2.85	2.79	2.72	2.65	2.57	2.40
12	3.89	3.49	3.26	3.11	3.00	2.91	2.85	2.80	2.75	2.69	2.62	2.54	2.47	2.30
13	3.81	3.41	3.18	3.03	2.92	2.83	2.77	2.71	2.67	2.60	2.53	2.46	2.38	2.21
14	3.74	3.34	3.11	2.96	2.85	2.76	2.70	2.65	2.60	2.53	2.46	2.39	2.31	2.13
15	3.68	3.29	3.06	2.90	2.79	2.71	2.64	2.59	2.54	2.48	2.40	2.33	2.25	2.07
16	3.63	3.24	3.01	2.85	2.74	2.66	2.59	2.54	2.49	2.42	2.35	2.28	2.19	2.01
17	3.59	3.20	2.96	2.81	2.70	2.61	2.55	2.49	2.45	2.38	2.31	2.23	2.15	1.96
18	3.55	3.16	2.93	2.77	2.66	2.58	2.51	2.46	2.41	2.34	2.27	2.19	2.11	1.92
19	3.52	3.13	2.90	2.74	2.63	2.54	2.48	2.42	2.38	2.31	2.23	2.16	2.07	1.88
20	3.49	3.10	2.87	2.71	2.60	2.51	2.45	2.39	2.35	2.28	2.20	2.12	2.04	1.84
30	3.32	2.92	2.69	2.53	2.42	2.33	2.27	2.21	2.16	2.09	2.01	1.93	1.84	1.62
∞	3.00	2.60	2.37	2.21	2.10	2.01	1.94	1.88	1.83	1.75	1.67	1.57	1.46	1.00

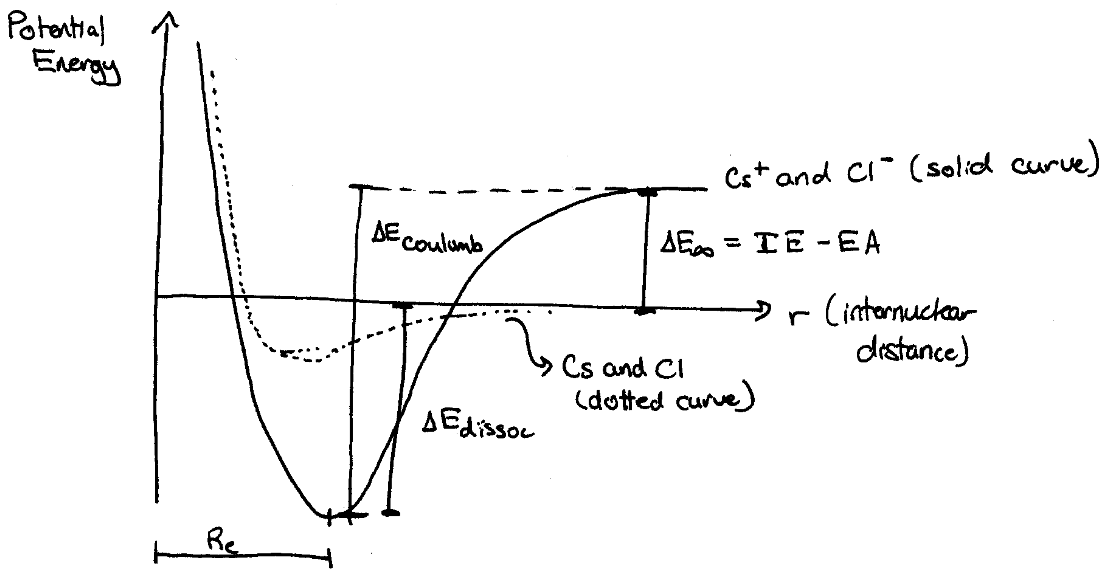
T-Table

DOF	50%	90%	95%	99%
1	1.000	6.314	12.706	63.657
2	0.816	2.920	4.303	9.925
3	0.765	2.353	3.182	5.841
4	0.741	2.132	2.776	4.604
5	0.727	2.015	2.571	4.032
6	0.718	1.943	2.447	3.707
7	0.711	1.895	2.365	3.500
8	0.706	1.860	2.306	3.355
9	0.703	1.833	2.262	3.250
10	0.700	1.812	2.228	3.169
15	0.691	1.753	2.131	2.947
20	0.687	1.725	2.086	2.845
25	0.684	1.708	2.060	2.787
30	0.683	1.697	2.042	2.750
40	0.681	1.684	2.021	2.704
60	0.679	1.671	2.000	2.660
120	0.677	1.658	1.980	2.617
infinity	0.674	1.645	1.960	2.576

	Cesium	Chlorine
Ionization Energy (kJ/mol)	375.7	1251.1
Electron Affinity (kJ/mol)	45.504	349.0

1. (10 + 10 points)

(a) Draw a diagram of the potential energy for CsCl and the ions Cs^+ and Cl^- versus internuclear distance. Label the major features.



(b) Estimate the dissociation energy of CsCl (in kJ/mol) relative to the separated atoms, use a bond dissociation of R_e=3.222 Å (1 Å = 10^{-10}m). State any approximations you make.

$$\Delta E_d = \Delta E_{coulomb} - \Delta E_\infty$$

$$= \Delta E_c - (IE_{Cs} - EA_{Cl})$$

$$= \frac{q_{Cl^-} q_{Cs^+}}{4\pi \varepsilon_0 r} \cdot N_A \cdot \frac{1kJ}{1000J} - (IE_{Cs} - EA_{Cl})$$

$$= \frac{(1.602\times10^{-19})(1.602\times10^{-19})}{4\pi(8.854\times10^{-12} C^2 J^{-1} m^{-1})(3.222\times10^{-10} m)} \left(\frac{6.022\times10^{23}}{mol}\right)\left(\frac{1kJ}{1000J}\right) - (375.7 - 349.0)\frac{k}{m}$$

approx.
- ions are point charges

[illegible]

$$= 431.05 \frac{kJ}{mol} - 26.7 \frac{kJ}{mol}$$

$$= \boxed{404\ kJ/mol}$$

2. (10 points) The element Pt has a relatively high workfunction of 5.65 eV (9.0513×10^{-19} J). 200 nm light is incident on the surface.

What is the kinetic energy (in J) of a photoemitted electron?

$$E = h\nu - \phi$$

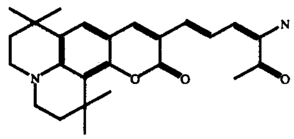
$$= \frac{hc}{\lambda} - \phi$$

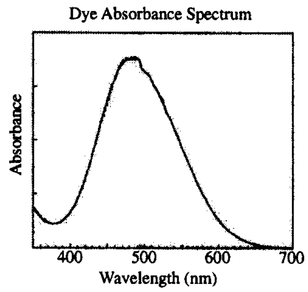
$$= \frac{(6.626\times10^{-34}\,\text{Js})(3\times10^{8}\,\text{m/s})}{(200\times10^{-9}\,\text{m})} - (9.0513\times10^{-19}\,\text{J})$$

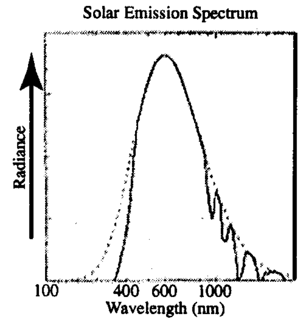
$$= 9.939\times10^{-19}\,\text{J} - 9.0513\times10^{-19}\,\text{J}$$

$$= \boxed{8.88\times10^{-20}\,\text{J}}$$

3. (10 + 10 + 10 points) A large amount of research has gone into developing organic molecules for use in thin film solar cells. Below is the structure of an organic dye molecule first synthesized in 2001, as well as its absorbance spectrum and the emission spectrum of the sun.







(a) For a hypothetical solar cell coated with a monolayer of the dye (a layer one molecule thick), the absorbance at 500 nm is 0.0340. What percentage of transmitted light does this correspond to?

$A = -\log_{10}(T)$

$-A = \log_{10}(T)$

$10^{-A} = T$

$T = 10^{-0.0340}$

$= 0.9247$

%T = 92.5%

(b) Assume that each monolayer is 1 nm thick and the molecules have an effective concentration of 6.40 mol/L in the film (1 L = 1 dm³ = 10^{24} nm³). What is the molar absorptivity at 500 nm? (report your answer in units of $M^{-1}cm^{-1}$)

$$A = \varepsilon l c \Rightarrow \varepsilon = \frac{A}{lc} = \frac{0.0340}{(1\,nm)(6.40\,M)} = \frac{0.0053}{nm \cdot M}\left(\frac{10^9\,nm/m}{10^2\,cm/m}\right) = 53125\,M^{-1}cm^{-1}$$

$5.31 \times 10^4\,M^{-1}cm^{-1}$

(c) Why is this compound useful for a solar cell? What property would one optimize to make it a better material for a solar cell?

Useful because there a strong absorption band between 400 - 600nm where the sun has a strong emission

The material would be better if it absorbed more light at longer wavelengths because the sun has a strong emission band out to ~1100nm.

4. (10 + 10 points) The gem stone ruby a is crystalline material composed of Al_2O_3 that contains a small amount of chromium which results in the intense red color of the gem. The FBI has intercepted two separate illegal shipments of rubies. They believe that the rubies came from the same source and analyzed one gem from each shipment. The mass of chromium in each gem are shown below as well as the number of times each gem was tested.

Gem	Amount of Cr (g)	Mass of Sample (g)	Number of Measurements
A	0.056 ± 0.002	3.27	20
B	0.06 ± 0.01	3.27	15

(a) Are the two gems from the same source based on a 95% Confidence Interval. Justify your reasoning?

$$F_{test} = \frac{S_B^2}{S_A^2} = \frac{(0.01)^2}{(0.002)^2} = 25 \qquad F_{test} \gg F_{table} \ (\sim 2.3)$$

thus Standard deviations are statistically different

$$t_{calc} = \frac{|0.056 - 0.06|}{\sqrt{\frac{0.002^2}{20} + \frac{0.01^2}{15}}} = \frac{0.004}{\sqrt{2\times10^{-7} + 6.6667\times10^{-6}}} = \frac{0.004}{\sqrt{6.8667\times10^{-6}}} = \frac{0.004}{0.0026} = \boxed{1.5265}$$

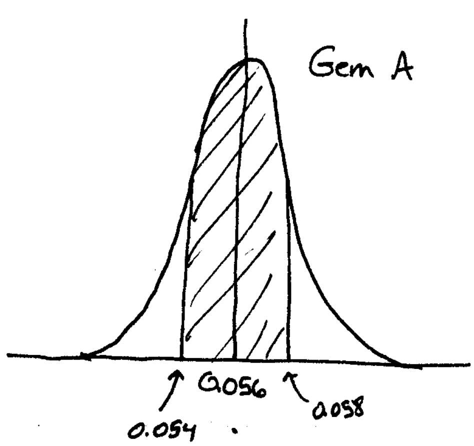
$$DOF = \frac{\left(\frac{0.002^2}{20} + \frac{0.01^2}{15}\right)^2}{\left[\frac{\left(\frac{0.002^2}{20}\right)^2}{21} + \frac{\left(\frac{0.01^2}{15}\right)^2}{16}\right]} - 2 = \frac{4.7151\times10^{-11}}{\left[\frac{4\times10^{-14}}{21} + \frac{4.444\times10^{-11}}{16}\right]} - 2 = \frac{4.7151\times10^{-11}}{2.7799\times10^{-12}} - 2 = 16.96 - 2 = 14.96$$

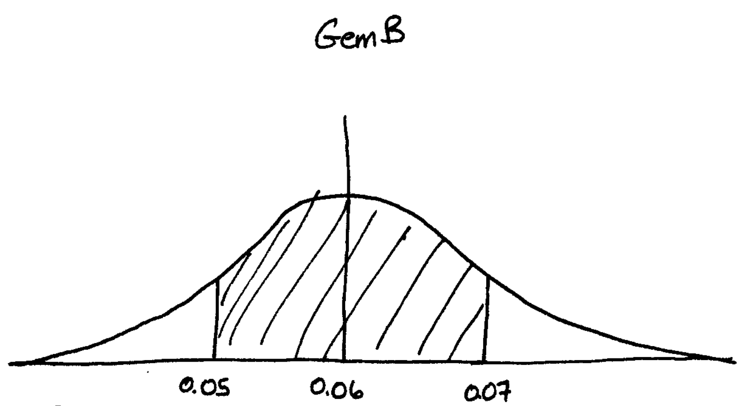
1.9048×10^{-15} 2.778×10^{-12}

$\boxed{DOF \approx 15}$

$t_{calc} < t_{table}$ therefore the Cr conc in the two rubies is not significantly different and they are from the same source.
(1.53)   (2.13)

(b) Sketch 2 gaussian curves: one for gem A and one for gem B. Label the mean, and label and shade the region between + 1 and - 1 standard deviation. Be sure your drawings clearly show how precise the measurements are for each gem.





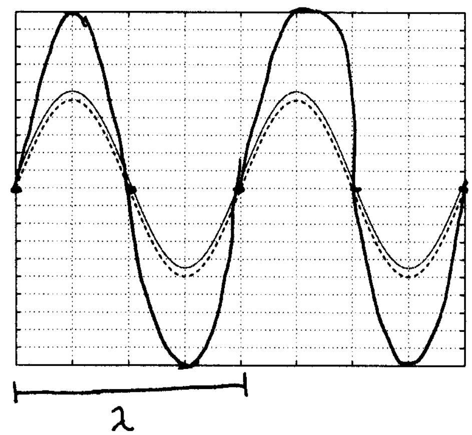
5. (15 + 5 Points)

(a) Shown below is a plot of the electric fields of two blue, 400-nm light waves (with a small vertical offset on the solid curve in order to visualize both waves). A single photon of blue, 400-nm light was measured with a photodiode detector placed in a spectrometer and has an intensity of 1. On the figure below draw the electric field that would result from constructive interference of two identical 400-nm waves traveling the same path in space and time.

- What is the wavelength for the new wave you've drawn? 400nm
- Label the wavelength distance on the drawing.
- What is the intensity of the new wave? → $I = |E^2|$ $I_{old} = 1^2 = 1$
- What is the amplitude of the new wave? 2

$I_{new} = |E_1 + E_2|^2 = |1 + 1|^2 = 2^2$

$I_{new} = 4$



(b) Shown below is a plot of the electric fields of two blue, 400 nm light waves that are 180° (π) out of phase with each other. On this figure draw the wave that would result from the interference of these two waves.