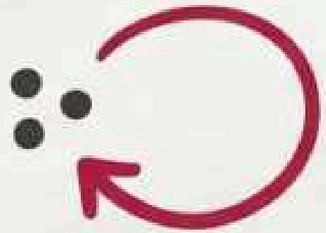
The Logic of Acid-Base Chemistry



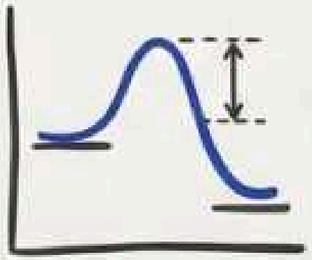
Acid Strength

- Predicting which compound is stronger



Electron Movement

- Using curved arrows to trace reactions



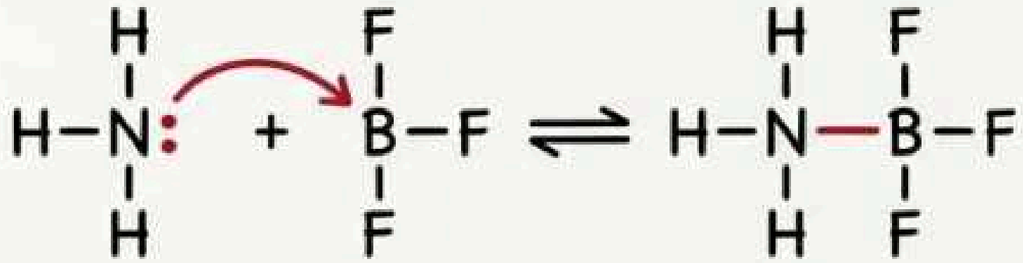
Reaction Energy

- Using energy diagrams for speed and extent

Acid–base chemistry is the simplest example of reaction logic, and it comes first.

Defining Acids and Bases: Two Frameworks

¶ 2.2

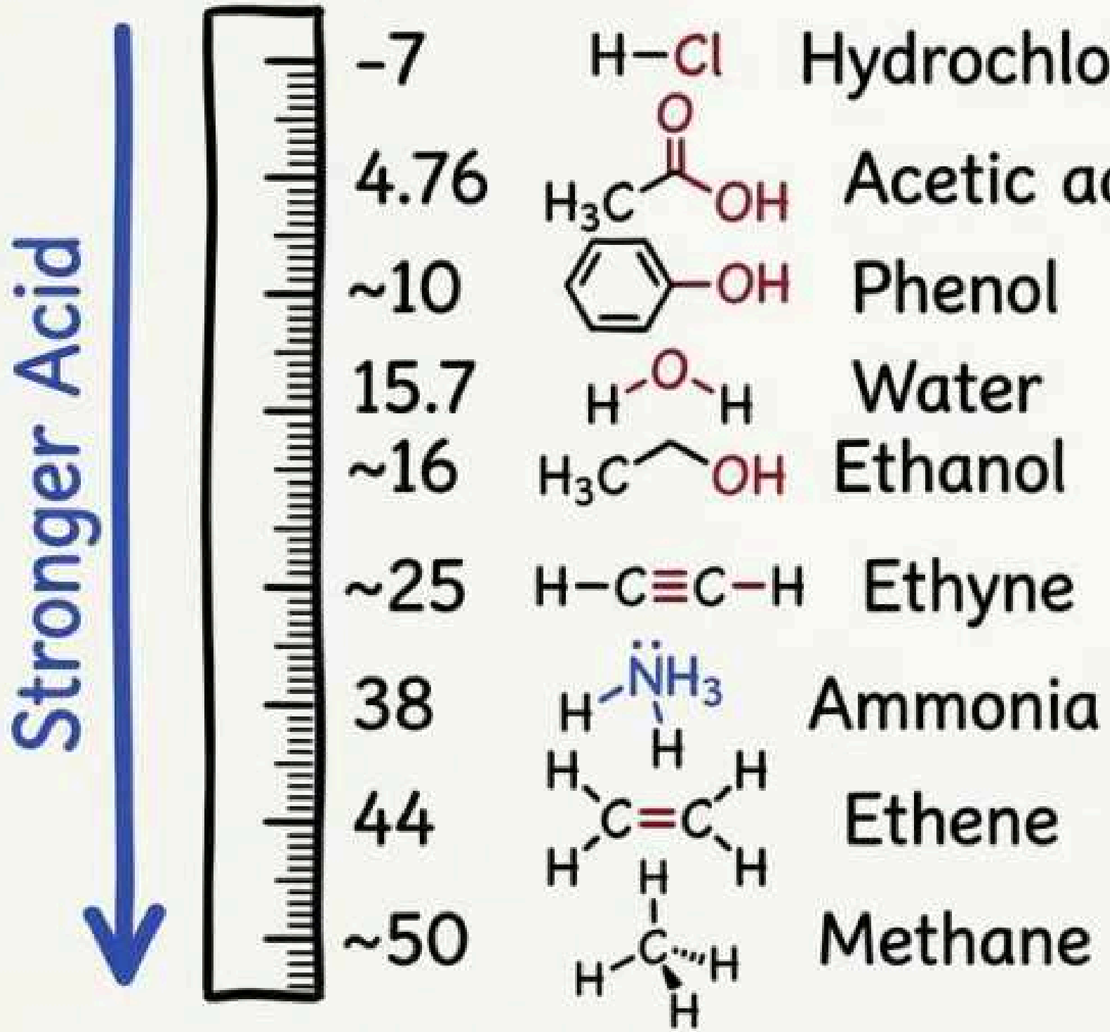
Focus & Rules	Chemical Mechanism
Brønsted-Lowry (1923) Focus: The Proton Acid = Proton Donor Base = Proton Acceptor	$HA + B \rightleftharpoons A^- + HB^+$ When an acid gives up a proton, what remains is its conjugate base.
Lewis (1923) Focus: The Electron Pair Acid = Electron Pair Acceptor Base = Electron Pair Donor	 Lewis acid-base adduct

Most organic reactions can be read through the broader Lewis framework.

Measuring Acid Strength: The pK_a Scale

¶ 2.3

$$pK_a = -\log(K_a)$$



Lower pK_a = Stronger acid.
Each unit on the scale represents a factor of 10.

What Makes an Acid Strong?

¶ 2.4

Golden Rule: Acid strength is driven by the stability of its conjugate base. A more stable anion (A^-) means a more willing acid (HA).

A
Atom bearing the charge

R
Resonance

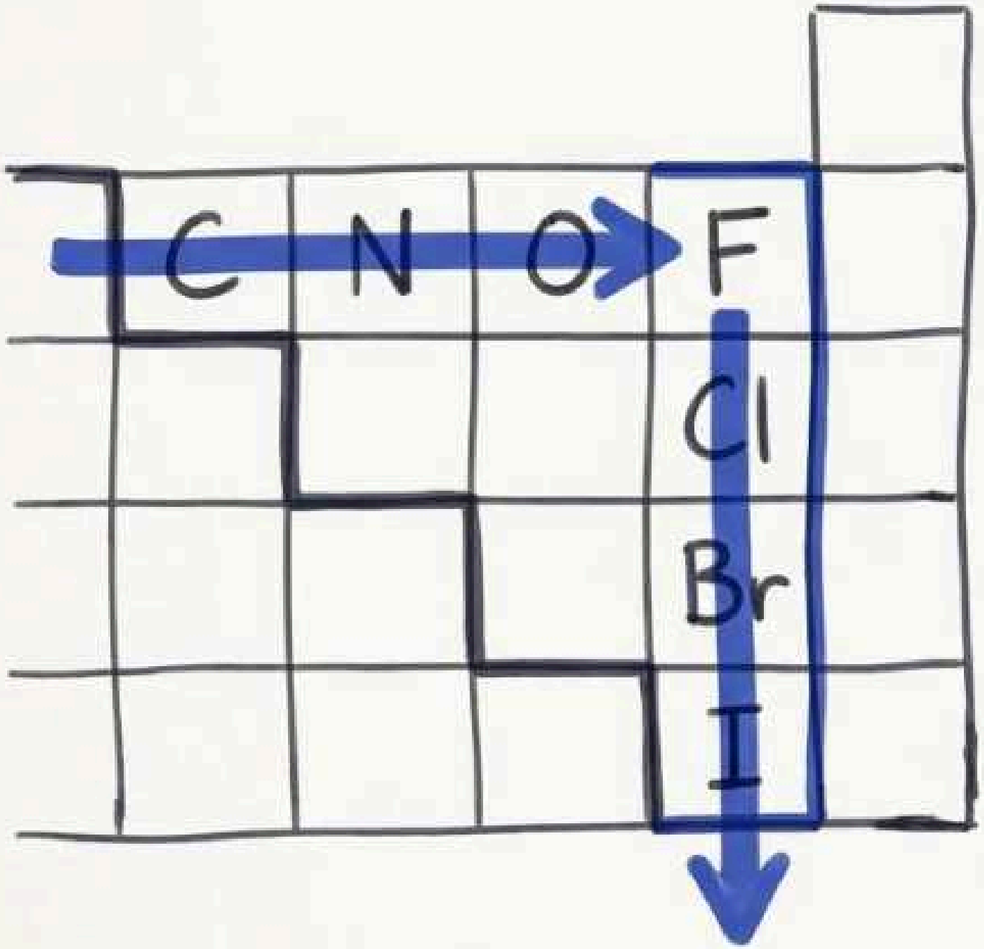
$$HA \rightleftharpoons H^+ + A^-$$

I
Induction

O
Orbital (hybridization)

Factor 1: The Atom (A)

¶ 2.5



Across a Row (Electronegativity)

Acidity rises as electronegativity increases.

Methane < Ammonia < Water < Hydrogen Fluoride

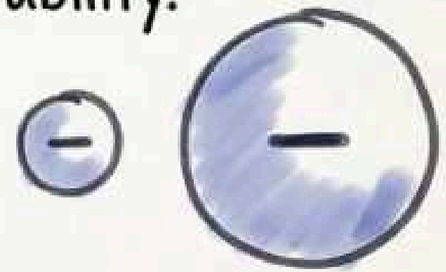
CH_4 < NH_3 < H_2O < HF

Down a Column (Atom Size)

Acidity rises with atom size.

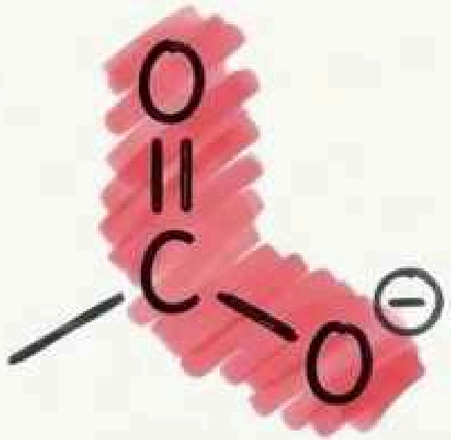
A larger anion spreads its negative charge over more volume, lowering energy and increasing stability.

Hydrogen Iodide > Hydrogen Fluoride



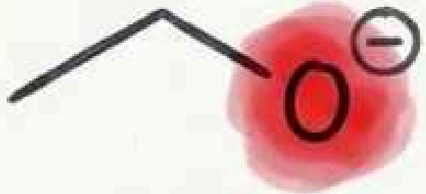
Factor 2: Resonance (R)

Acetic Acid (pKa 4.76)



- The acetate ion shares its negative charge equally between two oxygen atoms (delocalized). Stable anion = stronger acid.

Ethanol (pKa ~16)

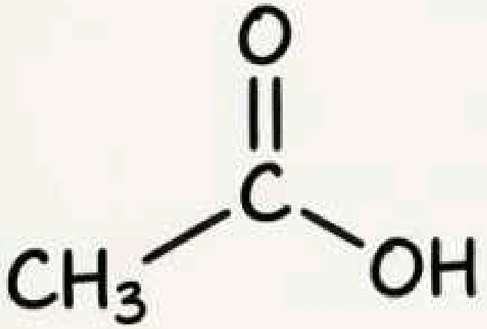


- The ethoxide ion keeps its negative charge isolated on a single oxygen atom.

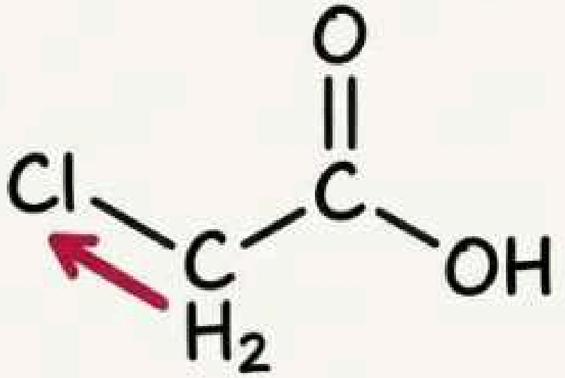
Scale of Impact: A difference of 11 pKa units represents a factor of roughly one hundred billion (10^{11}).

Factor 3: Induction (I)

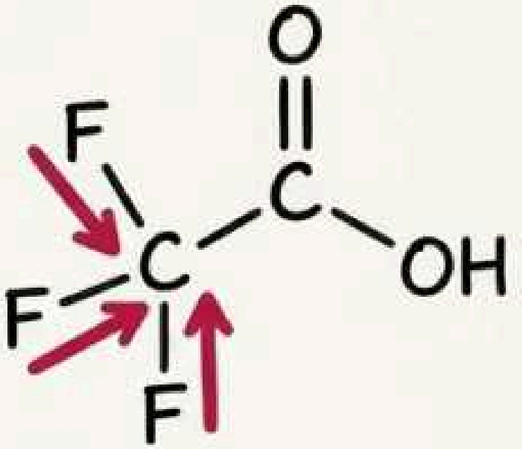
¶ 2.7



Acetic acid
(pK_a 4.76)



Chloroacetic acid
(pK_a 2.86)



Trifluoroacetic acid
(pK_a ~0.5)

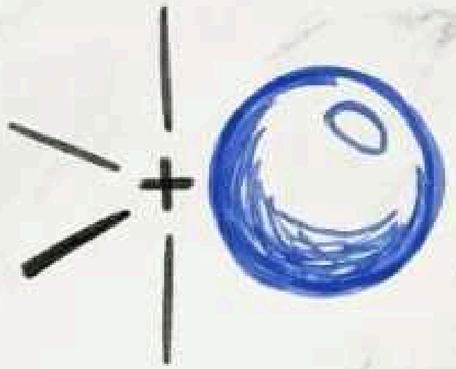
Mechanism: Electronegative atoms pull electron density through sigma bonds, stabilizing a nearby negative charge.

Constraint: This effect weakens quickly with distance (e.g., a chlorine two carbons away has far less influence).

Factor 4: The Orbital (O)

Core Principle: More 's' character means electrons sit closer to the positive nucleus, creating a more stable anion.

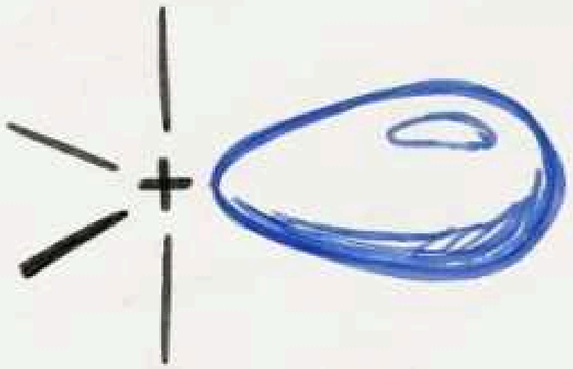
sp Carbon



Ethyne, pKa 25

50% s character
tightest, most stable

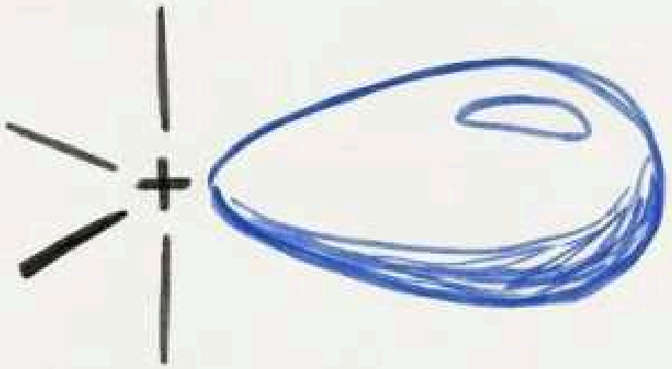
sp^2 Carbon



Ethene, pKa 44

33% s character

sp^3 Carbon



Ethane, pKa ~50

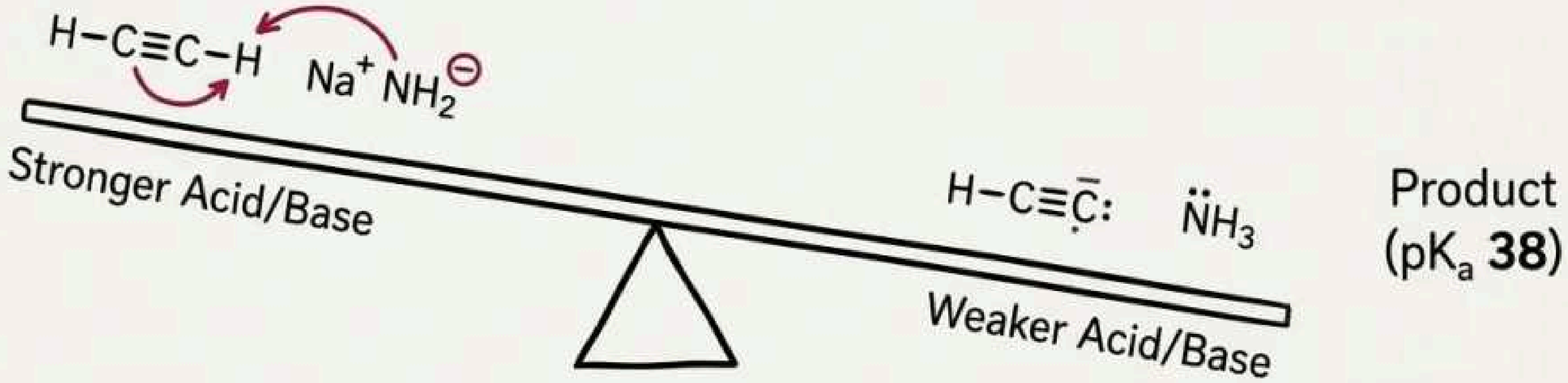
25% s character
most diffuse, least stable

Predicting Reactions with pK_a

¶ 2.9

The Rule: A base can only remove a proton if its conjugate acid has a higher pK_a than the acid being deprotonated.

Strong base (pK_a **25**)



Product (pK_a **38**)

SUCCESS

Sodium amide (conj. acid ammonia has pK_a **38**) easily removes the proton from ethyne (pK_a **25**).

FAILURE

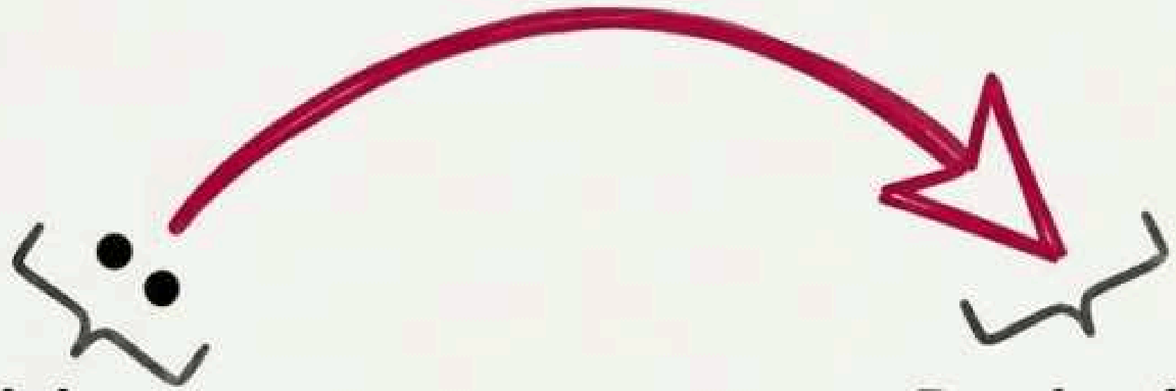
Hydroxide (conj. acid water has pK_a **15.7**) cannot deprotonate ethyne (pK_a **25**).

Takeaway: Equilibrium always favors the formation of the weaker acid and weaker base.

The Language of Movement: Curved Arrows

¶ 2.10

Anatomy Diagram



Origin:
Must start exactly where electrons are (a lone pair or a bond).

Destination:
Points exactly to where the electrons are moving.

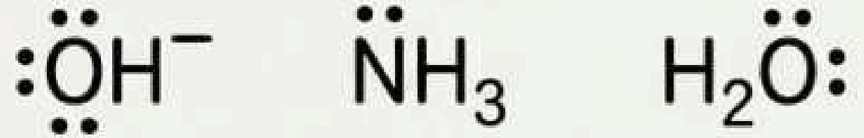
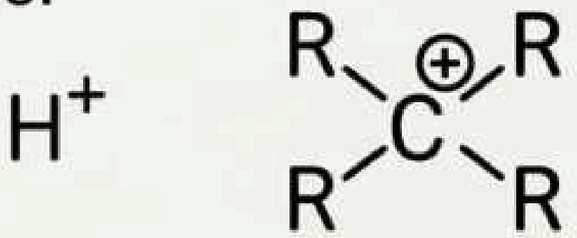
Full-headed arrow = movement of a pair of electrons.

Half-headed arrow = movement of a single electron.

THE CARDINAL RULE: Arrows follow electrons, never atoms.

The Professors Master Whiteboard

¶ 2.11

Nucleophile ("Nucleus-Loving")	Electrophile ("Electron-Loving")
• Role: Electron-rich. **Donates a pair of electrons.**	• Role: Electron-poor. **Accepts a pair of electrons.**
Examples: Hydroxide, ammonia, water, halide ions. 	**Examples**: Protons, carbocations, carbon atoms near electronegative neighbors. 

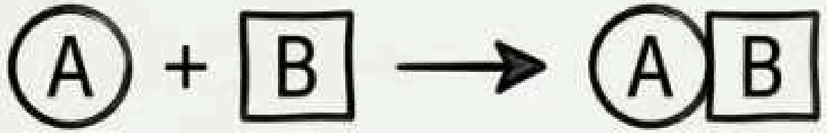
Historical Note: Terminology popularized by British chemist Christopher Ingold in the 1930s.

The Four Types of Organic Reactions

¶ 2.12

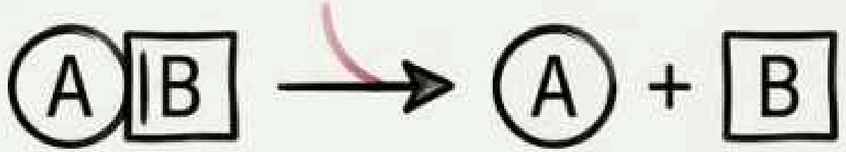
1. Addition

Two molecules combine into one.



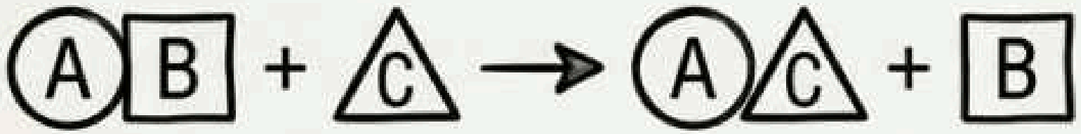
2. Elimination

One molecule splits into two (often forming a double bond).



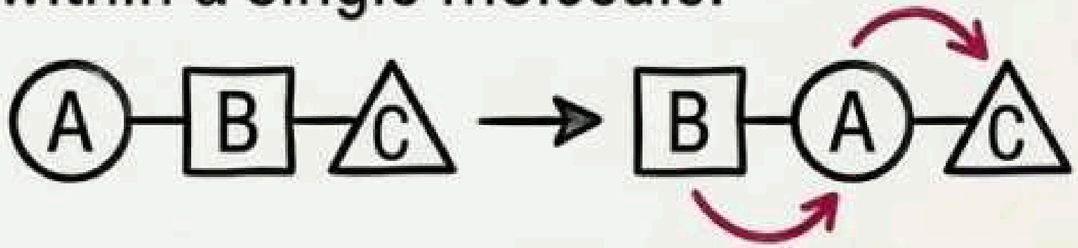
3. Substitution

One group replaces another.



4. Rearrangement

Atoms reorganize their connectivity within a single molecule.



Note: The first three types will be the primary focus of upcoming lectures.

Thermodynamics: Can the Reaction Occur?

Change in enthalpy.

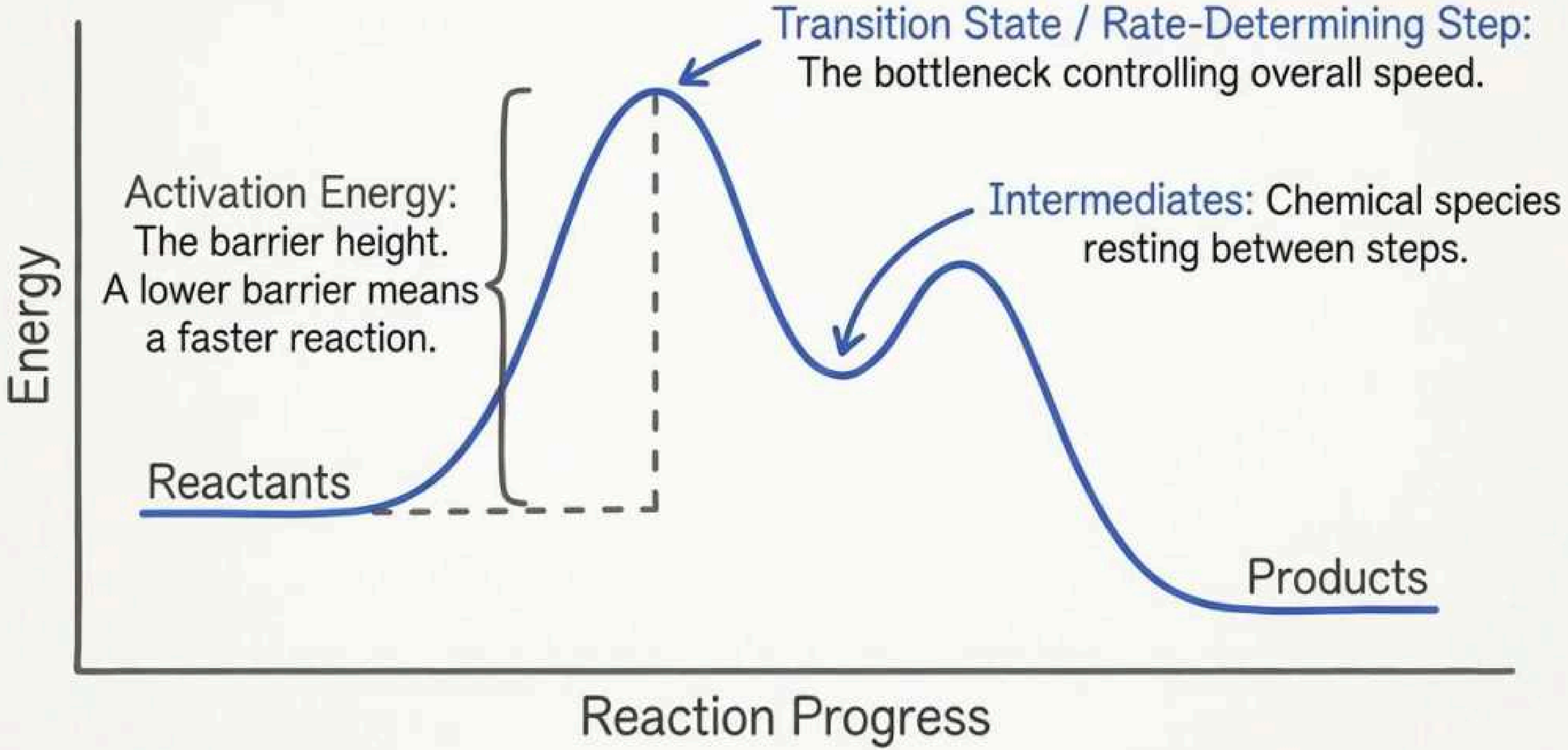
Change in Gibbs free energy. A negative value favors the formation of products.

$$\Delta G = \Delta H - T\Delta S$$

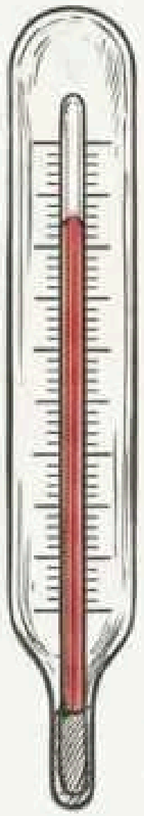
Temperature times change in entropy.

Equilibrium Impact: ΔG dictates the final state. At room temperature, every 5.7 kJ/mol difference in free energy shifts the equilibrium ratio by a factor of 10.

Kinetics: How Fast Does It Go?

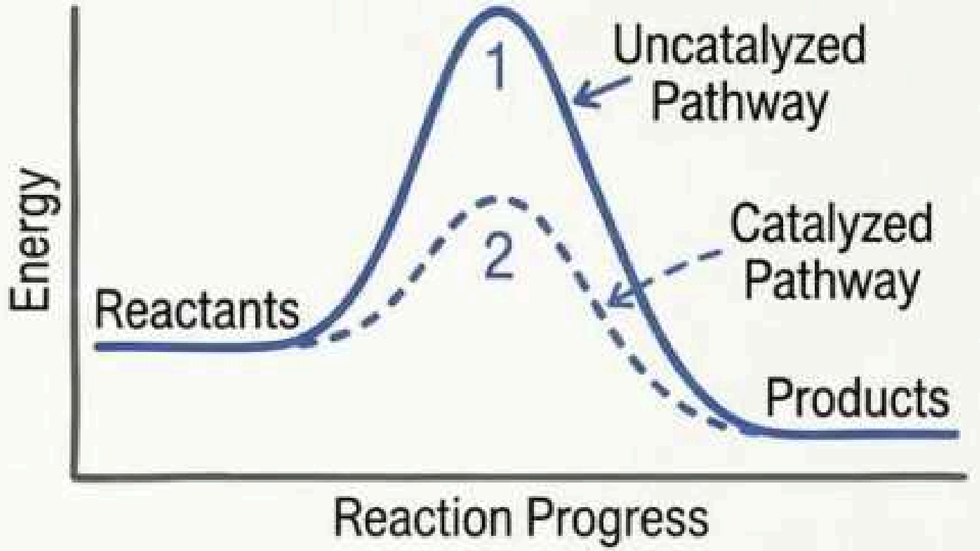


Accelerating Rates: Temperature & Catalysts



Temperature (Arrhenius, 1889)

Adding heat raises reaction rates because more molecules possess enough kinetic energy to clear the existing activation barrier.



Catalysts

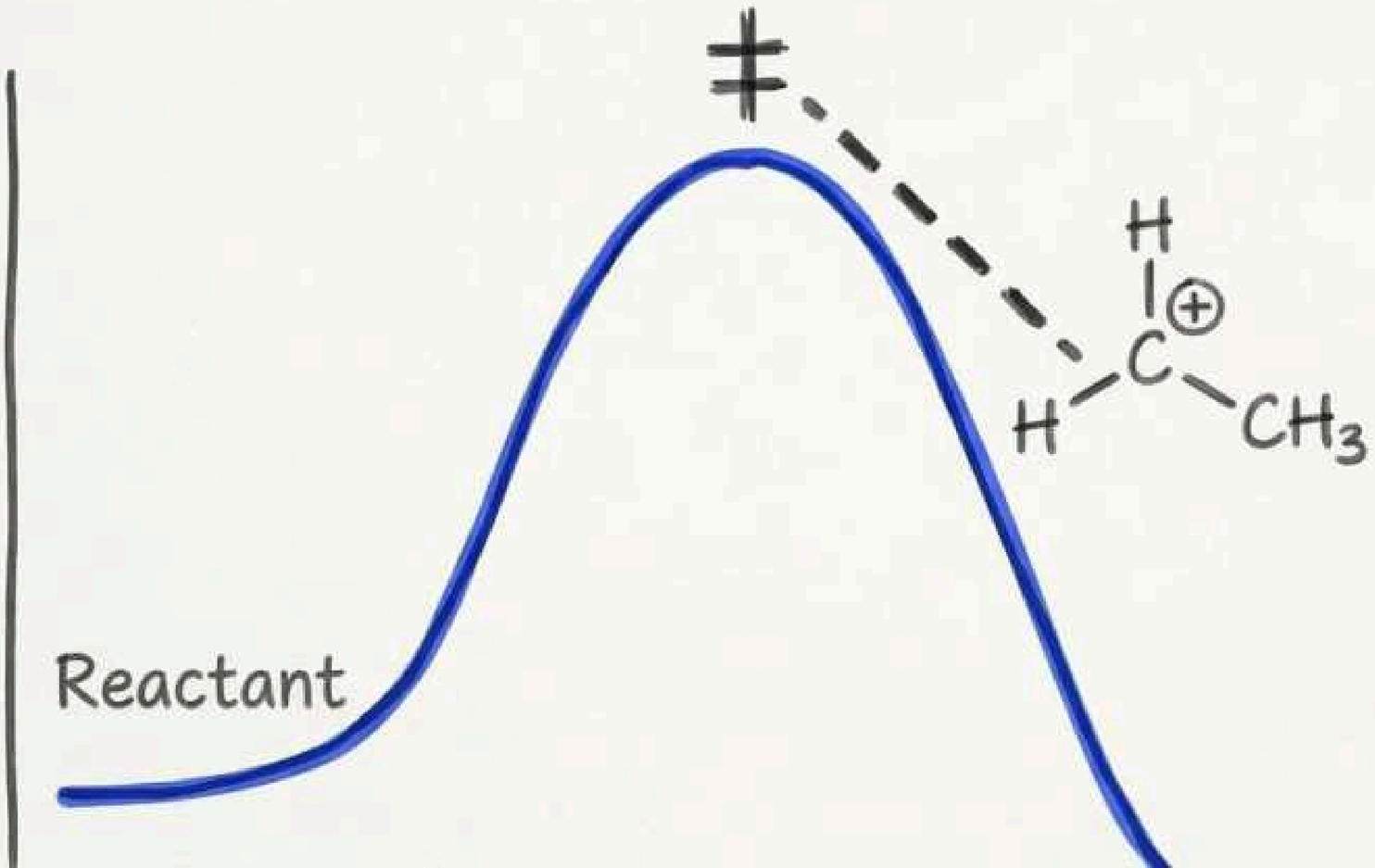
Speed up reactions by providing an entirely new alternate pathway with a lower activation barrier.

Crucial Constraint: Catalysts do not change the final equilibrium position (thermodynamics remain unaffected).

Hammond's Postulate (1955)

¶ 2.16

The transition state resembles whichever neighbor (reactant or intermediate) is closer to it in energy.



Application:

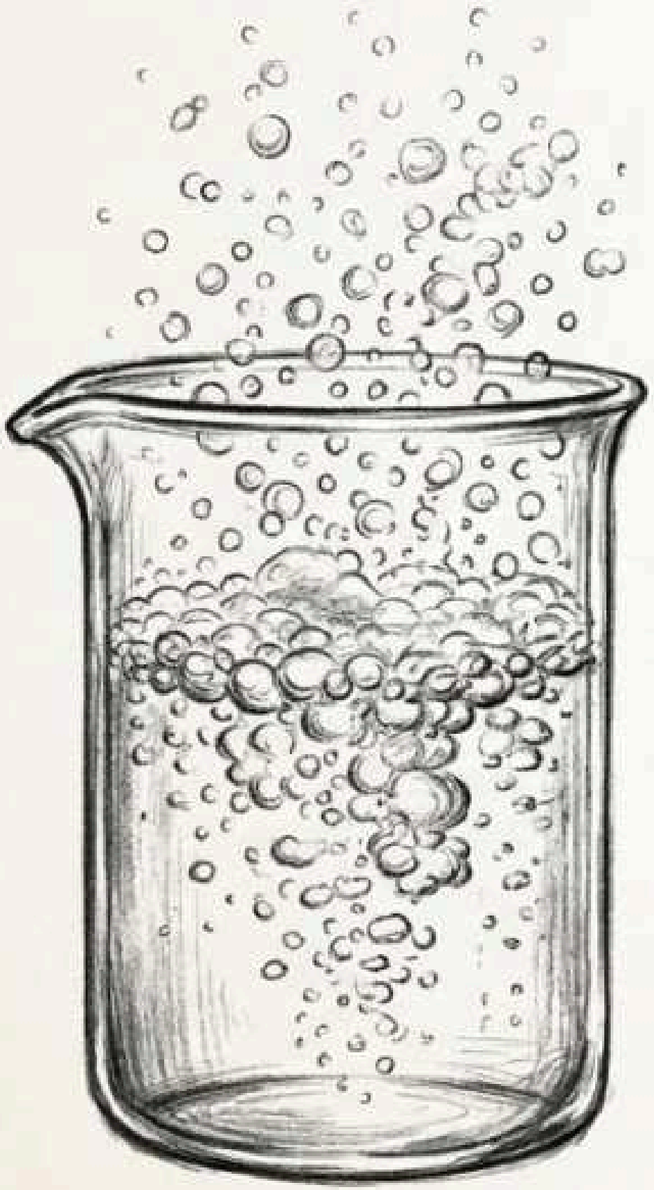
A high-energy intermediate is approached via a transition state that looks structurally very similar to it.

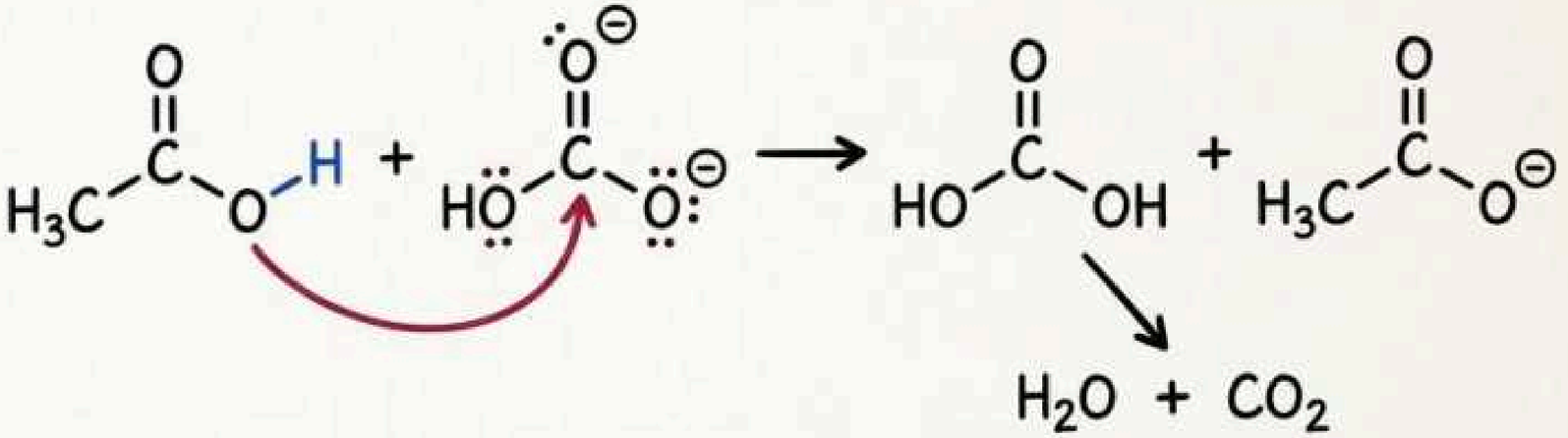
Strategic Insight:

Because they look similar, factors that stabilize the intermediate inherently lower the energy barrier leading to it.

Chemistry in the Kitchen: Vinegar & Baking Soda

¶ 2.17





- The Math: Acetic Acid (pK_a 4.76) is a far stronger acid than Carbonic Acid (pK_a ~6.4).
- The Mechanism: Acetic acid hands its proton to bicarbonate → creates carbonic acid → which rapidly decomposes into water and carbon dioxide gas.
- The Conclusion: The macroscopic bubbles are simply an acid–base reaction following the microscopic pK_a equilibrium rule exactly.

Lecture 2 Recap & The Path Forward

¶ 2.18

Lecture 2

Acids: Proton donors. Strength is dictated by conjugate base stability (Remember: ARIO).

$$HA \rightleftharpoons H^+ + A^-$$

Predictability: pKa values are the numerical key to predicting acid-base reactions.

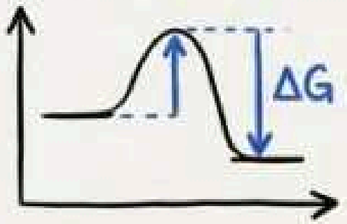


pK_a ~4.76 vs pK_a ~10.6

Movement: Curved arrows trace electron flow from Nucleophiles to Electrophiles.



Physics: ΔG (Free Energy) decides where a reaction ends; Activation Energy decides how fast it gets there.



Next Lecture Preview: Shifting focus from reactions to 3D shape, and exploring the compounds that make up our fuels: the alkanes.