Week 5

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5.1 ???

- Review of copper-catalyzed ATRP ligand effects.

  - They're trying to prevent termination by lowering the radical concentration.
  - Essentially, the ligand plays an important role in the rate of activation.

- Copper-catalyzed ATRP: Effect of initiator.

  - Initiator activity increase is related to the stabilization of the generated radical, so $3° > 2° > 1°$...

- Copper-catalyzed ATRP: ppm Cu.

  - Residual copper could have adverse effects if you're looking to make a medical product that will go into a person or a polymer to go into a piece of technology.
  - We typically need 0.1-1 mol% of copper relative to the monomer, so the product will contain a lot of it.
  - Thus, if we want to filter it out beyond just precipitating our polymer, we can throw in chelating agents or do fancier things, but that all adds cost and time to the process.
  - Termination does occur.
  - The rate of reaction depends on the ratio of $[Cu^+]/[Cu^{2+}]$ and not the absolute catalyst concentration.
    - So theoretically, we can go to much smaller catalyst loadings, as long as we keep that ratio high.
  - However, this is difficult to do because we need to regenerate Cu^+ using something other than radicals.

- Copper-catalyzed AGET and ARGET ATRP.

  - AGET (Activators Generated by Electron Transfer) ATRP: Stoichiometric amounts of reducing agent added to the reaction mixture containing alkyl halides...
    - Wrapping copper wire around your stir bar will usually do the trick.
    - Essentially, we're just adding in a reducing agent.
  - ARGET (Activators ReGenerated by Electron Transfer) ATRP: Similar to AGET, but we use an excess of reducing agent which allows the use of much lower amounts of copper.
  - We can also use electrochemistry of photochemistry to reduce down.
  - These methods are much more commonplace now than traditional ATRP, *especially* if we're working toward biomedical devices.

- Reversible Addition-Fragmentation Chain Transfer (RAFT).

  - You use a standard free radical termination, but instead of having reversible termination, you have a reversible chain transfer process.

- Discovery of RAFT polymerization (1998).

  - RAFT polymerization controls chain growth through reversible chain transfer.
  - It can be achieved by the introduction of a small percent of a chain transfer agent into a conventional free-radical polymerization.
  - We most commonly use dithioester derivatives.
  - The R group...

- Steps in RAFT polymerization.

  - We use a standard initiator (e.g., AIBN).
  - We then have a step of pre-equilibrium or initialization.

    - ■ Here, a polymer can add into the dithioester and kick out R$\cdot$ to begin a new polymerization.
  - Re-initialization: The growing of the new polymer from R$\cdot$.
  - Main equilibrium: Chain transfer back and forth through dormant chains bonded to dithioesters.
  - Various R groups for the chain transfer agent.

- RAFT: Snap shot of polymer chains.

  - A few dead chains, mostly dormant chains, and a few propagating chains.
  - Allows you to get a nice spike in molecular weight. Note that you might get a little tail on the low end due to dead chains.
  - All you have to do in the lab is throw in a bit of your RAFT pixie dust.

- RAFT equilibria.

  - The efficiency of a RAFT agent can be defined by C_{tr}. More active RAFT agents have larger C_{tr}. (C_{tr} should be at least 10; many are > 100.)
  - We have that $C_{tr} = k_{tr}/k_p$ where

  $$k_{tr} = k_{add}\phi = k_{add}\frac{k_\beta}{k_{-add} + ...}$$

- Kinetics and livingness.

  - We won't go in depth into how to derive this stuff.
  - The rate of polymerization is...
  - We can define the **livingness** (how much is dormant or growing vs. dead).

  $$L = \frac{[CTA]_0}{[CTA]_0 + 2f[\text{I}]_0(1 - e^{-k_d t})(1 - f_c/2)}$$

  - The number of chains produced in a radical-radical termination event.
  - $f_c = 1$ means 100% termination by combination, whereas $f_c = 0$ means 100% termination by disproportionation.
  - Monomers with high propagatino rates (such as acrylamides) and initaotors with high efficiency or high decomositio rate lead to fast polymerization rate while keeping low initiator concentration.
  - An optimal RAFT system requires a high rate of radical generation (considering k_d, for instance, by using thermal initiator at $T >$ their ten-hour half-life) and/or solvent induced acceleration.

– A large polymerization rate permits shorter polymerization time or lower amounts...

- Reactivity of the monomers and their propagating radicals.

  – Monomers can be classified into two general groups.
  – More "activated" monomers (MAMs).

    ■ Conjugated double bond (e.g., styrene, methyl methacrylate, acrylamide, acrylonitrile, . . .).
    ■ Reactive monomer.
    ■ Less reactive propagating chains.
    ■ This means that poly(MAM) is a relatively good homolytic leaving groups, and as such, the more active RAFT agents provide good control. Less active RAFT agents have lower C_{tr} and provide poor control.

  – Less "activated" monomers (LAMs).

    ■ Saturated carbon or oxygen/nitrogen.
    ■ ...

- Relationship of RAFT agent and monomer.

  – Optimal control in RAFT polymerization requires choosing an appropriate RAFT agent for the monomer(s) to be polymerized.

- Z group impacts the reactivity of the RAFT agents.

  – How reactive is C=S to attack?
  – The reactivity can be qualitatively understood in terms of the importance of zwitterionic canonical forms. The lone pair delocalization with the C=S reduces its double bond character and stabilizes the RAFT agent relative to the radical intermediate.
  – The reactivity of the RAFT agent can be increased if the electron density of the lone pair is reduced by delocalization everywhere.

- Relationship of RAFT agent and monomer; the role of the Z group.

  – Z modifies the rate of addition of propagating radicals (k_{add}); it can be altered by 5 orders of magnitude.
  – Z alters the stability of the radical intermediate; the rate of fragmentation k_{-add}.
  – Z should not cause any side reactions.

    ■ For xanthides...
    ■ If Z is strongly electron withdrawing, then the C=S an react directly with the monomer (e.g., a hetero Diels-Alder) or nucleophilic attack.

  – Guidelines for selection of the Z group of RAFT agents (ZC(=S)SR) for various polymerizations.

    ■ ...

- Relationship of RAFT agent and monomer; the role of the R group. *picture*

  – For an effective RAFT agent, R· should be...

    ■ A really good leaving group with respect to the propagating radical [P·] ($\phi > 0.5$);
    ■ Be able to reinitiate the polymerization efficiently ($k_{iR} > k_p$), otherwise retardation occurs. Related to the stability of R·.

  – Guidelines for selection of the R group of RAFT agents.

    ■ See Figure ??
    ■ A dashed line indicates only partial control (control of molar mass but poor control over dispersity or substantial retardation in the case of VAc, NVC, NVP).

- – Radical stability is important in determining the fragmentation rates.
        - – Steric factors play a role.
        - – Polymerization of 1,1-disubstituted monomers (e.g., methyl methacrylate, methacrylamides) which result in a tertiary $P_n \cdot \ldots$
        - – However, polymerization of monomers with high k_p are best controlled with primary and secondary R groups. Tertiary radicals are inefficient at reinstating polymerizations since $k_{i,R}$ is often lower than k_p.

- Just because someone gets it to work for styrene doesn't mean it'll work for everything.

- RAFT CTA choice is everything.

    - – A table that summarizes choices.

- Synthetic potential of RAFT.

    - – You can do chemistry on your RAFT chain ends.
    - – Example: You can react a diene with the C=S bond in a hetero Diels-Alder reaction.

- Targeting molecular weights with RAFT.

    - – Your number average molecular weight is

    $$\frac{\text{Total monomer concentration}}{\text{Total initiated-unit concentration}} \times \text{Conversion} \times \text{Monomer molar mass} + \text{CTA molar mass}$$

    - – Thus, ...

- Key points.

    - – Understand what a living polymerization is.
    - – What does that mean for the resulting polymerization?
    - – Standard living (ionic) and controlled living (reversible step).
    - – Know and understand RAFT, ATRP, and NMP; know how to decide which one you will use.

- Midterm.

    - – Know common monomers, know common polymers, know how they can be initiated.
    - – Know how to draw reaction mechanisms.
    - – There's at least one question that might require a calculator.
        - ∎ Implication: There's a kinetics question coming.
    - – For the grad level course, papers are 20% of the exam! Don't ignore them!!
    - – The kinetics from today's lecture won't be there.
    - – Focus on intro, cationic, anionic, and free radical classes.

5.2   ???

2/1:   • I was at ??