

Kinetics & Dynamics – Chem 633 – Spring 2012

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Tue – 7:20 -10 – Robinson A105

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Office hours – Tues 10:30-11:30 and 6:30-7:10

or by appointment or stop by

(days and times may change and will be announced in class and on the web page)

Kinetics & Thermodynamics – Chem 633


- Lecture & discussion format
- No dedicated/purchase required text book this year
- Copies of lecture notes will be made available
- Some books are on 2 hour reserve in JC library
- Assigned reading from texts, journals, etc.
- Journal references to be looked up and studied/discussed
- Student presentations/papers based on assigned journal articles
- Emphasis on Kinetics, somewhat less on Thermodynamics
- Need some skill with Excel and PowerPoint
- Stay ahead. Attend Class. Take notes. Don't depend only on slides used in class and on web page. Practice calculations so you can proceed on "autopilot" on tests.
- Class questions and discussion is encouraged

General Outline


See Syllabus

The general course outline follows. There may be slight changes in order. Some subjects will be covered to a greater or lesser depth than others. Attend class. Most lecture slides will be on web page. Everything is not on slides so take lecture notes and valuable information and concepts are through class discussion.

1. Introduction - basic concepts
 - What is Rate
 - Historical Perspectives
 - How is Rate Measured
 - Rate Equations - order, rate constants
 - Elementary Reactions vs. Net Reactions
2. Analysis of Kinetic Data
 - Differential Method
 - Integral Method
 - Graphical Techniques
 - Half-Life and Method of Half-Lives
 - Experimental Techniques for Fast Reactions
 - Flow Methods, Flash Photolysis, Shock-Tubes, etc.
 - Temperature Dependence and Arrhenius Equation
3. Activation Energy and Chemical Dynamics
 - Statistical Distribution of Energies – Statistical Mechanics
 - Partition Functions (we will probably spend a week or so here)
 - Potential Energy Surfaces
 - Quantum Mechanical Approaches
4. Reaction Rate Theory
 - Collision Theory
 - Statistical Approaches
 - Thermodynamic Approaches
 - Transition State Theory
 - Microscopic Reversibility
5. Gas Phase Reactions
 - Unimolecular
 - Bimolecular
 - Trimolecular
 - Disproportionation and Radical Recombination
6. Reactions in Solution
 - Solvent Effects
 - Collision in Solution
 - Transition State Theory
 - Solvation and Internal Pressure
 - Ionic Reactions
 - Substituent Effects
 - Diffusion and Diffusion Controlled Reactions
7. Reactions on Surfaces - Heterogeneous Reactions and Catalysis
 - Adsorption Isotherms - Langmuir
 - Mechanisms of Reactions on Solid Surfaces
 - Unimolecular
 - Bimolecular
 - Catalysis
8. Analysis of Complex Reactions
 - Multiple Differential Equations
 - Confirmation of a Proposed Mechanism
 - Steady State Approximation
 - Pseudo-First Order
9. Miscellaneous Topics of Interest
 - Photochemistry
 - Laser Spectroscopy
 - Others that come up during class discussion
10. Student Special Topic Paper



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Department of
Chemistry

Name:
Director:
UNION:
Faculty:
Research:
Graduate Programs:
Undergraduate Programs:
Course Descriptions:
Schedules:
Spring 2009:
Summer 2009:
6/30 Seminar:
Tutoring:
GenChem:
Activities:
FAQ:
Links:

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Fall 2011 Office Hours: Tue/Thurs 3-4:30 or by appointment or drop by. Changes will be announced in class and in "announcements" box below.

Background and Research Interests:
Robert Cozzens received his Ph.D. from the University of Virginia in 1966. His interests include material science, photochemistry, effect of lasers on materials, microwave induced chemistry, and nonlinear optical materials. He is actively involved in research jointly with the Department of Defense and periodically serves as an expert witness in several patent cases involving spectroscopy and material science of optical materials.

Useful Links to Other Chemistry Department Sites of General Interest

Link to GenChem Page <http://www.gmu.edu/departments/chemistry/genchem.html>.
Homework, Quiz & Tutoring Info

CHEM 332 - Spring 2012
Physical Chemistry 2
Tue/Thurs 9-10:15
Inovation Hall – Room 133

Text: "Physical Chemistry" – Adkins – 8th or 9th Edition (7th will do if you already have it)

Below are links to class related files and slides used in lecture. Files will be added and updated every week or so.

[Syllabus \(soon\)](#)
[Slide_Set 1 \(soon\)](#)
[Slide_Set 2 \(soon\)](#)

Announcements - Chem 332

CHEM 633 - Spring 2012
Kinetics and Dynamics
Tuesday 7:30 - 10 pm
Robinson - room A105

TEXTS – There will not be a specific assigned text. Several texts and assigned readings will be in the JC library reserve, including- [Chemical Kinetics](#) by Keith Laidler - third edition - Harper and Row Publishers, [Chemical Kinetics and Reaction Mechanisms](#) by Espenson - McGraw Hill, [Chemical Kinetics & Dynamics](#) – 2nd ed., Prentice Hall – J. I. Steinfeld, J. S. Francisco and W. L. Hase, others as needed. Lecture slides will be relatively comprehensive.

Below are links to class related files and slides used in lecture. Files will be added and updated every week or so.

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[Slide_Set 1 \(soon\)](#)
[Slide_Set 2 \(soon\)](#)

Announcements - Chem 633

Grading



Course grading is based on a mid-term test (20% in class, 80% take home), paper, a few graded homework sets and a final exam (20% in class, 80% take home).

Homework =10%, Mid-term =35%, Final =35%, Paper & Presentation = 20%.

Final Exam covers the entire semester. George Mason University has a Honor Code. It is strongly recommended that you review now related parts of your General Chemistry Text and Physical Chemistry Text to get up-to-speed.

In-class part of final exam is Tues May 15 7:20-10. Take-home part of final is also due at that time. Mid-term in-class and take-home due date is Tues April 3 (subject to change). Take-home tests are generally given out a week before they are due.

The goal of the course is to develop a broad understanding of those molecular and atomic forces and energy relationships that drive chemical reactions and determine their rate and equilibrium. Emphasis will be on Kinetics more than Thermodynamics. Numeric data analysis techniques will be used to develop and better understand the theories regarding these molecular forces. Math is a working tool in kinetics. The development of useful, user-friendly Excel spreadsheet “models” will be necessary. We will discuss laboratory techniques and their implication as applied to the study of the kinetics and dynamics. Although the course is taught in lecture format, discussion and questions are encouraged.

Kinetics & Thermodynamics – Chem 633

General Course Outline

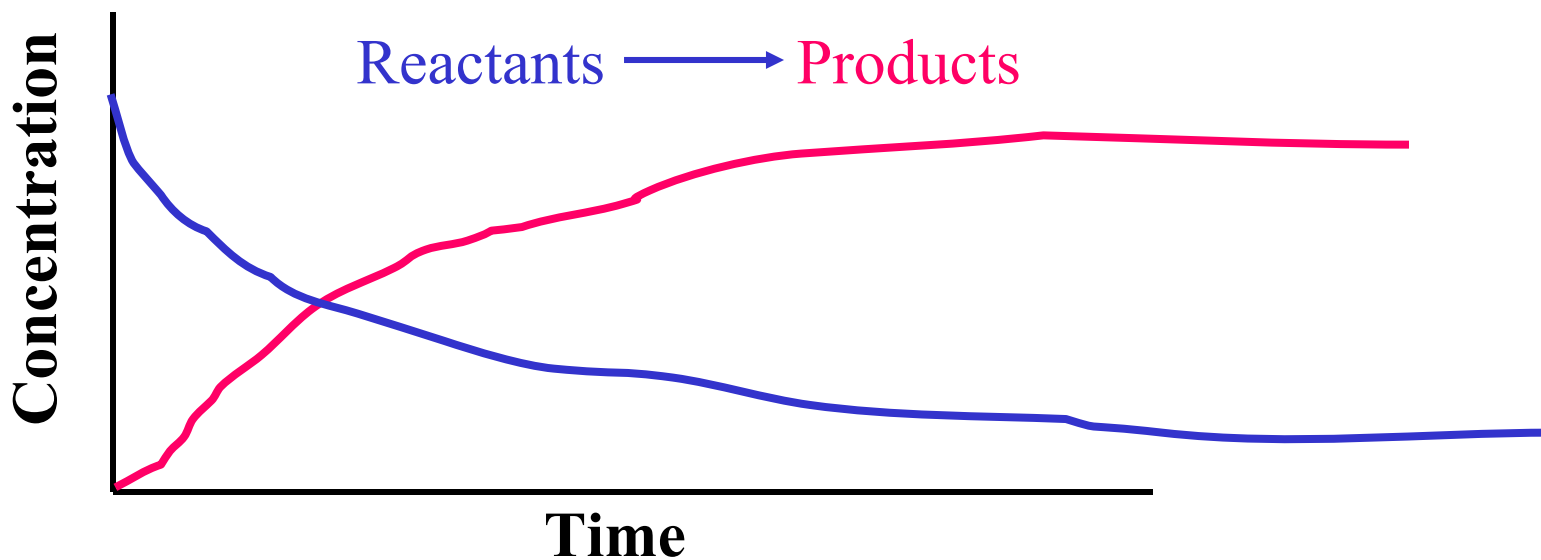
- Introduction-Overview-Review-Background
- Experimental Techniques Common in Kinetics
- Mathematical Analysis of Kinetic Data
- Activation Energy, Transition State and the Effect of Temperature
- Theories of Reaction Rates
- Statistical Mechanics and the Transition State
- Elementary Gas Phase Reactions
- Elementary Reactions in Solution
- Surface Chemistry and Solid State Catalysis
- Complex Reaction - Series, Sequential, Reversible, etc.
- Polymer Reaction
- Photochemical Reaction

Assignment – Read and Review kinetics chapter in a good Pchem Text (Adkins for example) and first two chapters in Kinetics Text - Laidler (library reserve)

Kinetics & Thermodynamics

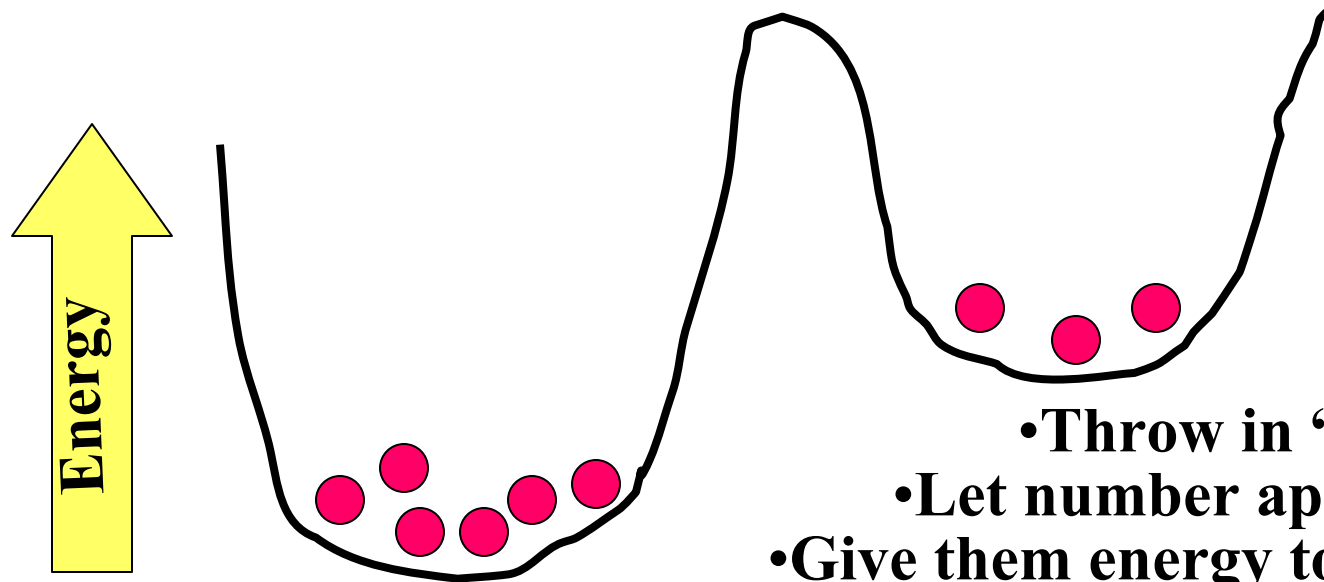
Kinetics -study of the **rate** or **speed** of chemical reactions and processes (range from femtosec to billions of years)

Thermodynamics -study of the **equilibrium** position/condition and the **energy** relationships responsible for that equilibrium condition which drive chemical reactions and processes (equilibrium constant K from 10^{-100} 's – 10^{+100} 's)



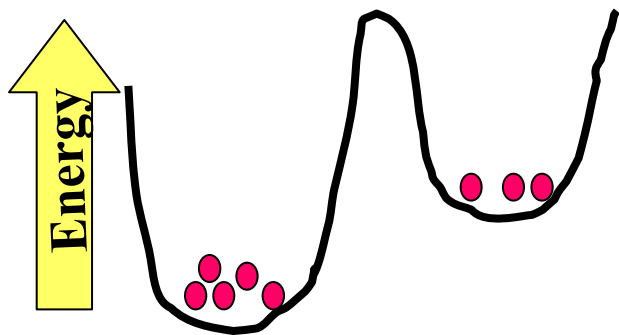
Distribution Between Energy States

Simple hypothetical energy relationship- 2 wells with an energy barrier



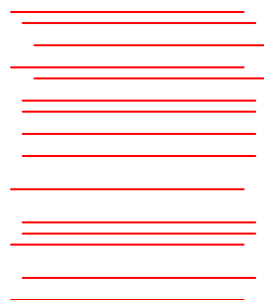
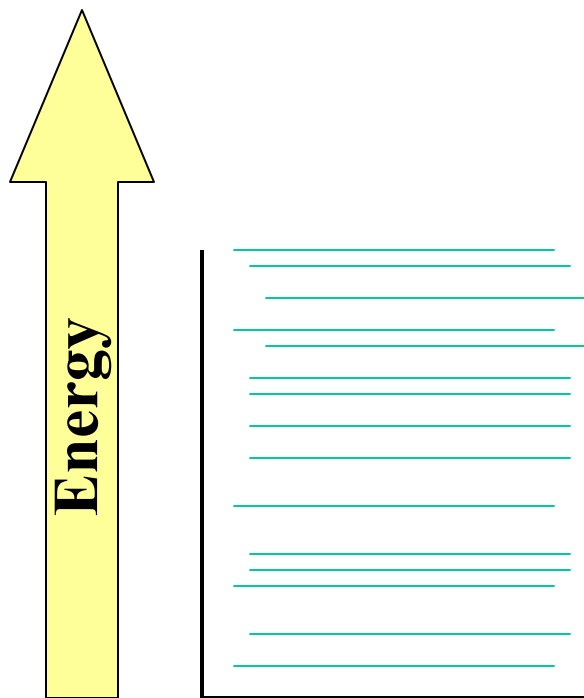
- Throw in “balls” – randomly
- Let number approach Avagadro’s
- Give them energy to “bounce around”
- The higher the temperature the more they bounce
- Relative well depths determine the ratio of the average number in each well after equilibrium is established (equilibrium constant K)
- Barrier height determines how long it takes to reach equilibrium
- The higher the temperature (more bouncing around) the more rapidly equilibrium is achieved (faster reaction or process)

More Detailed Energy Level View

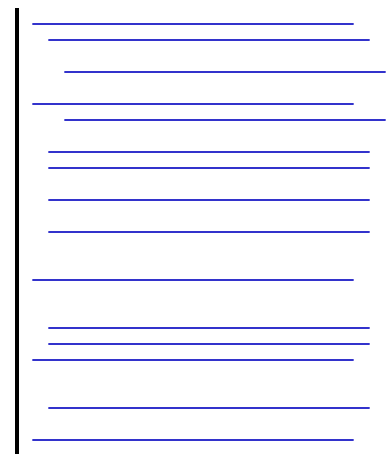


Distribution of Avogadro's number of molecules in a set of energy levels is based On Boltzmann statistics

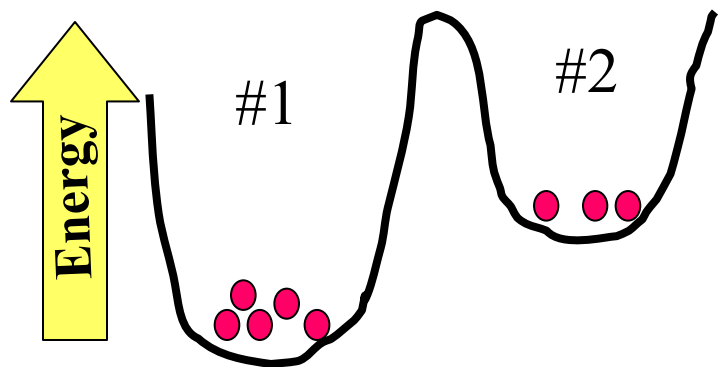
$$\text{Intrinsic Energy} = \text{fn}(\text{Temp } ^\circ\text{K})$$



↑
Transition State
no confining well



Relationship Between Kinetics & Thermo



Equilibrium – relative well depths

Kinetics – barrier height

- Molecules have energy directly related to absolute temperature °K
- Barrier height is function of how a molecule's structure and bonding rearranges as it goes from one well to another

Equilibrium constant: $K \sim [\text{number in well 2}]/[\text{number in well 1}]$
(*after equilibrium or steady state is established*)

Rate Constant: $k \sim \text{fn}[\text{barrier height \& temperature}]$
(*statistical probability of climbing out of well and over barrier*)

Relationship Between Kinetics & Thermo

Quantum Mechanics: determines the energy levels or states available to a molecule (**microscopic or molecular level**)

Molecular energy can be translational motion, rotational motion, vibrational motion or electronic state (nuclear states have energies exceeding those involved in chemistry)

Statistical Mechanics: relates quantum mechanics and thermodynamics – connects microscopic molecular world with the macroscopic bulk molar world of thermodynamics

Kinetics: determined by the barrier height which can not be directly measured (as can well depth) but rather only theoretically speculated about by assuming structures and energy states of the molecular system in the process of transitioning from one well to another. This is the basis of Theoretical Kinetics

Relationship Between Kinetics & Thermo



Equilibrium Constant K is very large [$\Delta G^\circ = -RT \ln K$]

Energetics drives reaction toward products (completion)

Spontaneous -->

but Kinetics is very, very slow (small rate constant @ 298K)

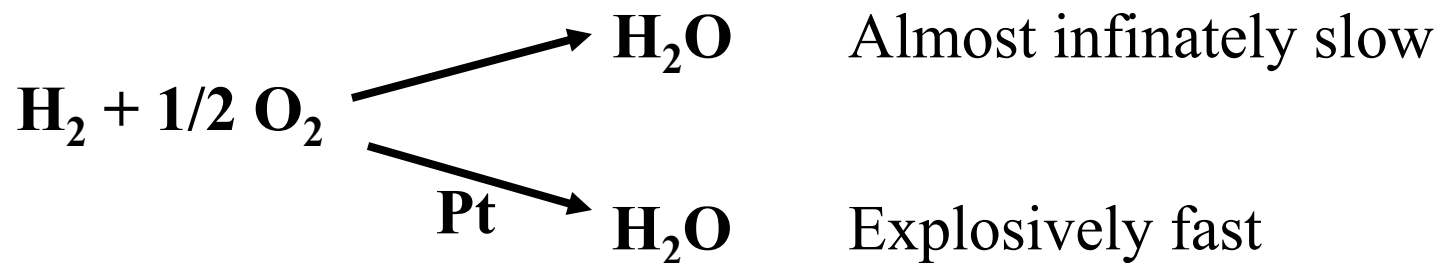
large activation energy barrier between reactants and products

If kinetics of this reaction were not slow the atmosphere be gone by now and the ocean would be nitric acid!

Thermodynamics depends only on **initial and final state** of system

Kinetics depends on the **path** between the initial and final states (the height of the barrier) some rates are very slow some very fast

Effect of Path (barrier) on Reaction Rate



- Same reaction (reactants and products)
- Same thermodynamics (ΔG ΔH ΔS)
- Same equilibrium constant K
- Very different rate/kinetics/path/mechanism

What is different on the molecular level?

How could you experimentally determine the mechanism?

Historical Perspective

Alchemy - more philosophy than chemistry

Scientific Method - first observation (experiment and measurements)
- then theory or hypothesis

Antoine Lavoisier - 1793-1797 - conservation of mass, new elements

Joseph Proust - 1754-1836 - law of definite proportions (atoms)

John Dalton - 1766-1844 - atoms

Dimitri Mendeleev - 1834-1907 - periodicity of the elements

A.L. Wilhelmy - 1850 - inversion of sucrose - measurement of rate
and the effect of concentration on rate (rate proportional to conc
of remaining reactant, independent of concentration of product)

Wilhelmy, L. Ueber das Gesetz, nach welchem die Einwirkung der
Säuren auf den Rohrzucker stattfindet. *Ann. Phys. Chem.* 1850,
81, 413-428.

M. Berthelot and L.P St.Gilles - 1862 - rate proportional to product
of concentration of two reactants and independent of concentration
of products $C_2H_5OH + CH_3COOH = C_2H_5OOCCH_3 + H_2O$

Berthelot and L. P. St. Gilles, Ann. Phys., 63, 385 (1862)

Kinetics & Thermodynamics-Chem 633-slide set 1- Spring12

Historical Perspective

Periodic Table of the Elements

1870

63 elements known at that time



Dmitri Mendeleev
(1834-1907)

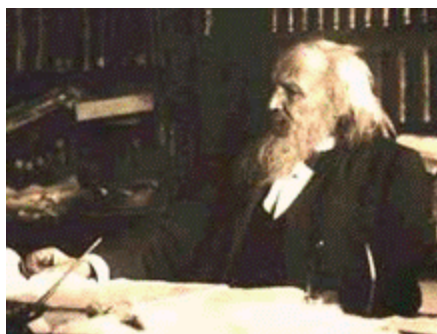


Tabelle II.

| Reihen | Gruppe I. — R ¹ O | Gruppe II. — R ² O | Gruppe III. — R ³ O ³ | Gruppe IV. RR ⁴ RO ² | Gruppe V. RR ⁵ R ² O ⁵ | Gruppe VI. RR ⁶ RO ³ | Gruppe VII. RR R ² O ⁷ | Gruppe VIII. — RO ⁴ |
|--------|------------------------------------|-------------------------------------|---|--|---|--|--|--------------------------------------|
| 1 | H=1 | | | | | | | |
| 2 | Li=7 | Be=9,4 | B=11 | C=12 | N=14 | O=16 | F=19 | |
| 3 | Na=23 | Mg=24 | Al=27,3 | Si=28 | P=31 | S=32 | Cl=35,5 | |
| 4 | K=39 | Ca=40 | —=44 | Ti=48 | V=51 | Cr=52 | Mn=55 | Fe=56, Co=59, Ni=59, Cu=63. |
| 5 | (Cu=63) | Zn=65 | —=68 | —=72 | As=75 | Se=78 | Br=80 | |
| 6 | Rb=85 | Sr=87 | ?Yt=88 | Zr=90 | Nb=94 | Mo=96 | —=100 | Ru=104, Rh=104, Pd=106, Ag=108. |
| 7 | (Ag=108) | Cd=112 | In=113 | Sn=118 | Sb=122 | Te=125 | J=127 | |
| 8 | Cs=133 | Ba=137 | ?Di=138 | ?Ce=140 | — | — | — | — |
| 9 | (—) | — | — | — | — | — | — | — |
| 10 | — | — | ?Er=178 | ?La=180 | Ta=182 | W=184 | — | Os=195, Ir=197, Pt=198, Au=199. |
| 11 | (Au=199) | Hg=200 | Tl=204 | Pb=207 | Bi=208 | — | — | — |
| 12 | — | — | — | Th=231 | — | U=240 | — | — |

Why should such an orderly arrangement of the elements exist?

Historical Perspective

- A. V. Harcourt and W. Esson - ~1866 - detailed rate data (conc vs. t)
mathematical expressions fitting experimental data
(potassium permanganate + oxalic acid forming CO₂)
- C. M. Goldberg and P. Waage - relation between rate and equilibrium
- J. J. Hood - 1878 - empirical observation of rate as function of Temp
 $\log k = B - A'/T$ A' & B empirical constants T in °K
- J. H. van't Hoff - 1884 - effect of temperature on equilibrium constant
thermo $d(\ln K)/dT = \Delta H^\circ/RT^2$ or $\ln(K) = -\Delta H^\circ/RT + \text{const}$
- S. Arrhenius - 1889 - quantitative explanation of temperature effect on
reaction rate $k = Ae^{-E/RT}$ (A and E have meaning - not empirical)
birth of kinetic theory and mechanism
concept of activated complex or transition state - energy barrier
- M. Bodenstein - 1894 - careful experimental data supporting
Arrhenius theory $2\text{HI} = \text{H}_2 + \text{I}_2$

Historical Perspective

W. C. Lewis - 1918 - frequency of molecular collisions effects rate

A. Marcelian - 1915

A. March - 1917

R. C. Tolmar - 1920

E. P Adams - 1921

} molecules cross an energy barrier

“energy surface” description

F. London - 1928 - quantum mechanics used to calculate properties of activated complex at peak of energy barrier
theoretical approach to kinetics - connecting the microscopic world with the macroscopic world

C. Eckart - 1930 -

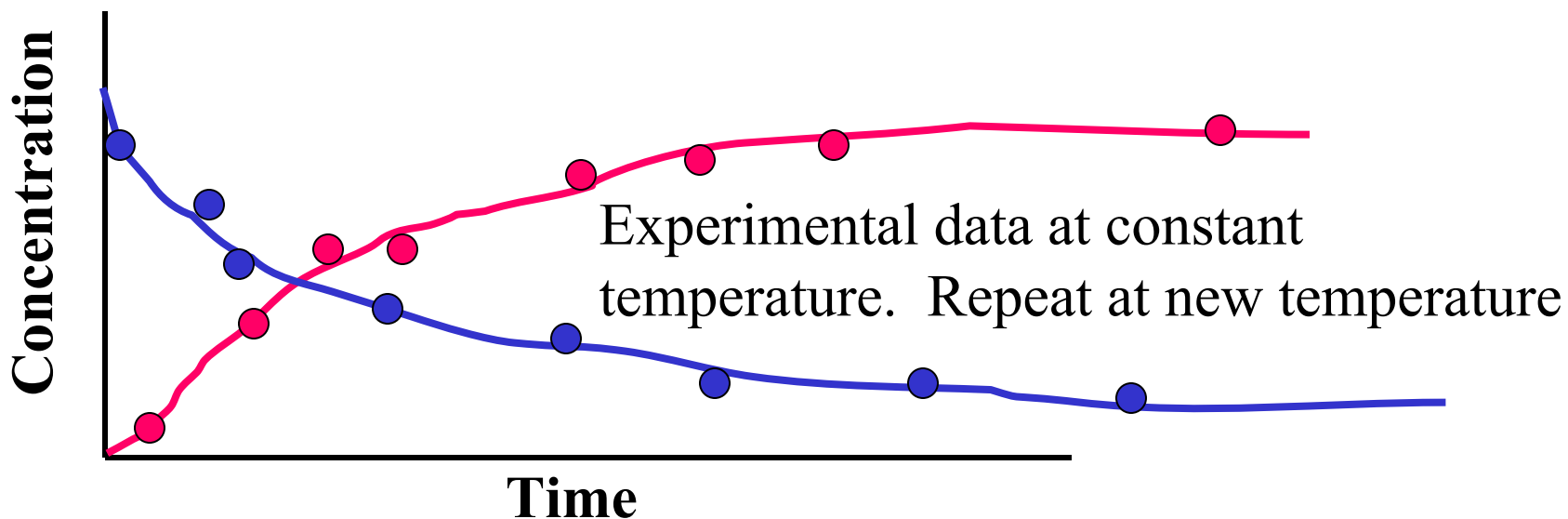
E. P. Wignen - 1932 -

R. P. Bell - 1933 -

} quantum mechanical tunneling between reactants and products through barrier

Experimental Kinetics

Measurement of changes in concentration of reactants and products as a function of time and temperature

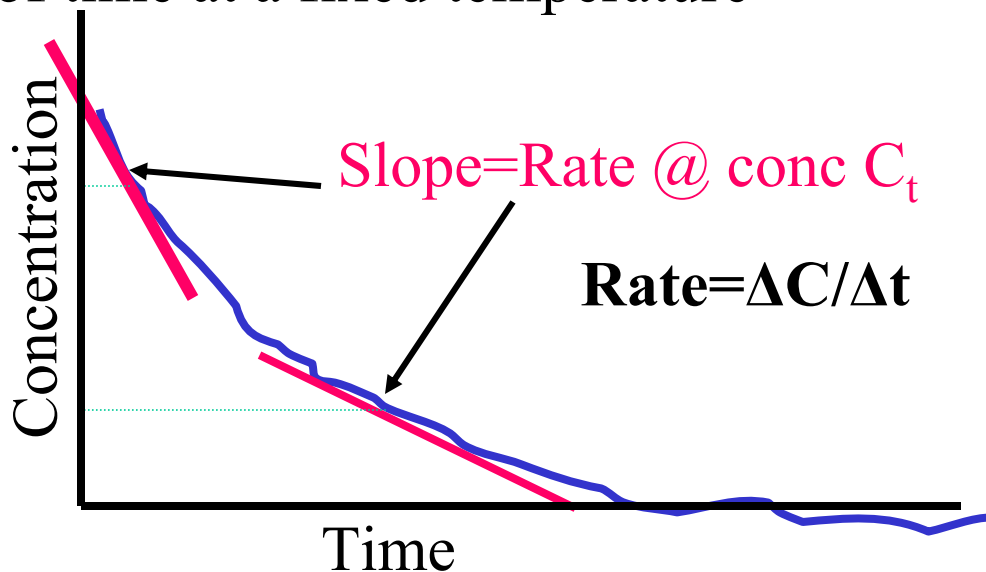


Kinetics: Mathematical relationship that describe the shapes of these curves as a function of time and temperature

Experimental Techniques: measurement of concentrations, time, Temperature in “real time” followed by mathematical analysis of data

Experimental Kinetics

Experimental measurement of concentration and/or something proportional to concentration of reactants and products as function of time at a fixed temperature



| DATA at temp T | | |
|----------------|-------|-------|
| Conc | Time | Rate |
| C_1 | t_1 | R_1 |
| C_2 | t_2 | R_2 |
| C_3 | t_3 | R_3 |
| * | * | * |
| * | * | * |
| * | * | * |

Note: Rate (slope) decreases with time and reactant concentration

Units: concentration -- molar (M), others as convenient

time -- sec, min, hr, femtosec, years, etc.

rate -- conc/sec, M/sec or mol/liter-sec, others

Experimental Kinetics

Concentration measuring technique must be more rapid than the rate of the reaction so that concentration does not change enough during the measurement to limit the accuracy (sig.fig.) of the measurement

Reaction Rate Increases & Time Scale Decreases

years **days** **hours** **seconds** **millisec** **nanosec** **psec** **fsec**

Wet Chemical Analysis

Gravametric/Volumetric analysis

Spectroscopy

↑
Light
Travels
~ 1 ft

↑
Lifetime
of H₃O⁺
in water
at 20 °C

↑
300 fsec
~1 vibration
I₂ molecule

Fast spectroscopy

Very fast spectroscopy

Special optics and electronics

Speed of light is a factor (<nsec)

Vibrations Electronic

Time Scales



Eye blink – 1/10 sec (*fast enough to protect from sun damage to eye*)

Liquid crystal response – milli to microsec (msec to μ sec)

Molecular vibrations – nanosec to picosec (nsec to psec)

Electronic transitions – micro, nano, femto and pico seconds

| | | | | | | | | | |
|-------|-----------|-------|-----------|------|-----------|------|------------|-------|------------|
| milli | 10^{-3} | micro | 10^{-6} | nano | 10^{-9} | pico | 10^{-12} | femto | 10^{-15} |
|-------|-----------|-------|-----------|------|-----------|------|------------|-------|------------|

-
-
- 1 nanosec - light travels about 30 cm or about 1 foot
 - 1 femtosec - light emitted by electronic transition barely escapes the atom
 - Nanosecond (10^{-9}) and shorter spectroscopy requires careful set-up of optics to allow for time delay of light due to optical path (*can be a useful tool*)
 - In 1966 microsecond spectroscopy was the state-of-the-art (*my grad work*)
 - Today picosec (10^{-12}) and femtosec (10^{-15}) is almost routine (*lasers*)

Reaction and Experimental Techniques

Reactions

- Gas Phase
 - high pressure
 - low pressure
- Liquid Solutions
- Solid Phase
- Polymerization
- Catalyst

Kinetic Experimental Techniques

(concentration as function of time)

- Stop Flow
- Flash Photolysis
- Shock Tube
- Refractive
- Calorimetric
- Electrochemical
- Spectroscopic (UV, Vis, IR, NMR, EPR)
- Photometric
- Photographic
- etc.

Reaction and Experimental Techniques

Experimental

Measure concentration of as many reactants and products as possible

Minimize error induced by measurement technique

Collect data over enough time that concentration drops more than 10x

Analysis of Data

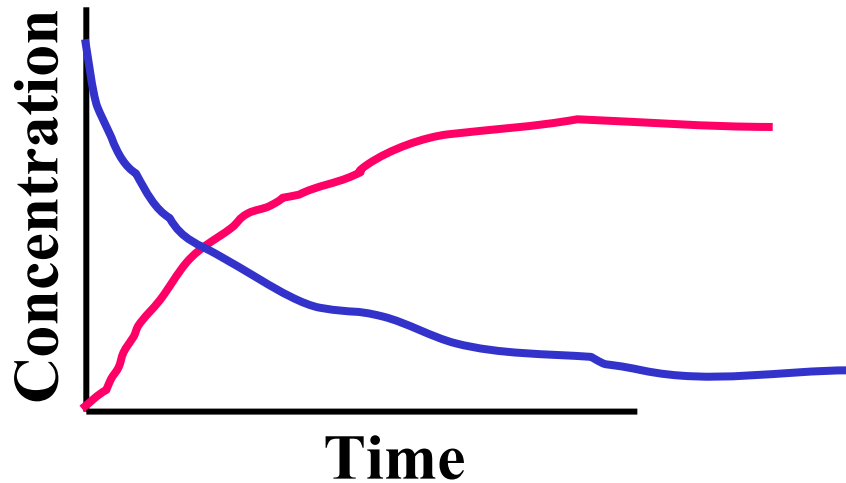
Mathematical treatment of data (spread sheets, graphs, etc.)

Develop an equation that describes the concentration vs. time data

Interpretation

Deduce a reaction mechanism (series of steps) compatible with the experimental data and its analysis

Reaction and Experimental Techniques



| Conc R | Conc P | time | rate |
|--------|--------|------|------|
| --- | --- | --- | --- |
| --- | --- | --- | --- |
| --- | --- | --- | --- |

$$\text{Rate} = d(\text{conc})/dt \sim \Delta(\text{conc})/ \Delta(t)$$

Isothermal – constant temperature – thermostated bath, etc.

Half-life – time for concentration of reactant to drop to $\frac{1}{2}$ of its value

$t_{1/2}$ or $\tau_{1/2}$ (sometimes 1/e life is reported $t_{1/e}$)

Initial concentration – concentration at time=0

Time for measurement of concentration should be \ll half-life

Time to initiate reaction (mix, etc.) should be \ll half-life

Many Ways to Measure Rate of Reaction



Measure any parameter that is proportional to concentration of a reactant and or product. You don't have to measure concentration itself but something proportional to concentration as a function of time.

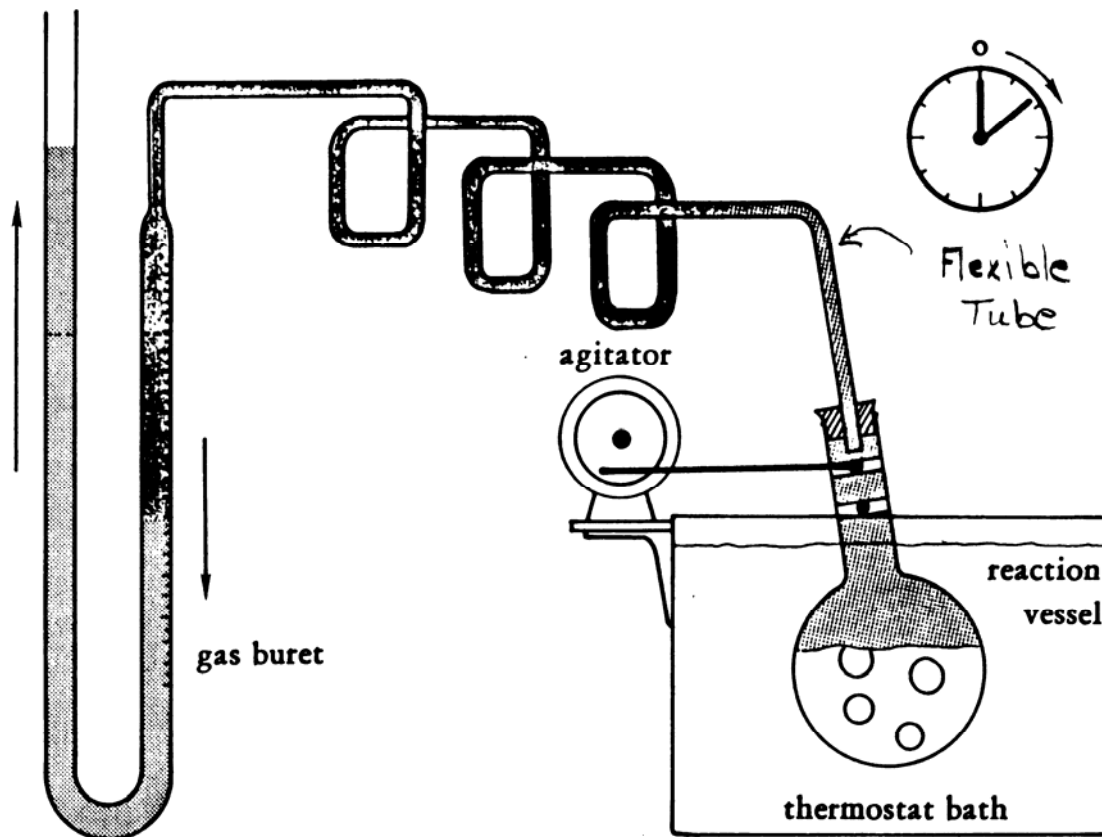
Example—

- Electrical conductivity of a solution is proportional to concentration of ions
 - Volume may change if density of products and reactant are different
 - The intensity of absorption at a specific wavelength of light is proportional to the concentration of absorbing species
 - Temperature increase or decrease is proportional to heat liberated by an exothermic or endothermic reaction
- etc.

A few of many possible examples on following slides

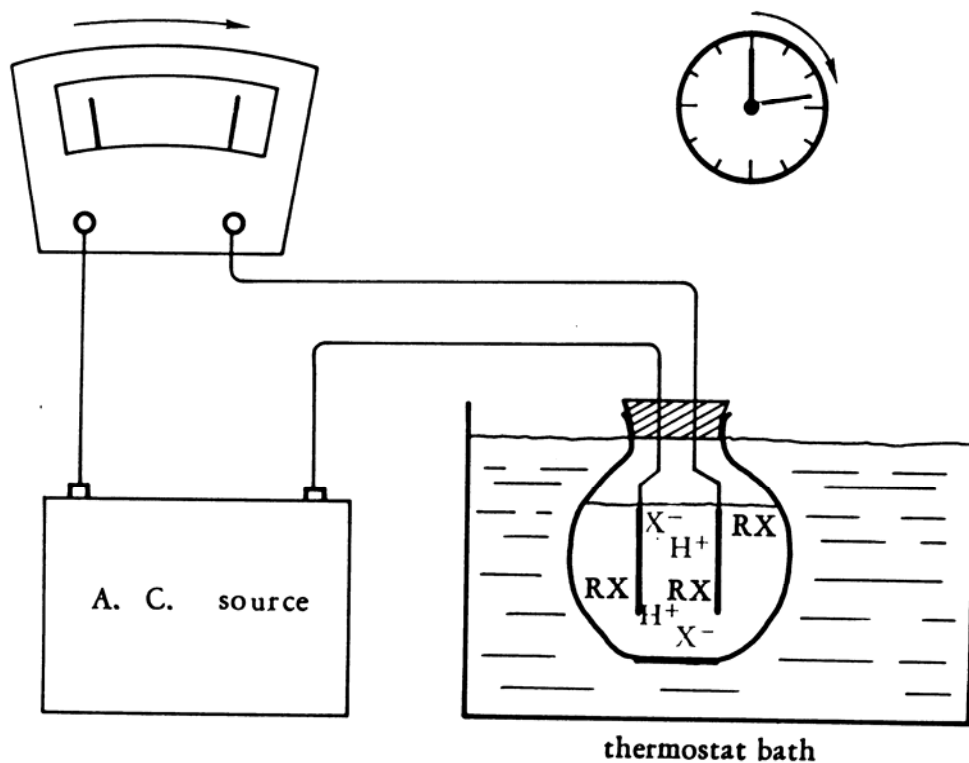
Rate of Gas Formation

Relatively slow (good for a freshman lab experiment)
Gas volume generated as a function of time



Electrical Conductivity

Electrical conductivity as a function of time - Ion formation or loss



Rate of measurement
limited by mixing and
electronics

Measurement Techniques

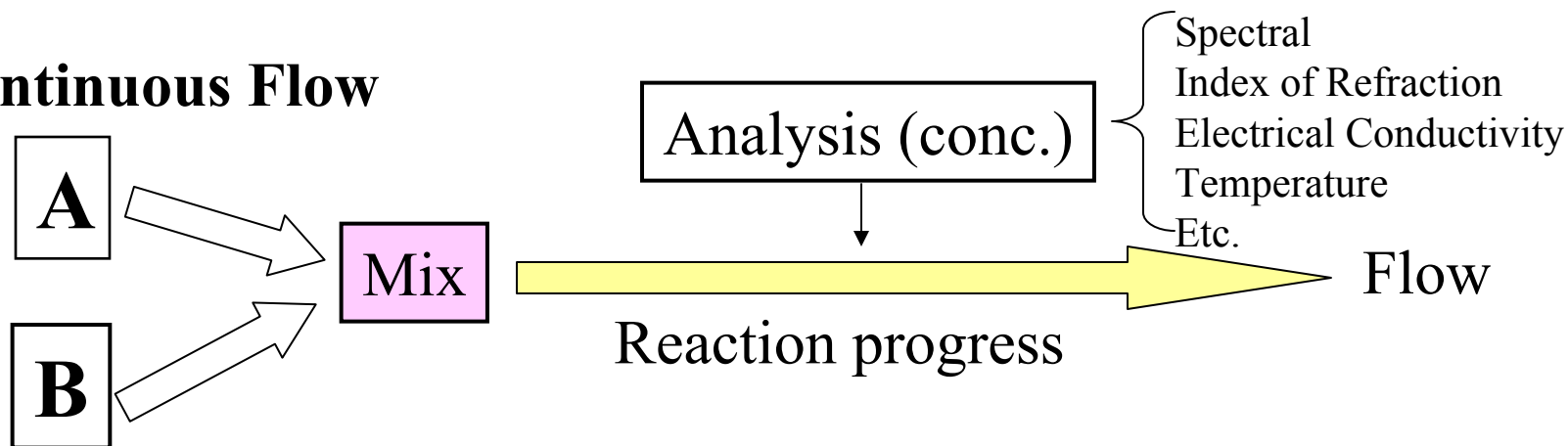
Flow Systems – flow rate and distance is related to time
mixing is limiting factor – continuous flow and stopped flow
Start far from equilibrium, allow reaction to approach equilibrium
 $A + B = \text{products}$ 1/10 millisecond and longer

Relaxation Methods – start at equilibrium, perturb system to upset equilibrium, allow system to attempt to re-establish equilibrium
pressure jump – temperature jump – shock tubes, etc
microsecond and longer time

Flash Photolysis – (a relaxation method) – initiate reaction by producing an excited state species by a short intense light pulse
 $A + h\nu = B^* = \text{products}$ (study kinetics of B^*) flash duration $\ll t_{1/2}$

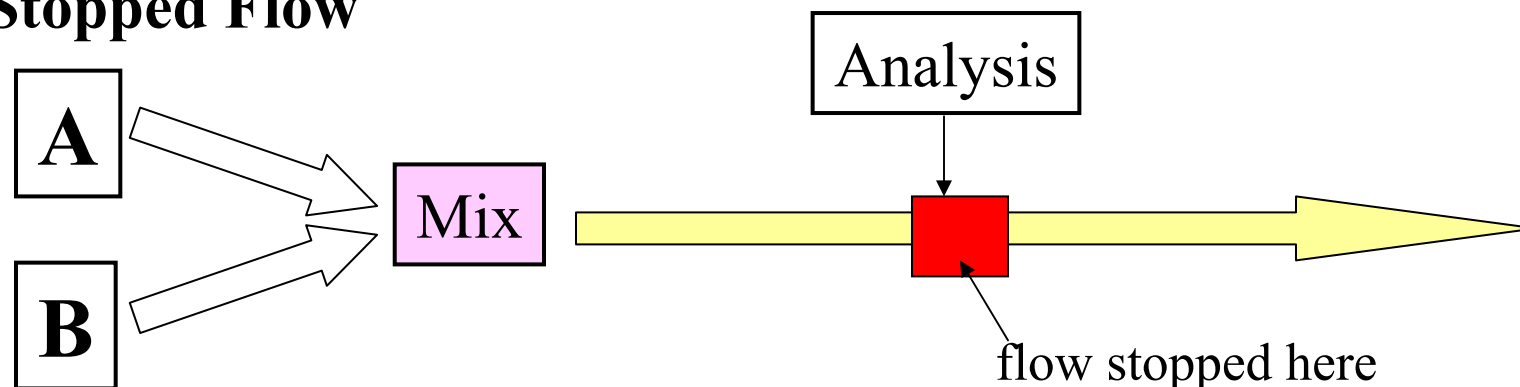
Flow Systems

Continuous Flow



time proportional to rate of flow and distance along flow path
(first flow experiment in 1905 – F. Raschig)

Stopped Flow



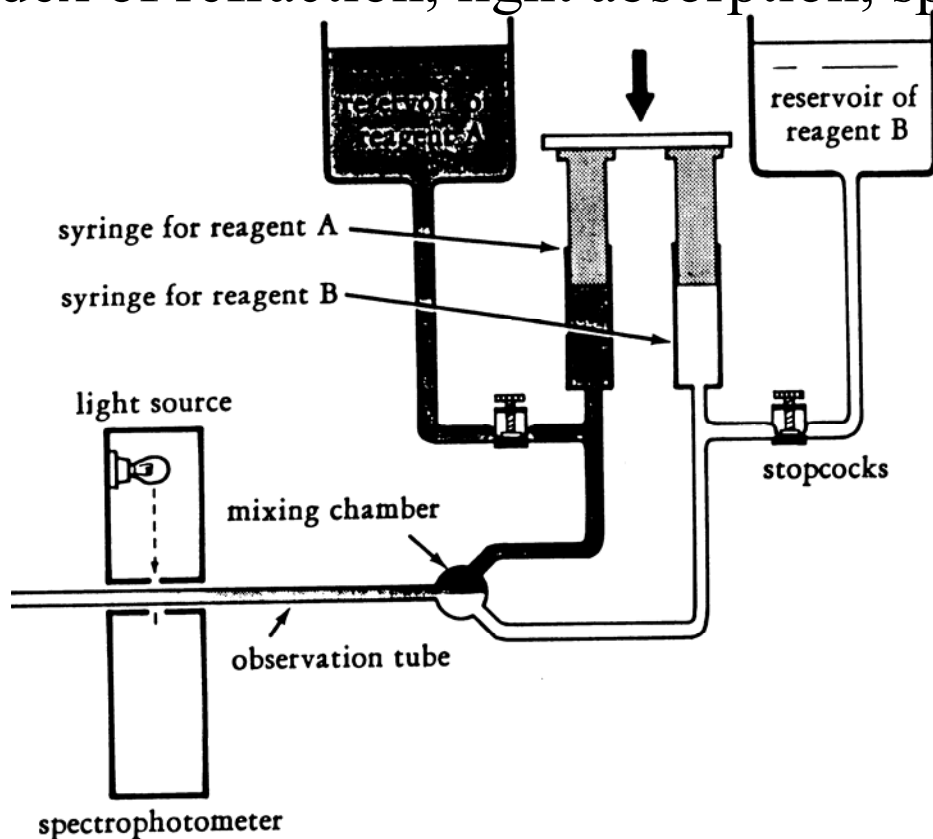
Flow Systems

Rate of mixing must be faster than half-life of reaction

Electric drive for syringes

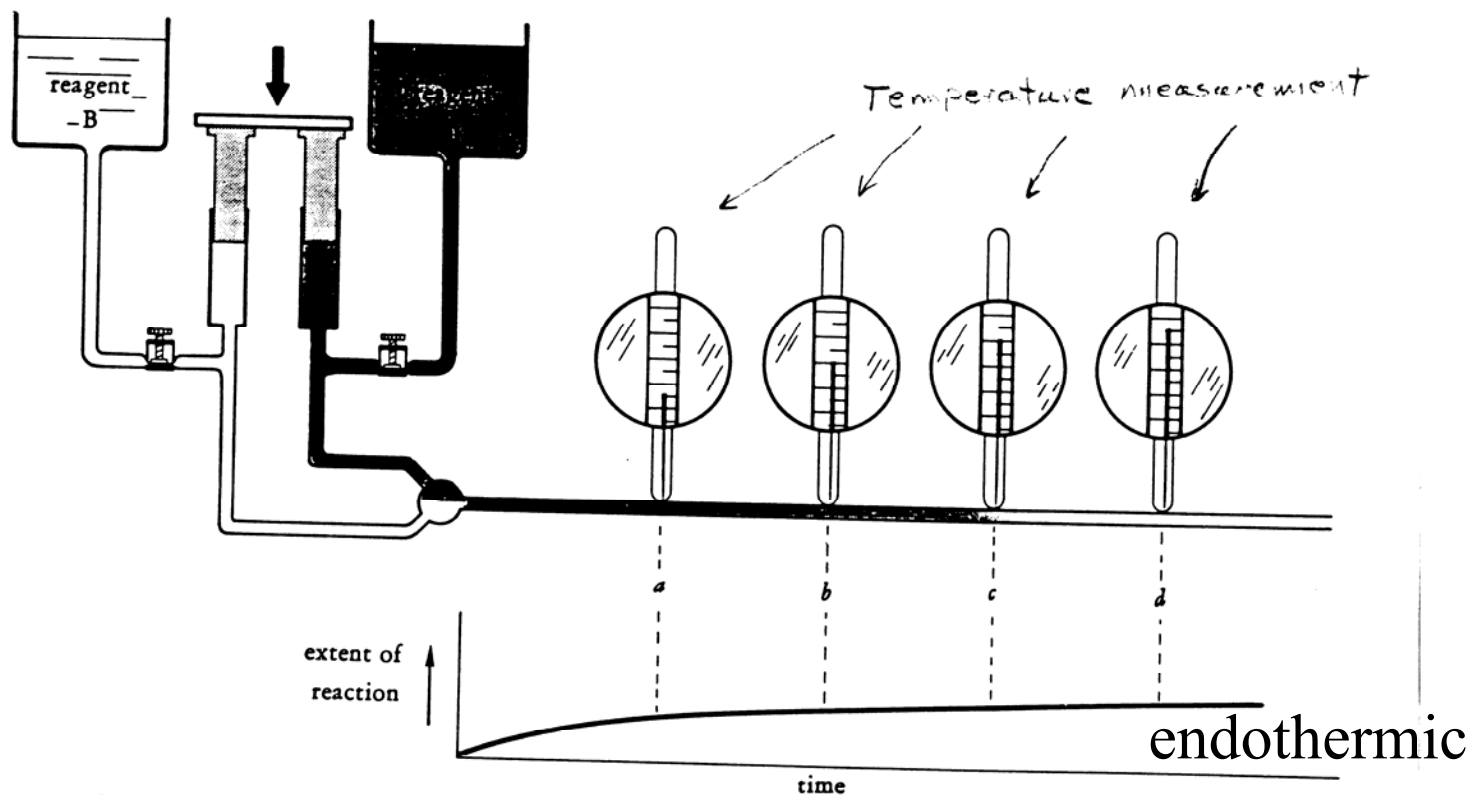
Move light source and detector along flow tube for different times

Detection by index of refraction, light absorption, spectroscopy, etc.



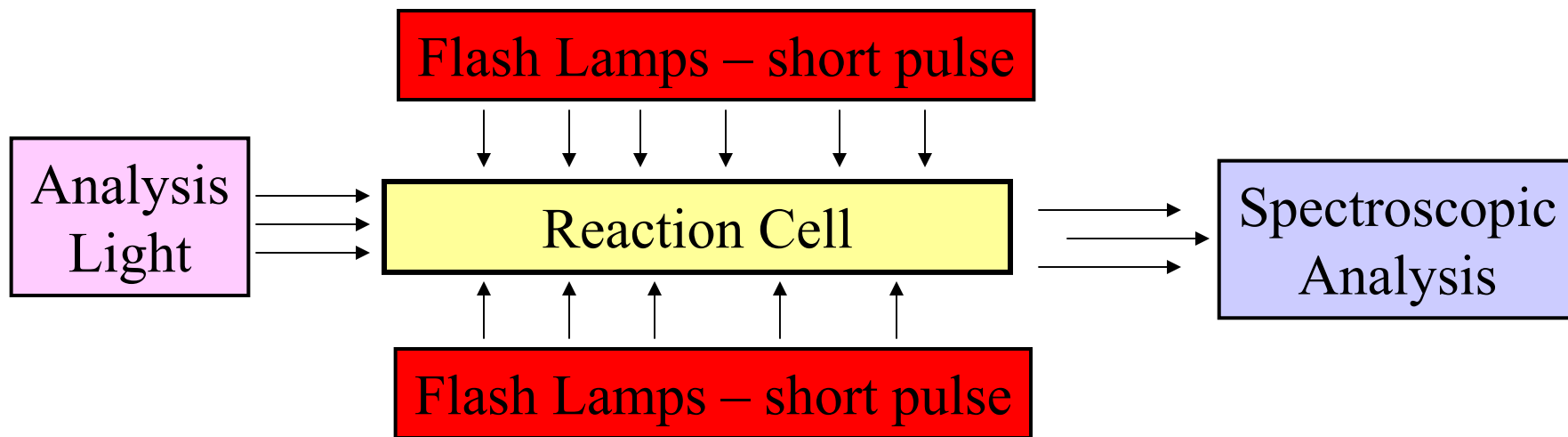
Flow System

$A + B = \text{products}$ (endothermic or exothermic reaction)



The extent of reaction in a rapid-flow experiment can be measured by the change in temperature. The temperatures at thermometers *a*, *b*, *c*, and *d* are different because the extent of reaction at each of these points is different and, therefore, the heat evolved is different at each point.

Flash Photolysis



- Light pulses must have pulse durations $\ll t_{1/2}$
- Light sources may be flash lamps or lasers
- Spectroscopic analysis may be IR, UV, Vis
- Spectroscopy involves optics, lenses, alignment, electronics, etc.
- Electronics must operate in times $\ll t_{1/2}$

Measurement Techniques



Exploding Wires – a relaxation technique

Flash Heating – a relaxation technique – light flash on black surface
microwave pulse, laser pulse, hot wires, etc.

heating rate should be $\gg t_{1/2}$

Molecular Beams – molecules, radicals, ions, molecular fragments
moving in same direction at same speed with out turbulence
no collisions so no reactions - introduce turbulence at time=0
a modified slow system – limited by mixing time

Thermal Quenching – sudden cooling to “stop” reaction for analysis
freezing, trapping in a frozen glass, cryogenic temperatures

Measurement Techniques

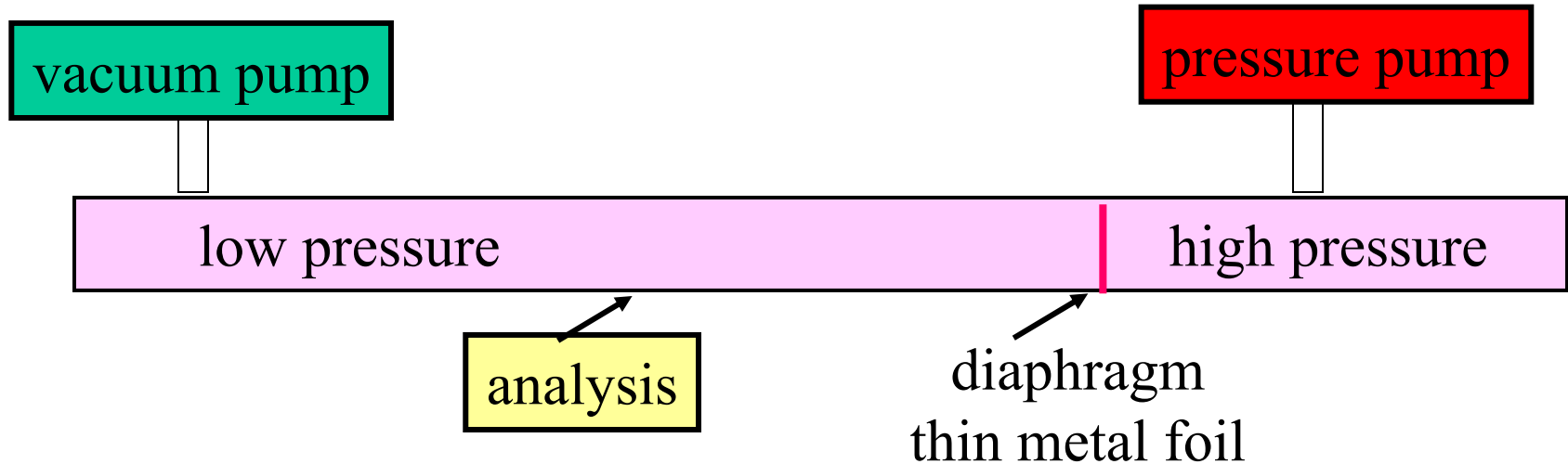


Chemical Quenching – addition of a reagent that “stops” reaction while analysis is conducted – “poison” a catalyst, add another reactant that very rapidly uses up other reactants much faster than reaction being studied, etc.

Shock Tubes – a relaxation method – sudden pressure and temperature jump - explosive

Shock Tube

system at equilibrium → “shocked” to non-equilibrium → return to equilibrium



Diaphragm is ruptured, producing a shock wave (pressure jump) that travels down tube producing a pressure and temperature jump as it travels at rates ~ 300 m/sec (\sim speed of sound). Tube is very long. Position along tube is proportional to time. Make observations (spectroscopy, etc.) at various points along tube in real time.

Photographic Techniques to Determine Rate

Example PHOTONIC SYSTEMS

Optical Diagnostics of Combustion Using a New Framing/Streak Camera

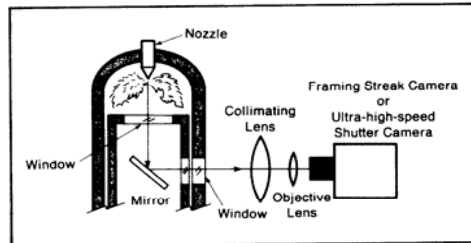


Figure 1

A 4-frame photo of fuel combustion in a diesel engine is shown in Figure 2. These frames were 1 microsecond exposures spaced at 300 microseconds. Up to eight frames as short as 50 nanoseconds each are possible at frame rates up to 3 million frames per second.



Figure 2 Photo courtesy of Advanced Combustion Engineering Inst. Co., LTD.

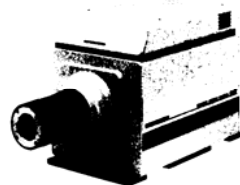
There are many ways to study kinetics of a process. Measurement of something related to reactants concentration as function of time. Many ways to measure time and relative concentration.

Product Focus:

Hamamatsu's New C4187 Framing/Streak Camera

Innovative triggering is featured on the new Model C4187 Framing/Streak Camera. With this new approach, up to 8 exposures with times as short as 50 nanoseconds can be randomly spaced along an optical event. In addition, exposure times can be independently varied within a single event, so a longer exposure can be programmed when the intensity is expected to decrease with time.

In addition to framing versatility, this new system offers a plug-in streak module with time resolution as short as 10 picoseconds—more than 10 times shorter than typically provided on a combination framing/streak camera.



5 nsec

For additional information about this or other applications, contact:

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Ideas and Guide for Paper – end of semester

- Paper should be well written, clear and in a professional format probably 10-20 pages
- Because of class size we will NOT have student presentations
- Instead of in-class presentations, prepare a PowerPoint Slide Presentation
- Hand in Paper and Slides (both printed) at/before last class of the semester
- PowerPoint slides should be clear and professional with technical content
- Slides should be what you would have used if you had presented it in 15 min to class
- Paper and Presentation contains technical information and science at PChem level
- Pictures, graphs, tables, equations, explanation, etc. are good
- Paper Topic is your choice determined in the following way –
 - go to a Chemical & Engineering News (C&EN a magazine of American Chem Soc)
 - http://pubs.acs.org/subscribe/journals/cen/88/i02/toc/toc_i02.html
 - in each issue there is a section called “Science & Technology”
 - that section each week has several 1-2 paragraph highlights on something new
 - look through several issues from recent years, find a topic of interest
 - research journals (there are many) on that topic
 - the news article probably will start you with names of people and a reference
 - use foot note references in your paper (there should be several not just 1)
- Your paper is a detailed review of the topic you select using C&EN to pick a topic
- An Example - C&EN Jan 11, 2010 in “Science and Technology”
 - <http://pubs.acs.org/subscribe/journals/cen/88/i02/html/8802scic8.html>
 - article “Clay-Polymer Nanolayers Improve Gas-Barrier Films” - could be a paper

Each year there are 100's of articles in C&EN