Kinetics

Use these Guided Notes to follow along with Jeremy Krug's AP Chemistry Complete Course on YouTube.

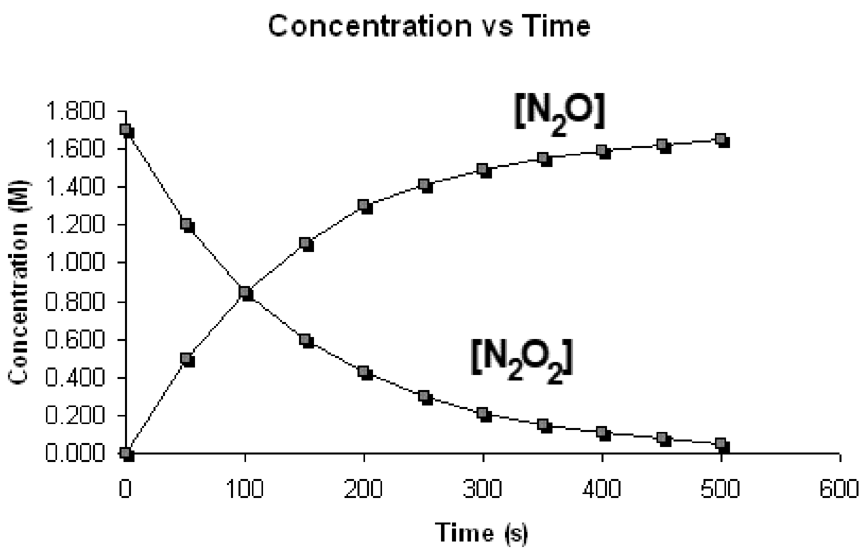
Topic 5.1 – Reaction Rates *Video (19:13)*

Thermodynamics	Will the reaction go?
Equilibrium	How far will the reaction go?
Kinetics	________________________________

Kinetics is the study of the ______ of chemical reactions and the _________ that affect those rates of reaction.

$$2\ N_2O_2(g) \rightarrow 2\ N_2O(g) + O_2(g)$$

Let's focus on the reactant, $N_2O_2(g)$, and one of the products, $N_2O(g)$. We'll ignore O_2 for now.



What do you notice about the rates of both these substances?

What do you notice about the coefficients of both these substances?

How does the rate of the reaction change as time progresses?

Determine the rate of change of $[N_2O]$ in the time interval from 0 to ____ seconds.

A more precise way of finding the *instantaneous rate* is to take the ____________________
____.

If the rate of change of $[N_2O]$ in the time interval from 0 to 50 seconds is $1.00 \times 10^{-2}\ \frac{M}{s}$, then estimate the rate of change of $[O_2]$ over the same time interval.

Estimate the rate of change for ________ over the same 50-second time interval.

Notice that *all rates* are always given as ______________________.

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Four Key Ways to Speed Up a Reaction

1. Raise the temperature.

   Molecules move faster, so they collide ________________and with ____________________.

   Rule of Thumb: For every 10°C increase in temperature, the rate of a typical reaction ____________.

2. Increase the concentration.

   Molecules are packed closer together, so they collide _______________________.

3. Decrease the particle size.

   The reactant has a greater __________________, increasing the number of _______________ where a reaction can occur.

4. Add a catalyst.

   A catalyst speeds up a reaction without being ____________.

   Catalysts __________________________________of the reaction.

   Catalysts provide a lower-energy __________________________ for the reaction allowing the reaction to be sped up.

Topic 5.2 – Introduction to Rate Law *Video (11:50)*

To write a rate law, we must have some experimental data. A *balanced equation is not enough*.

$$2\ ClO_2(aq) + 2\ OH^-(aq) \rightarrow ClO_3^-(aq) + ClO_2^-(aq) + H_2O(l)$$

Exp.	$[ClO_2]$	$[OH^-]$	Initial Rate (M/s)
1	0.020	0.030	0.00276
2	0.060	0.030	0.0248
3	0.020	0.090	0.00828

What is the order of the reaction with respect to ClO_2?

What is the order of the reaction with respect to OH^-?

Write the rate law for this reaction.

What is the overall order of this reaction?

Calculate the rate constant k for the reaction at this temperature, with correct units.

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Write the rate law for the following reaction, using this data:

$$2\ NO + Br_2 \rightarrow 2\ NOBr$$

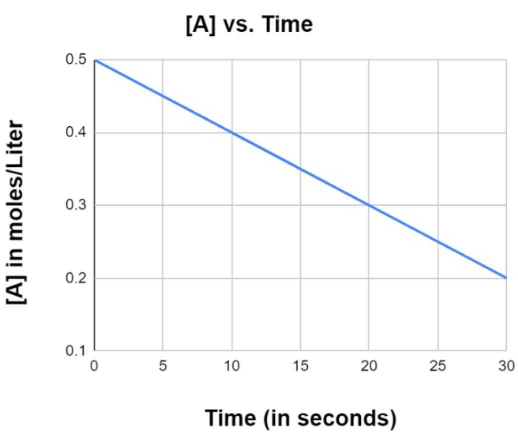
Exp.	[NO]	[Br_2]	Initial Rate (*M*/s)
1	0.020 *M*	0.030 *M*	1.4×10^{-3}
2	0.040 *M*	0.030 *M*	5.6×10^{-3}
3	0.020 *M*	0.060 *M*	2.8×10^{-3}

What is the overall order of this reaction?

Calculate the rate constant of this reaction, with correct units.

Topic 5.3 – Concentration Changes Over Time *Video (21:07)*

Another way to determine reaction order



Plot concentration of the reactant vs time…

If the plot is a straight line, the reaction is _______________.

The rate law is Rate = $k[A]^0$

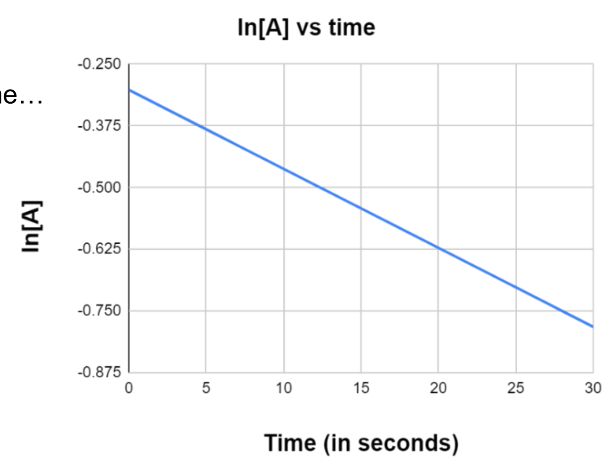
The rate constant *k* is equal to the ________________________ of the line.

Plot the natural logarithm of concentration (ln[A])of the reactant vs time…

If the plot is a straight line, the reaction is ________________.

The rate law is Rate = k[A]

The rate constant *k* is equal to the ________________________ of the line.



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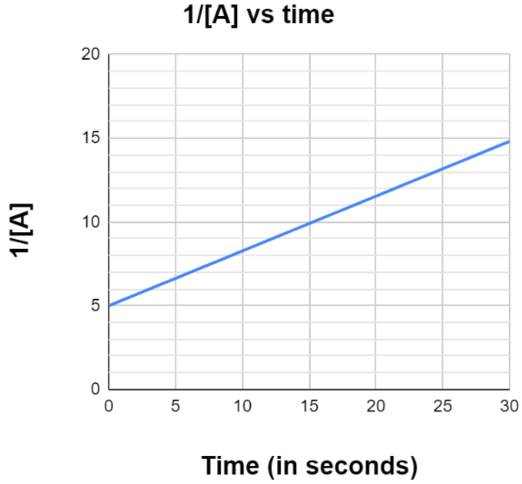


Plot the reciprocal of concentration ($\frac{1}{[A]}$) of the reactant vs time…

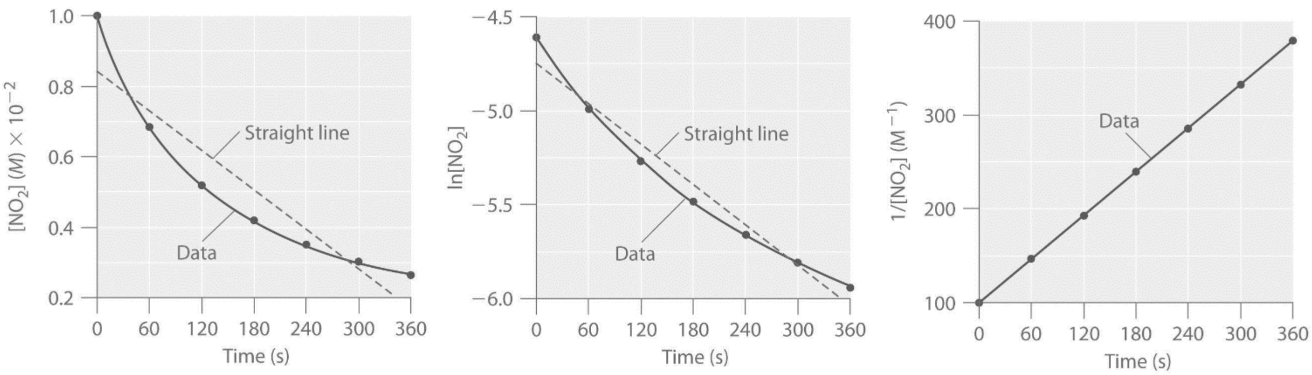
If the plot is a straight line, the reaction is _______________ .

The rate law is Rate = $k[A]^2$

The rate constant k is equal to the _______________________ of the line.

The reaction given below is studied. The following graphs are produced and used to analyze the reaction.

$$2\ NO_2 \rightarrow N_2 + 2\ O_2$$



(a) What is the order of this reaction with respect to NO_2?

(b) Write the rate law for this reaction.

(c) Calculate the rate constant k for this reaction, with appropriate units.

Integrated Rate Laws

If we know the order of a reaction with respect to a specific reactant and the rate constant, we can calculate its concentration at any time throughout the process.

For a 1st order process…

Rate = k [A]   can be integrated using calculus into…

$$\ln[A]_t - \ln[A]_0 = -k\,t$$

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A first order reaction has a rate constant of 3.8×10^{-2} s^{-1} at 270 K. If the reactant begins with a concentration of _______ *M*, what will be the concentration after 60. seconds?

A first order process at 300 Kelvins is measured. If the reactant's concentration drops from 0.95 *M* to ______ *M* in 170 seconds, what is the rate constant?

Half-Life

Often, for first-order processes we are interested in how long it will take for half of the initial reactant to be depleted. The time it takes for the reactant to be reduced ____________ is called the *half-life*.

$$t_{1/2} = \frac{0.693}{k}$$

In the previous problem, the first-order reaction had a rate constant of _____________ s^{-1}. What is the half-life of this process, in seconds?

Integrated Rate Law for 2nd Order Processes

$$\frac{1}{[A]_t} - \frac{1}{[A]_0} = k\,t$$

A second-order process has a rate constant of 2.6×10^{-2} M^{-1}s^{-1}. If reactant A has an initial concentration of 0.80 *M*, how long will it take for its concentration to drop to ______ *M*?

To Summarize…

	Rate Law	*Units for k*	*Integrated Rate Law*
0 Order	Rate = *k*	M s^{-1}	$[A]_t - [A]_0 = -k\,t$
1st Order	Rate = *k*[A]	s^{-1}	$\ln[A]_t - \ln[A]_0 = -k\,t$
2nd Order	Rate = *k*[A]^2	M^{-1} s^{-1}	$\frac{1}{[A]_t} - \frac{1}{[A]_0} = k\,t$

Study note: Any appropriate unit for concentration can be used in place of molarity. For example, molecules per cubic micrometer would be perfectly acceptable for concentration (though rare). Likewise, any unit of time can be used in place of seconds. For slower reactions, minutes, days, or even years may be used.

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Topic 5.4 – Elementary Reactions *Video (19:08)*

This reaction has two elementary steps.

Each step can be described with its own rate law.

$$N_2O\,(g) \rightarrow N_2(g) + O(g)$$
$$N_2O(g) + O(g) \rightarrow N_2(g) + O_2(g)$$

Identify the *bimolecular* step in this reaction mechanism.

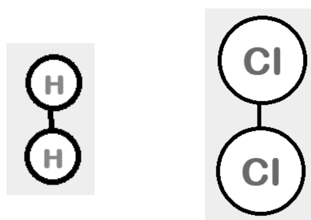
Identify the *unimolecular* step in this reaction mechanism.

Termolecular steps are ____________________.

Topic 5.5 – Collision Model *Video (19:08)*

A Simple Reaction

$$H_2 + Cl_2 \rightarrow 2\,HCl$$



When the two molecules collide, they have to collide with

1. ____________________________ 2. ____________________________

The two molecules ________, forming an ***activated complex***.

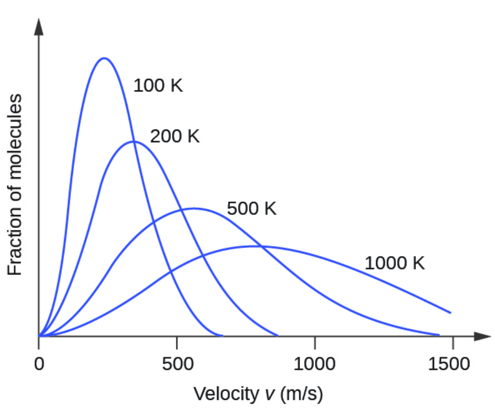
Activated complex –an unstable, high-energy molecule temporarily formed after the reactant state but

____

*Study note: On the AP Chemistry exam, the **activated complex** is often called a **transition state**.*

If the two original bonds break, the ____________ molecules are formed.

Maxwell-Boltzmann Distribution Curve



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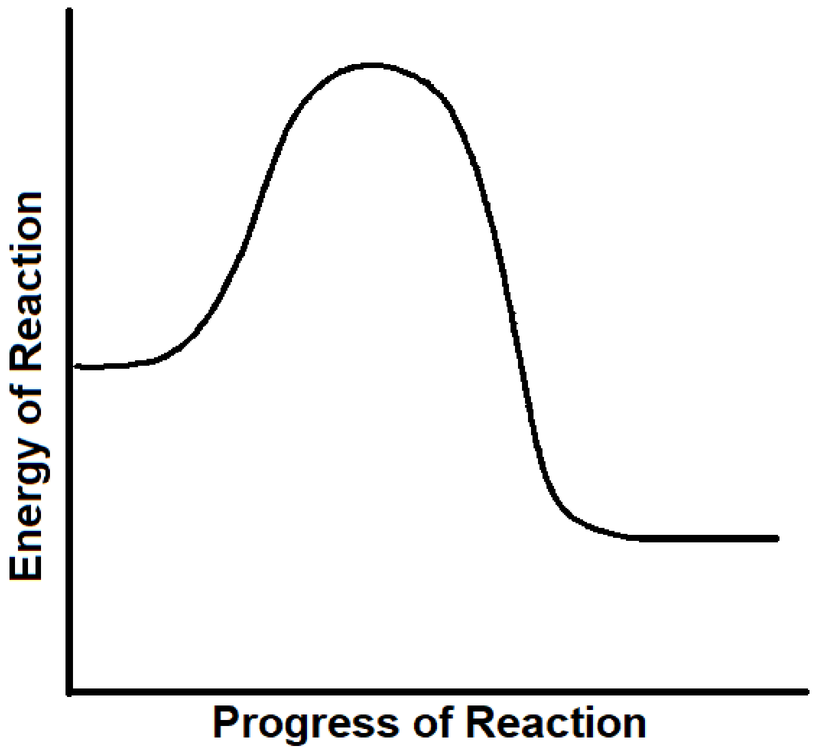
Topic 5.6 – Reaction Energy Profile *Video (19:08)*

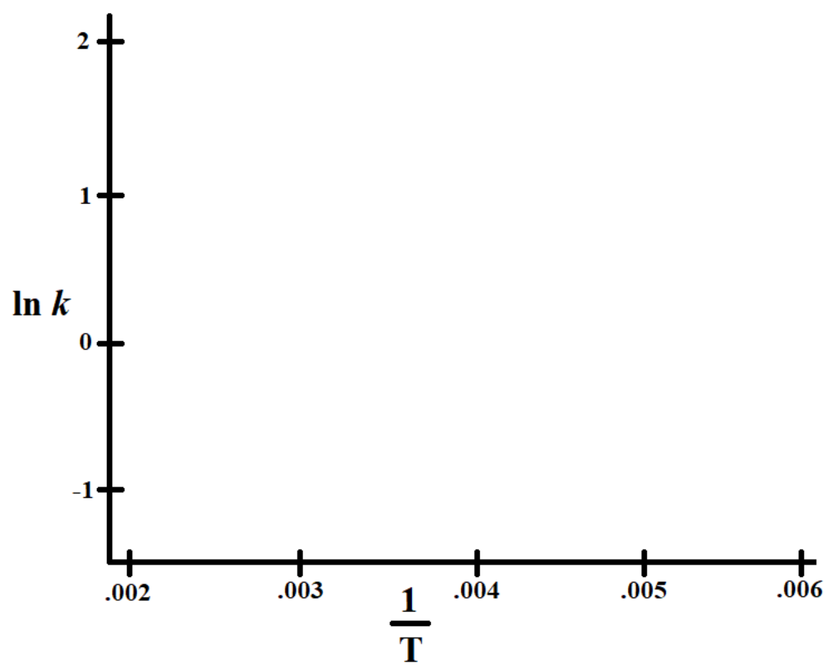


Is this reaction *exothermic* or *endothermic*?

How do you know?

Why does lowering the activation energy speed up the reaction?

Why does the catalyzed reaction profile have two 'humps'?



Study note: On the AP exam, you will not be asked to perform any calculations involving the Arrhenius equation.

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Topic 5.7 – Introduction to Reaction Mechanisms *Video (9:39)*

Many reactions take place in two or more steps!

$$N_2O\,(g) \rightarrow N_2(g) + O(g)$$
$$N_2O(g) + O(g) \rightarrow N_2(g) + O_2(g)$$

Write the equation for the overall reaction.

Identify the **reaction intermediate**.

Topic 5.8 – Reaction Mechanism and Rate Law *Video (9:39)*

If we know which of these two steps in the mechanism is the *slow step*, we can also determine the rate law!

The _______________ determines the rate of the overall reaction.

Topic 5.9 – Pre-Equilibrium Approximation *Video (9:39)*

Using the mechanism below, (a) Write the overall equation for the reaction, and (b) determine the rate law of this reaction.

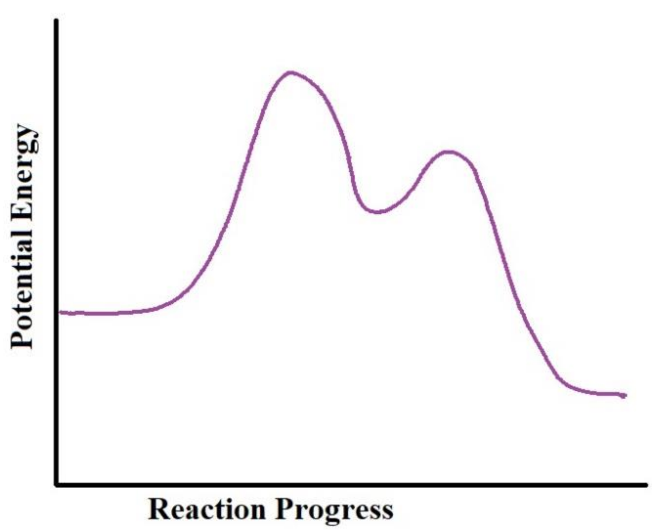
$$NO(g) + Cl_2(g) \leftrightharpoons NOCl_2(g) \qquad \text{(fast, equilibrium)}$$
$$NOCl_2(g) + NO(g) \rightarrow 2\,NOCl(g) \qquad \text{(slow)}$$

Do you see a problem with this rate law?

If a substance doesn't appear in the overall balanced equation, it ________ be in the rate law!

Study note: Remember, a reaction intermediate might appear in the rate law for an elementary step for a reaction, but it cannot appear in the rate law for an overall balanced equation!

Topic 5.10 – Multistep Reaction Energy Profile *Video (9:39)*



Topic 5.11 – Catalysis *Video (7:35)*

Using the mechanism below, (a) Write the overall equation for the reaction, (b) identify the reaction intermediate, (c) identify the catalyst, and (d) determine the rate law of this reaction.

$$H_2O_2(aq) + I^-(aq) \rightarrow H_2O(l) + IO^-(aq) \qquad \text{(slow)}$$

$$IO^-(aq) + H_2O_2(aq) \rightarrow H_2O(l) + O_2(g) + I^-(aq) \qquad \text{(fast)}$$

The **reaction intermediate** is produced in an early step, used up in a later step ____________

The **catalyst** is present at both the beginning and end, but never consumed = ____________

Rate law for the reaction ________________________

What if the catalyst isn't present?

Consider the reaction mechanism given below.

Step 1: $A + B \rightarrow AB$

Step 2: $AB + B + C \rightarrow ABC + B$

(a) Write the overall equation for this reaction.

(b) Which of the two elementary steps in this process would you expect to occur at a faster rate? Explain your answer.

Consider the slow steps from two different chemical reactions, given below. Which of the two processes will have the faster rate? Explain your answer.

	Process	*Rate constant*
Reaction 1	$P + Q \rightarrow PQ$	$2.8 \times 10^{-4}\ M^{-1}s^{-1}$
Reaction 2	$Y + Z \rightarrow YZ$	$9.5 \times 10^{-3}\ M^{-1}s^{-1}$

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