Transport

Chu/Radke

<u>Siddharth Dey</u>
The first problem was about heating of coffee in a microwave. I was asked what mode of heating is used in a microwave (radiation) and then was asked whether the cup would heat uniformly or whether there would a radial temperature profile (fumbled on that one a bit, but finally got it right- uniform heating). Was then asked to do a energy balance to find how the temperature of the cup changed with time (overall energy balance). Next the problem was extended by saying that the air around the coffee is flowing. Derive the temperature profile of the air surrounding the coffee cup (Do energy balance).

Next they moved on to momentum transport and asked me the physical significance of viscosity (I did the stuff that is given in BSL about a fluid between two plates and then one of them is made to slide relative to the other). They asked me the direction in which the momentum will be transferred and the velocity profile at equilibrium. They then asked me that if momentum is being transferred from the region of high velocity to the region of low velocity, where does it goes after it reaches the other end. (gets transferred to the medium that will be above that plate).

Finally they asked me to describe a viscometer that I have used in the lab (I told them ostwald's viscometer). Then they asked me how ill find the viscosity, so I used the equation of motion to find the required equation for viscosity. Then I was asked how ill determine if the fluid is Newtonian or non-newtonian fluid. First I blurted out some stupid answer, but finally got it right – changing the size of the bulb of the viscometer. If measured viscosity changes then non-newtonian.

Just before I was leaving Radke asked me why viscosity of polymers show shear thinning normally. I didn't know. He explained that initially it is newtoian and after a long period when the polymer can be stretched no longer the viscosity is again Newtonian, and in the middle region it is non-newtonian. (I didn't listen too carefully to it coz all I wanted to do was get of of the room). And then he said- that was a trick question and started laughing.........

<u>Ryan Balliet</u>

Radke
- I put a mug of tea in the microwave to heat it up. I take it out after, say, 90 s. How hot is the tea? First, assume no heat loss. Next, assume that there is heat loss--how does one account for this? What method would one use to solve the resulting equation? *Application of the energy equation—neglect end effects and assume cylindrical coordinates. Write out the equation. State assumptions and then start crossing out terms. Add boundary conditions. Separation of variables.*

Chu
- What is viscosity?
- What is a Newtonian fluid? What is a fluid called if it is not Newtonian?
- How does a viscometer work? *Application of Hagen-Poiseuille equation.*
- How could I use the viscometer to tell find out whether or not a fluid is Newtonian or not? *Vary the head pressure (which will change the fluid velocity) and measure the viscosity. If the viscosity does not change with velocity it is Newtonian.*

<u>Greg Stone</u>
Radke started off with a question about how much power he just used to heat up his tea in the microwave. He simplified the problem down so much that by the time it was done, it didn't even make sense (1st prelim of the day). Chu followed up by asking me for a qualitative description of viscosity and a bunch of little questions about Newton's law of viscosity.

<u>Andrew Behn</u>
I wasn't sure how the dynamic between these two would work, with Chu being the new guy in town and Radke the subject of prelim folklore. I thought I had done terribly on this exam when I walked out, but ended up getting a good grade (so don't panic).

The first question had to do with Radke's cup of tea, which he had just warmed up in the microwave. They had me set up the differential equations for the heat balance, assuming that the radiation was being absorbed evenly throughout, and that heat was being lost through convection over the entire surface of the mug (ignoring the exposed surface). I fumbled through this, but once I had gotten going in the right direction, Radke corrected my math errors. Then Chu asked what the temperature profile would look like in the mug (and outside) if there was no fluid movement. Then Radke asked me to determine the overall heat transfer coefficient based on the conductivity of the ceramic, the internal heat transfer coefficient, and the external heat transfer coefficient (series of

resistances stuff). Then, Chu asked which would be a bigger resistance. I guessed correctly, and let them believe I knew what I was talking about. Radke asked how the temperature profile would change if various heat transfer parameters were changed. Finally, Radke asked me to write the BC's and IC for the differential equation and how I would solve it. I said separation of variables which was apparently correct. Then, they asked what type of function the solution would be.

Me: "series of sines"
Radke: "nope, try again"
Me: "series of cosines?"
Radke: "you're guessing"
Me: "yup"
Chu: *laughs*
Radke: "Bessel function"
Me: "I knew that"
Radke: "No, you didn't"

The second question they asked was about how to determine the viscosity of a fluid. I drew a capillary type viscometer up on the board, and wrote the Hagan-Pousieulle equation, whose pronunciation I completely butchered. They asked if I could use this for a non-newtonian fluid. I said no, and when they wanted backup, I drew the H-P flow derivation shell balance, and said you assumed Newtonian fluids in shear stress components. (good enough). Then, they asked if I could use this to determine if fluid was Newtonian or not. The answer is yes, and you do this by changing the driving force on the fluid entering the capillary. Newtonian will give a constant visc, non-newtonian will differ for different pressures.

Graves/Muller

Scott Mullin

I walked in and shook both of their hands. Grave was in a jovial mood, while Muller was in the normal semi-smile mode. They had me take a seat, and asked what school I went to, and what transport book I'd used. I told them "welty, wicks and Wilson." Muller interjected "And Rorrer" – at which point I joked that I never say that one because it's hard to pronounce. They liked that one, and Graves continued on and apologized to me for Oklahoma's crushing defeat by Boise State in the football game over the weekend. Things were looking up, then the question came: "what would the temperature profile look in a cooling

wire that is moving from an infinite source on the 2nd story of a building into a pool of liquid at ground level at velocity v– the liquid and the wire are at the same temperature when the wire enters the liquid." I talked through and made sure what the details were – temp of the wire (hot or cold) and if we needed to consider convection (a 'tricky' subject as they remarked, because convection isn't a well-defined concept – "what is convecting?") etc. I also remarked that radiation shouldn't be considered because it would be negligible at the time scale and distances here. Graves said that's not necessarily true, then I continued on my way. Next I started to write a shell balance to solve for the heat in and out of a fluid element. I chose a stationary element, and couldn't figure out how to account for the wire moving. Both kept saying things like "you're missing a convective term... it's pretty obvious" and I finally realized I should add the moving wire in as... a convective term! I stumbled through the whole thing, but finally derived the equations with a lot of goading and many hints from the professors. I repeatedly made algebraic mistakes and had trouble setting up the shell balance. I mentioned that I was trying to think of it as a heat exchanger, as the heat exchanger equations were the only place I'd ever seen a shell balance for heat transfer. Their faces contorted a bit, and I knew I was in trouble, and on my letter at the end of the day they made it pretty clear that thinking of this problem as a heat exchanger was bad. At the end I just slunk out of the room and got some fresh air. Anyway, that one didn't go so well, but I had 2.5 hours to eat lunch and get Alisyn to cheer me up before the next ones.

Becky Rutherford
Have a small rod moving with a constant velocity through air and then into a liquid (think vertically). You draw the expected temperature profile, come up with some boundary conditions, develop an equation to model the temperature, use some dimensionless numbers to justify doing it in one dimension (Nu, Biot, Peclet). (~30 min) Next I had a fluid between two plates, top plate moving, had to draw velocity profile initially, at start-up, in-between, steady state. (~10 min)

Overall thoughts: Just memorizing dimensionless numbers will get you no where. You really need to know which ones to use to justify simplifications, and how to use them to get parameters (such as k or h). Look over the charts you'd use and see what information you need to know. However, memorizing Navier Stokes, continuity equations, and the del-operators is an excellent use of your time.

Albert Keung

I started off the day with Profs Muller and Graves. Both were very even-keeled throughout without much emotion either way even when I was clearly confused. They asked me what texts I used, I told them mostly lecture notes though we did use problems out of BSL for fluids. Also told them I had no mass transfer class, and they laughed and said, well I guess you're getting a mass transfer problem. Laugh. They were nice and Muller gave me a heat transfer problem first: metal rod moving into colder fluid, ignore radial resistance to conduction in rod, steady state, draw the temperature profile in the rod, setup how you would calculate the temperature profile (easiet to just use the energy eqn and not shell balance), boundary conditions?...T=Tinfinity at far from fluid, T=Tfluid very far into fluid (also I think you can split up the problem into two by above and below the fluid interface and use matching conditions at the interface, how do you get the heat transfer coefficient? nusselt-know Re, Pr, Nu, Sc, etc., also know units of all types of diffusivities is [=]m2/s. Both profs asked questions throughout. Graves then asked derive velocity profile in cylindrical tube....results in hagen-p eqn. What is stress profile? Is that stress profile still valid for a non-newtonian fluid...I think the answer is yes because you get that profile before substituting in the constitutive eqn...but they didn't give me a clear no or yes. They asked some smaller questions about calculating viscosity and friction factors but I can't remember exactly what.

Jarred Ghilarducci
Temperature profile for wire going into bath; velocity profile of non-Newtonian fluid between two plates.

Muller/Radke

Raj Gounder
First, Muller asked me about the steady-state axial temperature profile in a wire that is being pulled at a constant velocity into a pool of liquid maintained at a constant temperature. She also told me that the temperature of the wire infinitely far away from the liquid surface was known. I started with a shell balance in the z-direction, but instead wrote down the microscopic energy balance and solved it from there. You get a second-order linear ODE which she had me solve. Then she asked me what would happen if there was an appreciable temperature gradient in the radial direction and what new boundary conditions I needed. Along the way, she and Radke asked many, many questions about assumptions I was making, dimensionless groups that were relevant, etc.

Then, Radke asked me to essentially model the problem that causes "dry-eye". He said that, on average, a person blinks every five seconds and renews a layer of liquid (mainly water) over the surface of the cornea. The liquid has some small concentration of salt in it. In between blinks, some water will evaporate from the liquid film and cause the salt concentration to rise - there is some threshold at which this irritates the cornea (this is apparently a big problem on airplanes and in Arizona). I started off modeling the thin film as a flat surface, saying the per area flux of water into the air can be determined by some mass transfer coefficient times a concentration gradient. Then we had a side discussion about where to get mass transfer coefficients, how to find concentrations, etc. To solve the problem, you equate that flux to a change in volume (related to a change in height) of the water as a function of time and then integrate to find the thickness of the film as a function of time (turns out to be a linear decrease).

Other thoughts: I don't know why, but coming into this exam, I was a little nervous (I wasn't going into my other two). I think this was because, since I had three hours between my first one and this one, I decided to look over some problems and study a bit more before the test. This was probably a bad idea and why I was nervous going in, and it definitely reflected on my performance. These two also asked a lot of "rapid fire" questions while I was at the board working the problems. It seemed like Radke asked me something new every ten seconds when I was trying to work his problem, and I didn't really have time to think because he kept interjecting with a new question. In the end, I think he was trying to see how well I could think on my feet and respond under pressure, and even though I stumbled through some parts, he was reassuring at the end. My advice for this test is to basically study the conservation equations and know important dimensionless groups, and definitely try not to study or look over stuff right before you go in to the exam – all it will do is confuse you and add anxiety to your life. Also if you have Radke, try not to get flustered when he starts asking you a billion things at once.

Kevin Haas

Muller. Infinite rod dropping into liquid at constant temperature. Use microscopic balance. Don't neglect vz*dT/dz term. Obvious. Talk about type of boundary conditions and correlations used for heat transfer coefficient. Remember: use the density, viscosity, and thermal conductivity of the phase through which one assumes a gradient. Here the rod is uniform in temperature in the radial direction so the surface heat transfer correlation needs to use water's physical constants. Know a little

boundary layer theory and the Pr=cp*mu/k.

Radke: Contact lens drying. Simple diffusion problem to determine water loss per second then this gives volume loss per second and the rate at which the thin film of water over the eye evaporates. Know how to derive the wet bulb temperature (this is in McCabe Smith and Harriot in the humidifier section) for the boundary conditions.

<u>Will Vining</u>
Muller asked about a wire moving into a bath at a velocity, v, and I had to determine the temperature profile in the wire neglecting radial changes in temperature and with radial changes in temperature. Then I had to solve the differential equation. It turned out to be a 2nd order differential so I used the indicial eqn. I also had to know the Pr, Nu, Sc, St, and Re numbers. They asked me those directly. The second question was to determine the salt concentration in the eye, so I used diffusion of water from the eye to calculate the concentration of salt wrt time. Be sure to start with mass balances with Radke, and don't be flustered when he constantly harasses you.

<u>Hagar Zohar</u>
See Raj, Kevin, and Will's description of this exam above, mine was identical.

Graves/Chu

<u>Claire Woo</u>
Graves asked the silicon processing question. You have O_2 diffusing towards a Silicon slab, which has a growing layer of SiO_2 on top. How fast does SiO_2 layer grow? First, assume quasi-steady-state, so the SiO_2 has a certain thickness x (draw out what is happening).   Then use the conservation of mass equation to find the concentration profile of O_2 across the SiO_2 layer (you should get a linear profile since there is no reaction in the SiO_2 layer).   Reaction only occurs at Si interface, and you can balance the flux with reaction rate to get a quasi-steady surface concentration of O_2. Now you have a concentration profile with 2 terms that depend on time (the thickness x and the surface concentration). Lift the quasi-steady-state assumption and use p/MW dx/ dt = reaction rate/ area = k $C_{O2, surface}$).

Chu asked me the meaning of viscosity, which I didn't explain well.   Consider 2 parallel plates, the top one is moving at velocity V, and the bottom one is stationary. What is the velocity profile? In what direction is momentum

transferred? He wanted a molecular explanation of why this happens. Molecules can jump between levels and that's how momentum is transferred. Lastly, what is dependence of gas and liquid viscosity on temperature? (this is the kinetic theory of gases.)

Vicky Tran
I was told this and I believe it to be true "Prelims is the most fun you'll never want to have again."

Both of these guys are very nice. I felt that the entire time they just wanted to teach me.

Graves:
1.) You have a spherical thermocouple and it is being blown by a hair dryer on its low setting. What does the thermocouple read as time passes when it switched to high?
> Assume that the thermocouple all at the same temperature. Justify by using the Biot number.

2.) You have a solid sphere with a reaction of A→ 2B. A is in the bulk and there is a stagnant boundary layer. Do a flux balance. Is it reaction limited or mass transfer limited. Determine the concentration profile.
> Shell balance or conservation equation is fine for the profile. I wrote down the conservation equation, but mumbled about how I didn't account for the A→2B and he said it was fine.

Chu:
You have a sphere in creeping flow. What is the equation for Stoke's Flow? What would the equation be if the fluid was stationary but the sphere moved? Draw the flow profile around the sphere. Pick a point around the sphere. Which direction is the momentum flux?
> I was supposed to justify something with the stress tensor but Graves said time was up and I could go.

Kinetics/Thermo

Bell/Clark

Ryan Balliet
Bell
- Consider a 2nd order reaction. What is the physical reason why a reaction might be second order? Why do molecules react? *Collision theory.*

- Consider a 2nd order reaction and two equal-volume reactors, one PFR and one CSTR. In order to maximize conversion, assuming that they are arranged in series, which be first? How does this change for a 1st order reaction? *For first order reaction the order doesn't matter. For higher order the PFR should come first. You can verify this using the design equations but I just stated it (we had covered this in ChE244) along with a brief verbal explanation about the concentration profile in a PFR vs. CSTR and they seemed fine with that.*
- Consider a falling film of KOH. CO2 is in the gas phase adjacent to the film. The CO2 is absorbed into the film and reacts. What does it form (what is the reaction)? What does the concentration profile look like inside and outside the film?

Clark
- Consider a gas at pressure in a pipe. The gas leaks out through an orifice. Does the temperature go up or down?
- What if you did not know the Joule-Thompson coefficient for the gas? How can you make a thermodynamic argument that will tell you the temperature response?

Claire Woo
Bell first asked me about kinetics. Reaction A + B -> C, what is the rate law? What does order of the reaction mean? If you have a unimolecular reaction, say O_2 -> 2O, why is it first order (i.e. why does increasing the O_2 concentration increase the rate)? Basically, I think he just wants you to say that when there is more O_2, there are increased chances of collisions, leading to transfer of kinetic energy, and more molecules can get over the activation energy hump.
Then he asked me about the reaction of silane (SiH_4 -> Si + 2H_2) and what does the concentration profile look like in a tubular reactor that only has reaction at the walls? What is the design equation?
What is the concentration profile in a falling film reactor?
Then Clark moved on to thermo questions on protein unfolding. So the reaction is: folded protein -> unfolded protein. What is the dependence of delta G on T? (think whether the reaction is spontaneous at room temperature. What about at higher T?) Then we went on to discuss the dependence of delta H and delta S on temperature, mentioning the first law, second law etc. Lastly, is delta H or delta S for this reaction positive or negative?

Kevin Haas
Clark: Basically some bio questions about the free energy of mixing different amino acids and similar biomolecules. Talk about enthalpic

benefit of hydrogen bonding but loss of entropy because of necessary linear orientation of solvent/solute interaction. Also asked some real basic thermo stuff like what happens in adiabatic expansion, dQ=0, PV^gamma=const.
Also what happens to entropy as something is heated i.e. dS=dQ/T.

Bell: How does a reaction work, i.e. O2 dissociation. (maybe talk about some transition state theory about the redistribution of kinetic energy into a sufficient push over the reaction coordinate) Why is this reaction first order. Does the box size have an effect? (I said no).

Greg Stone
Bell asked me about the decomposition of silane into hydrogen and silicon. He asked me about why the rate constant increases with increasing temperature, but without using the Arrhenius relationship (I gave a stat mech answer about probabilities of energy states). He also asked about a surface reaction and about the shape of the concentration profile. Clark asked me about the heat capacities and how I derived them.

Katz/Prausnitz

Will Vining
They asked me what the third law of thermodynamics was, why it was useful, and how to determine all of the values, eg entropy of melting. Why is Cp greater than Cv for an ideal gas? Then we moved to kinetics, and I had to draw the concentration profiles for two reactions in series for pssh and non-pssh. Then I had to discuss how to calculate the kinetic data given a black box for a reactor and the rtd. Finally, we came back to thermo and I had to tell them how to calculate the thermodynamic properties of the reaction and the conditions under which those values can be used, eg T,P. Very friendly committee and helpful.

Albert Keung
Prausnitz started off by asking about how to separate gases (a process question I thought!, but hey, anything's better than fugacity). I answered linde process. Explain Joule-Thomson coefficient and inversion temperature. How to cool H? use liquid N2. How to cool He? use liquid H. Where does cooling take place in your kitchen? Fridge. Draw refridgeration cycle. Then he proceeded to aske me tons of fugacity and activity coefficient stuff at which I blankly just wrote up definitions. He told me I was just writing definitions, so I wrote more

definitions of other fugacity-related things. He asked how to calculate fugacity coefficient, I wrote down int(Z-1)dP/P. He asked what Z was, eqn of state, then he asked about correlations for that eqn of state...I mentioned correlation of parameters/states. Katz asked: you have a tank reacting A, with flow in 2vo and flow out vo. Calculate the concentration profile with time. To do this, write out mass balance then write out "volume balance" of the tank to get V as a function of time so you can plug this into your mass balance. They just had me set it up then moved on. Katz asked: if you heat up polymer solution, why does the polymer phase separate into a gel? entropic effect similar to hydrophobic effect where solvent molecules have less entropy when forming a solvating cage around polymer moleucles, so thus gain entropy when the polymer phase separates. Asked me how to calculate heats of reaction not occuring at standard states (just drawing up a diagram of calculating a 3 step reaction path from nonstandard to standard reactants, standard reactants reacting to standard products, standard products converting to nonstandard products. Overall, a nice pair even through the fugacityness.

Hagar Zohar
What is the Joule-Thompson coefficient?   Why is it important? Where is it used in your kitchen? Refrigerator. Why is the compressor in your refrigerator held at a higher pressure than ambient? If there's a leak you don't want ambient air with water vapor getting into your refrigeration system where it will freeze and bang up the equipment. How do you find fugacity - what experiments are done to get the values in those charts and tables? How do you get values for entropies and how does the third law let you do this? How do you determine Keq? If you have a tank of constant volume initially with only a small volume of contaminant present, how can you estimate the time necessary to flush out the contaminant? Key was residence time and an understanding that tank behavior is between two extremes CSTR (it takes infinite time to remove all contaminant) and PFR (all contaminant leaves at residence time).

Vicky Tran
Both of these guys are very friendly. Prausnitz started and ended my exam with questions about Lowell's history, industries, and culture.

Prausnitz:
1. *What is the Joule Thompson Coefficient and its significance?*
    Goes into Joule Thompson effect, refrigeration cycle, and liquefaction of air, helium, and hydrogen.
2. *What is the third law of thermodynamics? What is its significance?*

Use the relationship between Gibb's energy and the equilibrium constant. You can calculate concentrations of the species in equilibrium using the equilibrium constant, fugacity, and fugacity coefficients.

Katz:

1.) You have a tank and 1/10 of it is filled with a solution of bacteria. If you empty at a volumetric flow rate of v_0, and fill with a volumetric flow rate of $2v_0$, how do you obtain a certain concentration?

Do a mass balance on the concentration of bacteria.

2.) You have a continuous reactor but don't know what kind. Material enters at one temperature and leaves at a higher temperature. How do you determine the exit concentration?

Do an energy balance.

Clark/Katz

Scott Mullin

This test went much better. Clark and Katz were in a good mood, and asked me what books I'd used, etc. Neither had heard of Jack Winnick (Uncle Jack?). That didn't really matter, as most of my test was based on kinetics. The first question was: "Imagine you have 10% of a biological contaminant such as bacteria in a bioreactor, and you want to purge it. How long will it take to have less than one millionth of the original concentration (best and worst-case scenario). The flow rate into the reactor is 2vo, and the flow rate out is vo" You don't know what kind of reactor it is, so you want to think of the max/min mixedness models (CSTR and PFR). I set up a material balance and solved the equation for the CSTR model. At one point I took the differential of some term, and Katz took exception to it. He hinted that I'd done it wrong, and kept asking me to "find the error in my equation." I had written a little bit small on the board, which is at an angle to his desk, so I re-wrote it closer to him. After about 5-7 minutes he realized I'd done it right and he just couldn't read my writing. It was awkward. Clark asked a few questions about how I'd solve for the time (answer: it's the solution to the diff eq. you just wrote). The next question was about an adiabatic reactor and how you'd solve for its temperature. I had trouble understanding how they wanted to set up the problem, but was able to whip out some heat balances like a short-order chef at lunchtime. I made similarly bad analogies during the test, all of which went right over their heads (no sense of humor, these people!) Also had to mention how to find the entropy of the system (integrate Cp/T, much as you find enthalpy from the integral of Cp). My final question-ish (there were several other small

questions) was about protein folding and the associated thermodynamics. Nothing too complicated here.

Raj Gounder

This was my last of the day and I was very relaxed going in, and it definitely showed in my performance as well as the mood during the exam. Katz started off with a question about a general exothermic reaction (A goes to B) in an adiabatic black box. We know the temperature going into the reactor and the conversion of A - how do we figure out the exit temperature (basically set up an energy balance, explain all terms, units, etc.) Then he asked what delta heat of reaction I should use and made me draw a temperature versus reaction coordinate diagram. I explained to him that since enthalpy is a state function, we can add the enthalpies of first raising the temperature of the feed from T_initial to T_final, and then reacting it all at T_final (obviously other paths work as well).

Next, Katz told me we had a CSTR filled with a solution with dye in it. At time 0, we start flowing in clear solution. He wanted me to describe the concentration of dye in the reactor as a function of time. Pretty straightforward.

Then, Clark asked me a question about protein folding. He started with questions about N Methyl Amine compounds and if it's soluble in water versus benzene and the different forces present in the two. Then he asked why it dimerizes in benzene (hydrogen bonding). He asked how to determine the change in Gibbs free energy between the two (in water and in benzene) and I explained that $\ln(K_{eq}) = -DG/RT$. He asked me what K_{eq} was and how to calculate it and I started explaining to him about liquid activities and all the terms that went into that, but ideally, you can just measure concentrations. Then he asked if K_{eq} was a function of temperature, so I started deriving the van't Hoff equation and he saw that I knew what I was doing and went back to protein folding. He said the change in Gibbs free energy in benzene for the N Methyl Amine compound was 6 kcal/mol, but only 4 kcal/mol for a protein, so why is the hydrogen bonding apparently stronger in a protein. The answer to this is the enthalpy-entropy trade off. In a folded state (or a dimerized state for the N Methyl Amine), there is a loss in entropy, but this value is far less negative for a protein because it is already constrained by the backbone whereas the N Methyl amine compounds are losing translational degrees of freedom, etc.

Finally, Katz asked me how I would measure the change in entropy of vaporization of water. I said at equilibrium, dG is equal for the vapor and liquid, expanded that using H-TS and showed that you can calculate it at a given temperature if you knew the delta H of vaporization.

Other comments: This is a good committee to have – both professors were very kind and helpful throughout the exam and there was a relaxed atmosphere throughout. Everything they asked mainly tested your understanding of the fundamentals – I was able to answer everything by applying fundamental thermodynamic/kinetic relationships, which is theoretically what prelims should be a testing for. Overall, the entire prelim experience seemed more of a test of how well you carried yourself and could explain things and how engaging you were at the board, as well as your demeanor under pressure when they started bombarding you with rapid fire questions, instead of your level of knowledge, because even if you didn't know some details, they would walk you through them.

<u>Andrew Behn</u>
This exam was pretty straightforward. The first question was on the concentration vs time plot for a A->B->C type reaction. They wanted to know what I would call "B" if the second reaction (B to C) were very rapid (answer: reactive intermediate). They had me draw the plots for the two cases where k1 and k2 were similar in magnitude, and the plot where k2 was much greater than k1. Then, they asked how I would justify the PSSH on B by pointing out characteristics of the second graph (relatively constant B concentration throughout reaction)

The other questions were about thermo. First, they asked why proteins unfold at higher temperatures (classic prelim question). I can't recall the other questions, but they were similarly predictable. This exam was actually quite short, as they had gotten behind schedule and wanted to make up time.

Bell/Prausnitz

<u>Siddharth Dey</u>
First Prausnitz began by asking about the Joule-Thompson coefficient……Didn't know that stuff so well so I couldn't answer much. He then asked me how the refrigerator works. Next he asked me about throttling. I was pretty blank about it. By now I thought I was going to fail this one. Thankfully though things became better from here. He then swithched to solution thermodynamics and

asked me what the Gibbs-Duhem equation is and what it is used for. 1. For determining the thermodynamic consistency of expt data 2. To obtain the activity coefficient for the second component in a binary mixture, if the activity coefficient for one of them is known. He then asked me about models for activity coefficient (Margueles eqn).

Bell then started off with kinetics asking me how to derive the equation for equilibrium constant. He then went to a problem of Silane deposition in a tubular reactor. I had to write the differential mass balance equation in the reactor. He then moved on to asking me about thiele modulus and I had to derive the equation in a flat bead. He then asked me to plot effectiveness factor VS thiele modulus. He then said that it was reported on literature that some reactions have inverse order of reaction. If such a reaction was carried out in pores how would the above graph look. I said that effectiveness factor will now be greater than one and that seemed to please him. He then asked me if the catalyst should be uniformly coated on the catalyst pellet or not. I told him that it will be better to have higher concentration of the catalyst at the center. He told me that's correct and then Bell and Prausnitz started discussing how someone in Berkeley had done this stuff.

Before leaving Prausnitz asked me to write the equation between Cp and Cv for a ideal gas and explain physically why Cp is always greater than Cv. I didn't understand how to explain it physically first, but with some help from him I finally got the right answer. (In a piston arrangement- Cp involves a work term and thus is greater than Cv)

Becky Rutherford
Thermo: Joule Thompson coefficient, refridgeration cycle, Gibbs-Duhem equation (Why's it so important? not how to derive it)

Kinetics: What is k? Got off into collision theory, tried to explain 'k' for a unimolecular reaction in terms of collision theory, did some reactor RTDs, which type of reactor would you use for second order, high temperature, etc?

Overall thoughts: Good luck.

Jarred Ghilarducci
Joule-Thompson coefficient, Henry's law for gases, intuitive reasons for Cp = Cv + R; intuitive reasons for rate law and rate constants (hard sphere model etc).

Process Design

Alexander/Blanch

Raj Gounder

They started off asking me about my senior design project, which was to design a plant to produce biodiesel from waste vegetable oils. I started to describe the project and explain the process that we had come up with but they really weren't interested in hearing about the details. I got about halfway through when they stopped me and asked me other things.

First, Alexander asked me to come up with different ideas to control the temperature in a packed bed reactor for the hydrogenation of benzene over a nickel catalyst, which is apparently very exothermic (some ideas are a cooling jacket, inert packing, staged feed, etc). Pretty straightforward stuff, just discussed the pros and cons of each, as well as temperature profiles and thermal runaway in a PBR.

Then, Blanch asked me to separate HCl from air. Immediately, I thought of using water in an absorption tower for HCl scrubbing, and explained how absorption worked, what kind of packing to use in the tower, what concentration profiles looked like in the gas and liquid, temperature profiles in the tower, etc. Then he followed up with a question on what I would do if the vapor leaving the tower still had HCl in it. I brainstormed about improvements I could make to the tower such as using a basic solution, increasing the pressure, condensing the vapor and running it through again and so on. He still wanted a different answer, and asked me to think back to kinetics class. I asked him if he wanted me to react it with something, and said no, and had me draw a CSTR on the board and asked me what I would do with it. I said you have a CSTR with some water in it and you bubble the HCl containing vapor through it (a bubble column), which confused me because I thought that's what an absorption tower basically was except better because you have more interfacial surface area and contact. He then asked how I could design the CSTR to drop the HCl concentration in vapor to zero, and I just said that theoretically, the HCl concentration would drop to zero with a long enough residence time.

Other thoughts: Both professors were very nice and helpful, so be glad if you get either one on your committee. They were friendly when I walked in the room, and I was able to joke around with them throughout the exam which definitely lightened the mood. This was the first exam of the day and I didn't know quite what to expect, but the thing that threw me a little off guard was all of the little questions they kept asking you as you solved a problem (a theme

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during the entire day). Overall, this was a good exam - the professors worked with me and the subject matter was relatively straightforward.

Hagar Zohar
What was the most challenging aspect of your senior design project? You want to get drinking water from ocean water by freezing and crystallizing out pure water. Design this process. Some general topics of discussion: if you use a jacket to cool the vessel, crystallites will form at the surface and inhibit heat transfer. Also, after you remove the remaining brine and rinse the crystallites, you have to melt them, they suggest using the latent heat of condensing steam. You want to make cyclohexane from benzene, write the reaction, is this endo or exothermic? It's very exothermic, draw the T-profile in a packed bed reactor. How would you control temp in this reactor? Incrementally add feed so it comes in cold along the length of the reactor, load catalyst at different concentrations along reactor.

Andrew Behn
This was the first exam, and the one I actually (in a bizarre way) enjoyed. They were both very jovial and provided positive comments and hints throughout the exam.

The first question had to do with designing a plant to desalinate water through freezing. They asked me in a very general way, how this would be done. Without any really good ideas, I started by drawing a tank with a cooling jacket and some coils. Dr Blanch asked how I would manage to collect the ice after it had frozen into a solid mass in my hard-to-stir reactor. I conceded defeat and abandoned the tank idea. Then, in a flash I remembered an episode of something on the discovery channel where they made ice (like you buy in the store in bags) by freezing it on big vertical slabs that have internal cooling systems. So I drew this up, said that you would develop a layer of ice, and then knock it off onto a conveyer belt waiting below. Bingo. They also asked how I would determine the amount of heat I needed to remove from the water. They also asked what refridgerant I would use. I said 134a, which they seemed happy enough to accept. Finally, they asked how I would melt the ice after collecting it. Blanch pretty much held my hand through explaining that you could use saturated steam, which would melt the ice, and condense the water vapor all at the same time. I don't really see why that was the only answer they wanted, but it was time to move on.

For the second question Dr Alexander had me write the balanced equation for hydrogenation of benzene to cyclohexane. They then asked if this would be endo, or exothermic. Its exothermic because you're breaking pi bonds, and creating sigma bonds, which are stronger and lower in energy. Next, they had me draw a picture of the temperature profile for this highly exothermic reaction in a PBR. They asked what the problems associated with the high exit temperature would be (dangerous, hard to control, product degradation, catalyst coking etc). Then, they had me think of as many ideas as I could to alleviate this problem. (this is their version of putting the exam on auto-pilot.) I gave a few answers including a cooling jacket (revolutionary, I know), adding an inert (to allow heat transfer over a longer area), building multiple reactors with interstitial heat exchangers, and putting multiple feeds of hydrogen (or benzene) along the length of the reactor, to control the rate. They seemed happy, and it was time to go.

Moral of the story: Don't study, watch Modern Marvels.

Reimer/Segalman

Becky Rutherford
What was your design project? (~5 minutes)
Ethanol production from corn (~ 25 minutes)
How volume of hydrogen would you need to power your car? (~10 minutes)

Overall thoughts: More helpful to know chemistry behind separations than to really know anything about unit operations, equipment, etc.

Claire Woo
Princeton didn't have design or unit ops, so they decided to start with an easy question: how to concentrate fruit juice. They made me draw the flow diagram of the process, starting with whole oranges in a box and concentrated fruit juice at the other end (so this includes a slicer, a press, evaporator). Then they asked how I could use the waste heat more wisely (from steam coming out of the evaporator) – use the outlet steam to heat another evaporator. If you were the farmer, how would you decide how many evaporators to use? They just wanted a qualitative analysis of balancing capital cost and utility cost.
The second big question was about cleaning an underground aquifer that has been contaminated by gasoline from a gas station above ground. Use activated carbon. How would you do it? I said you would pump the water above ground to an activated carbon column. (in reality, pumping water above ground is

expensive, so they actually pumped air into the underground aquifer and somehow managed to absorb the gasoline and then use activated carbon to clean the air). Then Reimer said you could refrigerate the column and make the activated carbon more efficient. When would you want to do that? Again, he just wanted a qualitative economic analysis of balancing capital cost (cost of column + refrigerator) and energy cost.

Jarred Ghilarducci
I read all the questions from previous years, but felt none of them described what actually happened. So I figured I would give one detailed account of my first--and worst--experience of the day. So here is how it went down:

   My first prelim was process design with Reimer and Segalman. It's a wild card topic, but I was banking on passing it over thermo. Bad idea. I walked in at 8am and they asked me what my senior design project was. Interestingly, they wanted me to balance relevant reactions. They then wanted me to suggest another method to remove CO. Stuck thinking about my specific project, I wasn't sure where they were going. Reimer then tells me that there are approximately 60 million of these in California. Feeling like we had moved from chemical engineering to Jeopardy, I answered in the form of a question, "What is people?" No, there are only 30 million of those apparently. Eyes perhaps? Well, it turns out that the average Californian owns two cars because that was the answer. Afterwards, Reimer paused so I could answer his original question. This created an awkward silence, since I had long forgotten what the hell we were talking about. Oh, a cat converter! That was it. Back to the senior design project... After two minutes Segalman switched to fuel cells. I sketched out the general design by thinking of a battery. I had the half reactions and basic principles, but I kinda mumbled through labeling the cathode/anode (as in I didn't). Segalman caught it by asking me to clarify which one was which. I immediately guessed hoping to dodge a bullet. When Reimer asked "Are you sure?" I knew I had just taken the bullet. To stop the bleeding, I launched into my reasoning but ultimately had little to say since there is only a labeling convention/definition which I obviously didn't know. Segalman then gave me some really convoluted hints that made me only more confused as I tried to determine the relevance of her statements. Reimer, knowing Segalman wasn't helping, reinterpreted her hints so I could answer. They then asked me about the water coming out of the back end of the fuel cell. I went blank. What about it? Reimer then said to think of it as a distillation column. BAM! (Emeril style) I had the answer: weeping v. flooding. We then went on to designing the membrane. After some rudimentary analysis (H+ conductor, not e- conductor), I had little to add. So they suggested that I

list my functional groups from ochem and tell me which one would work well. After tuning out Segalman's advice, I got it down to either carboxylic acids or alcohols. Reimer asked which one would make the more "facile" membrane. I went with the alcohol, because it's the solution to all life's problems. He said that we were out of time and that the correct answer was carboxylic acid. If I wanted to know why, I could discuss it with my classmates during dinner. I shook their hands, smiled, and left. It was a solid hour before I could construct a sentence without the F word. I was so pissed because I felt the exam tested electrochem, ochem, and Californian history, not chemical engineering.

Flash forward twelve hours and I was shocked to see that I had passed with a B. I later decided that handling yourself under pressure is key. I had little to say (that was constructive), but I said it with the most confidence and poise I had. So although I was constantly frustrated, I didn't let it show. When they shot me down, I got right back up. I was also the first person of the day, so they may have simply used me as a benchmark for comparison. For the record, I still don't know which one is the anode and the cathode, nor do I care.

Blanch/Reimer

Scott Mullin

I'd never met Blanch until I walked in and shook his hand. He and Reimer were both in good moods, and were happy to be done with these tests. I was too, and the mood was pretty light. After asking my design background/senior project, Reimer starts by pulling out a huge silicon wafer, and asks me how I'd make it, given only sand, coal and air. I drew out a quick PFD, and he threw in whatever details Reimer gave (burn coal for heat, and coal also reduces SiO_2 to Si). They asked for a balanced reaction, but it got tricky and they just said to skip it. The trick is that the Si has to have fewer than 1ppb impurities. We talked awhile about separations, but none seemed very good to me. My idea was to throw in some sort of inorganic salt. They said that's the way to go, and I decided on HCl (impurities were Fe and Al). It turns out that of all the chlorides that form, $SiCl_4$ has the lowest boiling point, so you can then distill it off. There were some other details I went through, but I made it clear that I was familiar with those (heat integration and other **optimizations – the most important key word** in the design exam) and Blanch continued with another question – how do you make vitamin D? It requires UV light, but if it gets too hot (really hot lamps) the system produces an undesirable side product (both the starting material and vitamin D degrade). The solution they led me to was to use a PFR with lights on both the inside and outside shell, and having the fluid flow through the annulus with baffles (good mixing, maximize surface area,

minimize heat buildup). Took a lot of twists and turns through all of this, but Reimer and Blanch were great at feedback. Both were very smiley and I could tell from the looks on their faces if I was approaching the correct solution to whatever they were getting at. It went well, and was very relaxing actually. At the end Reimer asks a question he read in an engineering book, "You own a high-rise hotel, but the suites at top are too expensive and nobody rents them, so you remodel to smaller rooms at the same price as the lower floors. The rooms fill up, and things are good, but people start to complain about how long the elevators take. How do you approach the problem?" I asked about optimizing the elevators, and he said to assume they're already optimized, and you can't build more of them. I then said I'd lower the price to the top rooms so people wouldn't complain. He concluded with the philosophy that engineers try to solve the wrong problems sometimes, and that the real problem was that people were complaining. To stop that, you put mirrors in the elevators, because people like to look at themselves (true story). Then I got drunk.

Kevin Haas
Blanch: dilute HCl removal from gas stream: bubble through water column, need tall column to ensure full absorption. Need recycling water through heat exchanger to remove heat of reacting HCL with water. Draw concentration gradients of HCL and resulting Cl- H3O+ ions in solution. Talk about how to solve transport problem balanced with residence time of bubble to make sure get sufficient HCL removal.

Reimer: Gas station tanks leak so need to remove contaminated groundwater most efficiently. Option 1: pump through water and then carbon filter. Really need only a few water passes but activated carbon doesn't work great with water. Option 2: pump through air and carbon filter. Need more air passes to adsorb all the leaked gasoline but carbon filter is more effective. Break through curve based upon cost of air compressor compared with initial investment and activated carbon cost.

Albert Keung
They asked if I had a process class. I told them a quarter and a mini project. They didn't ask me about the project. Overall, nothing they asked I studied, but it was ok cause they were nice and led me through the questions and based the questions more on "chemE common sense" taken from other chemE areas. Prof Reimer started off by asking for 6 or 7 ways to separate water: distillation, ion exchange, reverse osmosis, electrodialysis, freezing...i can't remember more. Then he gave three locations in the world with different

energy/space/sourcewater constraints and asked which methods I would choose for each location. Blanch asked for what feels like about 10 different ways to separate lactic acid, and had me draw several flow diagrams for 2 or 3 methods. This question I really was reacting to him alot and got alot of hints. Both were nice and didn't react negatively when I froze. Blanched smiled all the time.

Vicky Tran
Both try to help you out. I found Reimer puts unnecessary details in his questions to make them more interesting... for himself.

Reimer:
1.) What was your design project?
2.) What are all the ways you can think of to purify water. Which processes and why would you use on a nuclear submarine (reverse osmosis), shady rural town (ion exchange), and a dessert (evaporation)? Draw the process flow diagram for the evaporation process in the dessert.
3.) How would you remove gasoline from contaminated ground water?
    Activated Carbon

Blanch:
You want to create vitamin D from Egesterol. It is made by UV activation, but heat will cause the reactant and the product to form an undesired product. Design the reactor. How do you know how long to make the reactor so that you obtain a certain concentration?
    Use a tubular reactor that has clear walls. Need the glass to be permeable to UV light. Use quartz glass. Want good turbulent flow. To prevent the formation of byproducts, cool by adding tubes through the reactor with cooling water. To determine the reactor length, he really just wants you to point out all the info you needed as in velocity, viscosity, density, Re, surface area.)

Alexander/Segalman

Siddharth Dey
I was lucky that I had done I detailed design in my senior year and they asked me about it. I rambled about it for nearly 15-20 min drawing the process flow diagram with the odd question from them. Next they moved onto hydrogenation of benzene. Highly exothermic reaction. Said how ill control this

reaction. (I told them various options: multiple reactors with intermediate cooling, injection of benzene along the length of the tubular reactor, having catalyst with various activities packed along the length of the reactor, fluidized bed reactor). Next they moved onto methods of de-salinating water. Told them the three methods I had read just a day before ☺. They then went into evaporation asked he about multi effect evaporators. By then time had run out......I thought that my design was the best but I got my worst grade in it. Don't know what else they were looking for.

<u>Ryan Balliet</u>
Segalman
- Describe how a hydrogen fuel cell works. *This was asked because of my background (in the FC industry) in place of the standard "tell us about your Senior design project" question.*
- Let's say I own an orange grove and I want to start selling orange juice.
  - What would be the advantage of selling concentrate? *Lower transportation costs.*
  - Assuming the product is to be concentrate, what are the different processes that one could use? What are the advantages/disadvantages? *Staged evaporation, reverse osmosis.*
  - Draw a process flow diagram for staged evaporation
  - Describe reverse osmosis
- Now let's say that I want to desalinate water. What are the different ways that this could be done? Consider 3 applications: a desert climate, a nuclear submarine, and a remote village in an arid climate. Which method would be best suited for each case?
- *General advice: Study <u>basic</u> good practice for schematic representations of processes. My diagrams tended to be more free-form, which I believe lead to confusion and an impression that I knew less than I did.*

Alexander
- Asked clarifying questions related to those above.

<u>Will Vining</u>
First they asked about my design project, then moved onto making ethanol for cars. I needed to know how to purify the ethanol, and where most of the work would be involved. Segalman seemed to ask this question to make a point about the inefficiencies of this process because once we went through the whole thing she gave a 5 minute lecture about why it was stupid. Next, given the hydration of benzene to cyclohexane, I had to design a reactor and determine ways to use the heat and prevent runaway. The last question was on

the three ways to desalinate water, and I had to determine which one to use on a deserted island, nuclear sub, and desert. The answer was ionic membrane, osmotic pressure, and evaporation. My least comfortable committee, but not too bad.

Greg Stone

Asked me about my design project (standard). This led to a talk about using supercritical CO_2 to make decaffeinated coffee. Segalman asked me how it was previously done and then proceeded to answer the question with little to no input from me. Alexander asked me about the design of a catalytic reactor for an extremely exothermic reaction. I mentioned cooling water and spacing the catalyst out with inert. They led me through a couple more ways. He then asked me about what happens to the hydrocarbon if it gets heated up too much, while I knew nothing about coking of reactors. It went something like this:

Alexander: What happens to the hydrocarbon if the reactor temperature runs away?

Me: It vaporizes and the reactor blows up.

Him: Not what I'm looking for. Hotter than vapor.

Me: Plasma?

(Everyone in room laughs at my expense, including me)

He then mentioned coking and moved on. This was about 20 min in and they did not stop laughing for the rest of the time, but they always assured me that they weren't laughing at me. Segalman finished by asking me about how to purify water and where these different methods were best suited.

Overall, I say just be confident. You can't know everything that they ask you so don't bother. Just study enough to feel confident.