



Atomic Theory

Periodic Trends

Chemical Bonding

Intermolecular Force

Session Slides with Notes

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Physics

MECHANICS

- Kinematics ✓
- Newton's Laws ✓
- Work, Energy, and Power ✓
- Harmonic Motion
- Elastic Properties of Solids
- Fluid Mechanics

WAVES

- Waves

GRAVITATION

- Gravitation

THERMODYNAMICS

- Heat & Temperature
- The Ideal Gas and Kinetic Theory *preview*
- The First Law of Thermodynamics
- The Second Law of Thermodynamics and Heat Engines

ELECTRICITY & MAGNETISM

- Electricity ✓
- DC Current
- Magnetism

LIGHT & OPTICS

- The Properties of Light
- Geometric Optics
- Wave Optics

MODERN PHYSICS & NUCLEAR PHYSICS

- Modern Physics
- Nuclear Physics

General Chemistry

THE STRUCTURE OF MATTER

Atomic Theory ✓
Periodic Properties ✓
The Chemical Bond ✓
Intermolecular Forces ✓

STOICHIOMETRY

Stoichiometry

CHEMICAL THERMODYNAMICS AND CHEMICAL KINETICS

Thermochemistry
The States of Matter
Chemical Thermodynamics and the Equilibrium State
Chemical Kinetics

SOLUTIONS AND AQUEOUS SYSTEMS

Water
Solutions
Acids and Bases

OXIDATION REDUCTION AND ELECTROCHEMISTRY

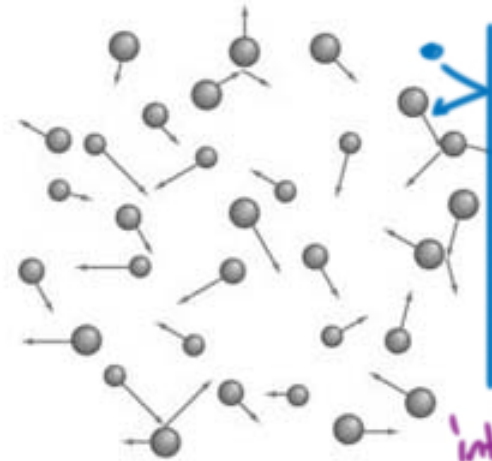
Oxidation/Reduction
Electrochemistry

COORDINATION CHEMISTRY

Coordination Chemistry

The Internal Energy of an Ideal Gas Depends on Temperature

only the kinetic energy of the particles
ie. thermal energy



- point masses
- no action at a distance forces
- only elastic collisions

$$\frac{U}{N} = \frac{3}{2} kT$$

$$U = \frac{3}{2} NkT$$

$$\frac{1}{2} m\bar{v}^2 = \frac{3}{2} kT$$

U = internal energy
 N = number of molecules
 k = Boltzmann's constant
 = R / Avogadro's number
 T = temperature

internal energy

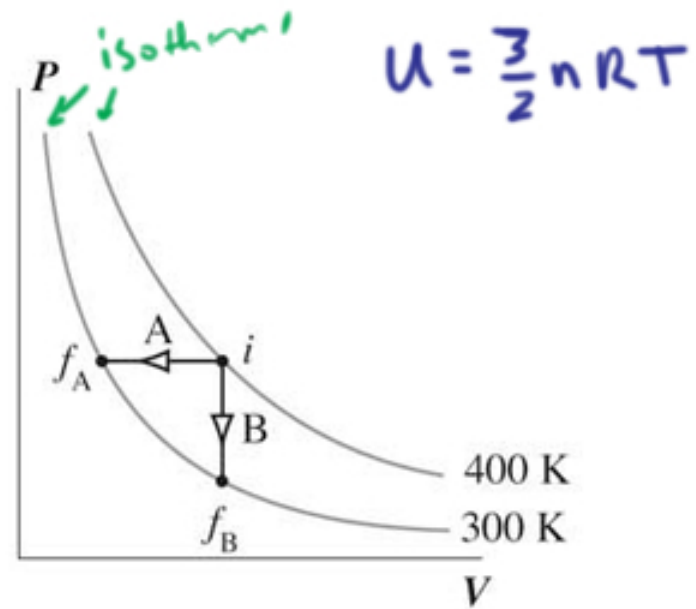
$$U = \frac{3}{2} nRT$$

n = moles of gas
 R = ideal gas constant

↑
Kelvin

Our starting point
to understand
internal energy

The graph at right shows two isotherms corresponding to pressure vs. volume of a sample of ideal gas at 400K and 300K respectively. Path A shows the *isobaric* compression of the gas from initial state i to final state f_A . Path B shows *isovolumetric* cooling from initial state i to final state f_B . Which of the two transformations represents the greatest internal energy decrease for the gas?



- a. Path A
- b. Path B

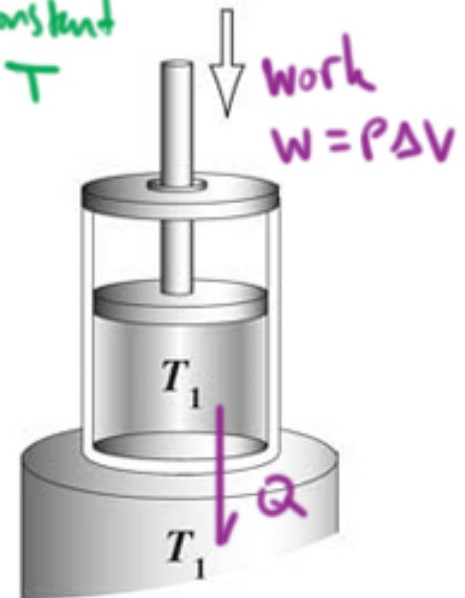
- c. The internal energy changes are equal
- d. Both paths increase internal energy

A piston containing ideal gas is slowly compressed in thermal contact with a heat reservoir. Constant temperature is maintained throughout the compression. Which of the following must have occurred?

isothermal compression

constant
 T

$$\Delta u = 0$$



- a. Heat flowed into the reservoir.
- ~~b.~~ The pressure of the gas decreased.
- ~~c.~~ The internal energy of the gas increased.
- ~~d.~~ The internal energy of the gas decreased.

$$\Delta u = Q - w$$

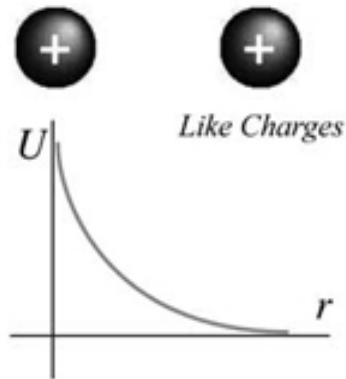
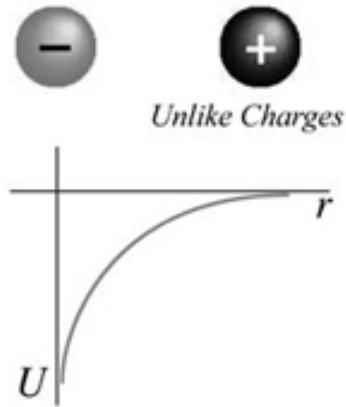
$$\Delta u = 0$$

$$w = Q$$

Real substances

$$U_e = k \frac{q_1 q_2}{r}$$

ΔU may involve
charges in terms of
electrostatic
potential
energy.

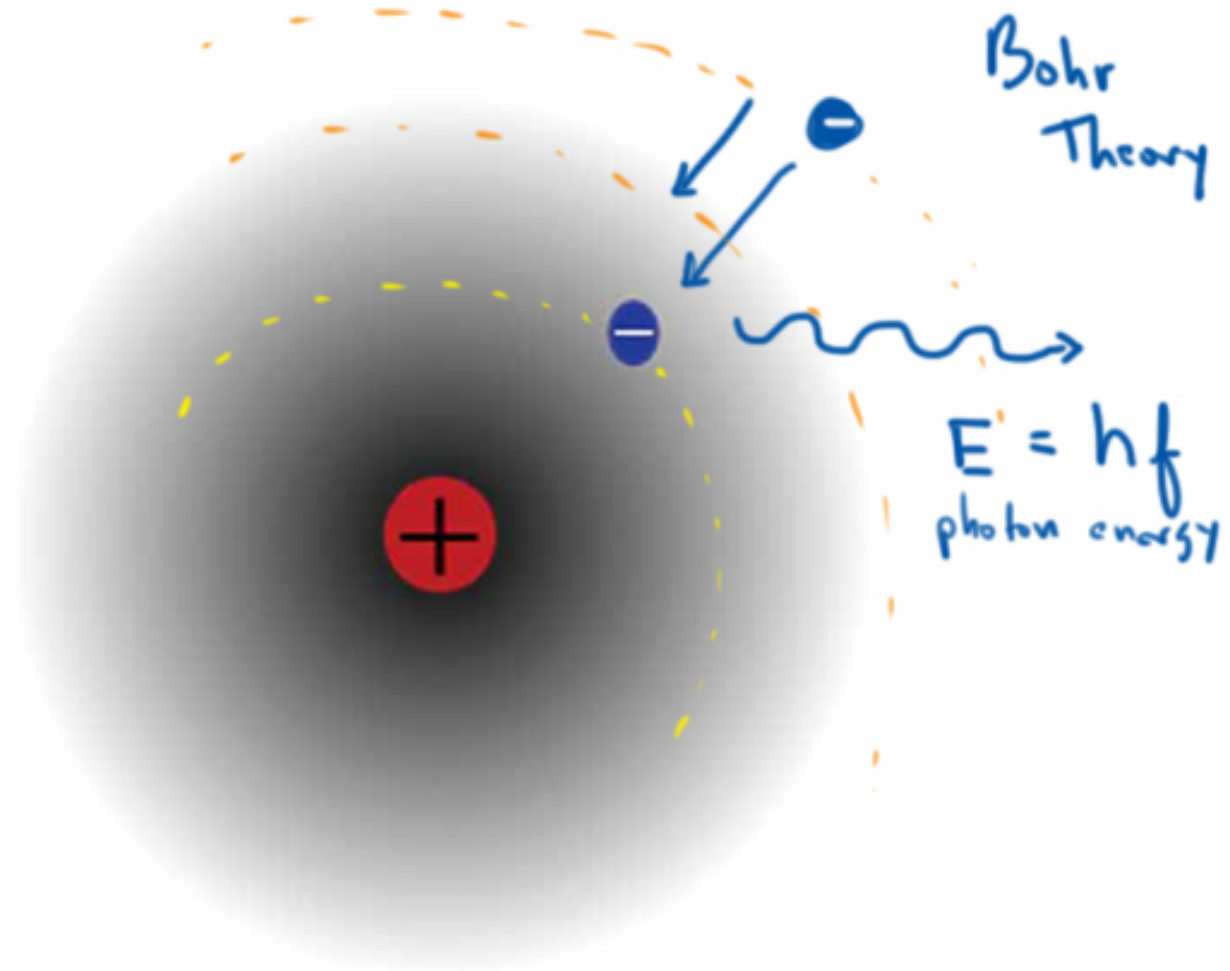


classical

$$U = \frac{kq_1q_2}{r}$$

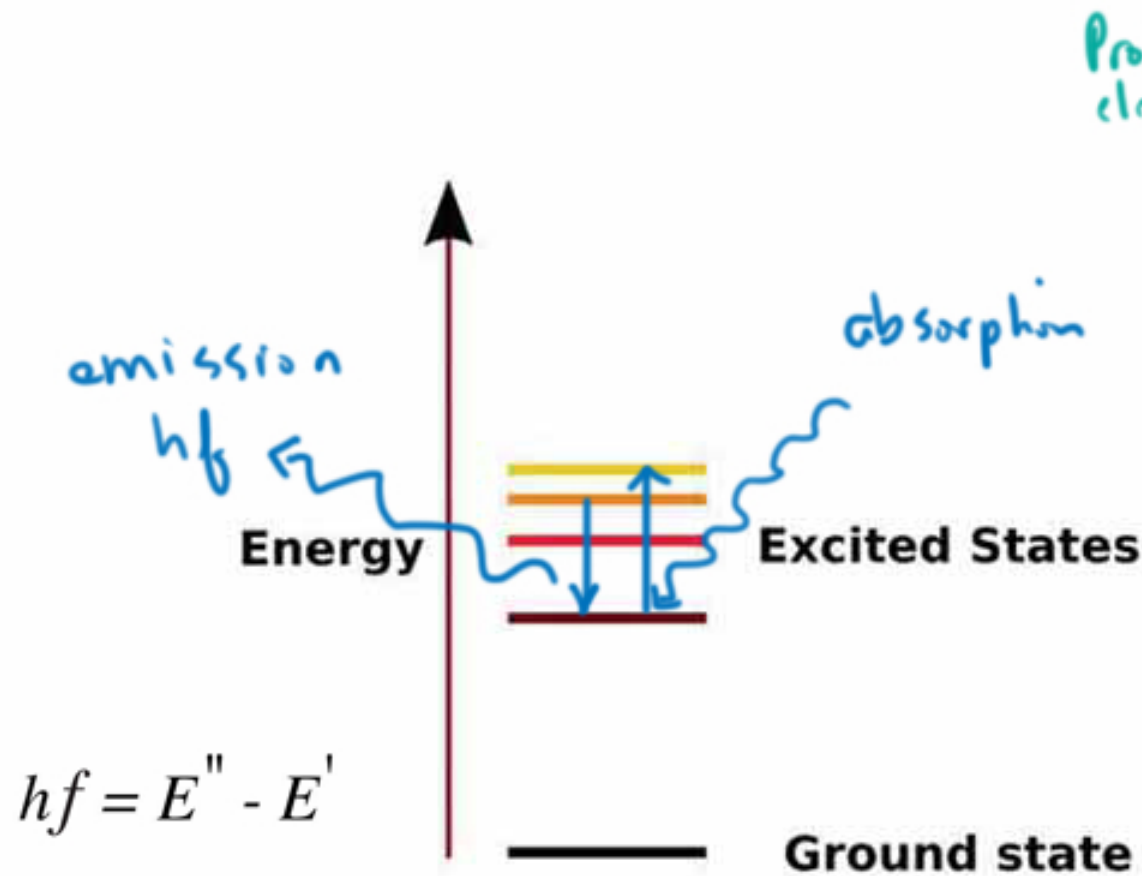


Quantized



Line Spectrum





Prototype for electronic transition

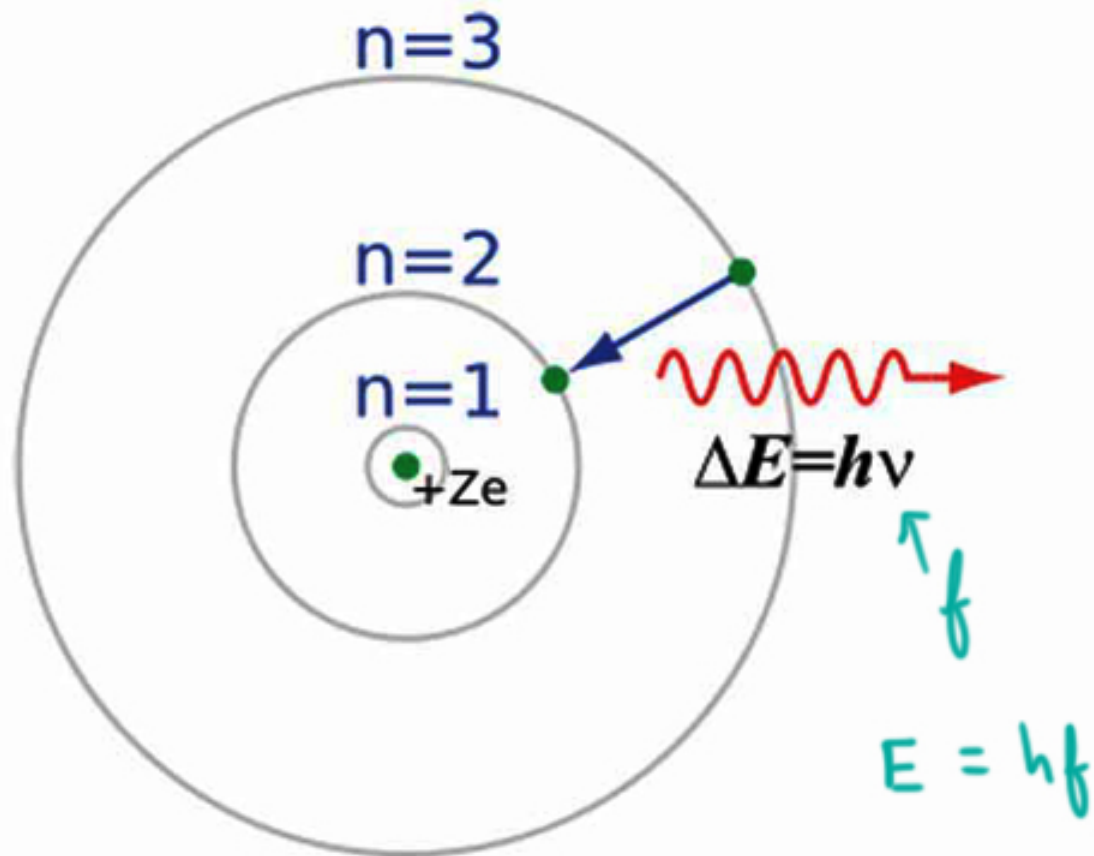
later examples

- UV spectroscopy



- crystal field splitting

- fluorescence



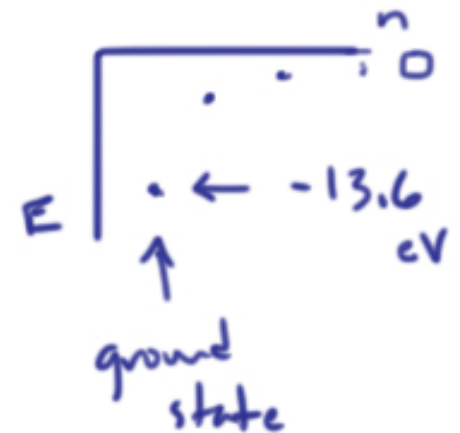
In the Bohr theory of the atom the energy of the n -th level for any atom is given by the following equation

$$E \approx \frac{-13.6Z^2}{n^2} \text{ eV}$$

Handwritten notes: $Z = 1$ for hydrogen
 $n = 1, 2, 3$ etc

where Z is the atom's atomic number. Which of the following is a true statement according to the theory?

- A.** A ground state hydrogen electron has about 13.6 eV less energy than an electron far from the nucleus.
- B.** The ionization energy of hydrogen is approximately 50 eV.
- C.** The minimum energy possible for a hydrogen electron is zero.
- D.** Less energy is required to elevate an electron from the ground state to the 2nd energy level than from the 2nd to the 3rd.



Ionization energy
of hydrogen is
13.6 eV

Quantum Numbers and Atomic Orbitals

n = principle quantum number **shell**

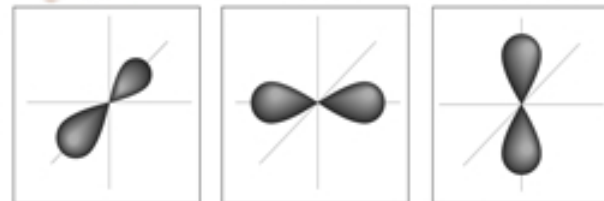
Electron energy within an atom mainly depends on the principle quantum number, n , which can have values of 1, 2, 3 . . . Orbitals with the same principle quantum number are said to belong to the same *shell*. Shells are designated with the letters 1 = K, 2 = L, 3 = M, and so on.

l = angular momentum quantum number **subshell s, p, d**

l determines what kind of *subshell* contains the electron. l values are constrained by n . For a given value of n , l can be any integer: 0, 1, 2 . . . $n - 1$. The subshell determines the shape of the electron orbital. Subshells are designated with letters corresponding to 0 = s, 1 = p, 2 = d, 3 = f, etc.

m_l = magnetic quantum number **orbital**

m_l determines the *orbital* within a subshell. It's values are constrained by l . For a given l , m_l can be any integer between $-l$ and l . Thus, an s subshell ($l = 0$) has one orbital, while a p subshell ($l = 1$) has three ($m_l = -1, 0$ or 1).



The three orbitals of a p subshell.

m_s = spin quantum number **spin**

In addition to orbital angular momentum, characterized by l , electrons possess quantized angular momentum corresponding to rotation about their own axis. The values of electron spin are designated by the spin quantum number, m_s , which can be either $+\frac{1}{2}$ or $-\frac{1}{2}$.

• de Broglie - wave nature of electrons

• Schrodinger - the wave equation

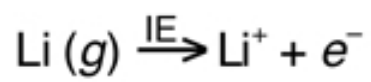
• Pauli exclusion
• on orbital holds 2 electrons max

• Aufbau principle

$1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10}$

• Hund's rule





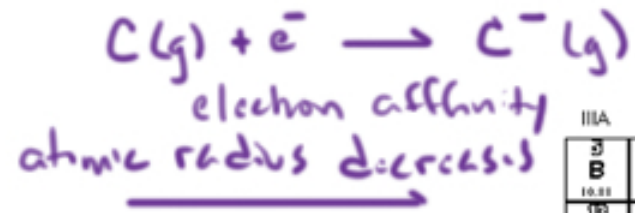
ionization energy increases



ionization energy decreases



EA decreases



Groups	IA												VIIA		VIII A				
Periods	1	H 1.6807											2	He 4.0026					
	2	Li 5.391	Be 9.01219											B 8.01	C 11.011	N 14.007	O 13.1394	F 18.99849	Ne 20.81
	3	Na 22.3697	Mg 24.895			Al 26.36954	Si 22.895	P 20.92074	S 22.86	Cl 25.451	Ar 29.947								
	4	K 29.890	Ca 46.00	Sc 44.9559	Ti 47.88	V 50.9415	Cr 51.996	Mn 54.9380	Fe 55.847	Co 58.9332	Ni 58.70	Cu 63.546	Zn 65.38	Ga 69.72	Ge 72.59	As 74.9216	Se 78.96	Br 79.904	Kr 83.80
	5	Rb 39.8426	Sr 37.46	Y 38.9049	Zr 91.22	Nb 92.9044	Mo 95.94	Tc (98)	Ru 101.07	Rh 100.905	Pd 106.4	Ag 107.868	Cd 112.41	In 114.82	Sn 118.69	Sb 121.76	Te 127.60	I 126.9045	Xe 131.29
	6	Cs 39.0964	Ba 37.00	La* 138.905	Hf 178.49	Ta 180.9479	W 183.85	Re 186.207	Os 190.2	Ir 192.22	Pt 195.09	Au 196.9665	Hg 200.59	Tl 204.37	Pb 207.2	Bi 208.9804	Po (209)	At (210)	Rn (222)
	7	Fr (223)	Ra (226.074)	Ac** (227.0729)	Unq (241)	Unp (242)	Unh (243)												

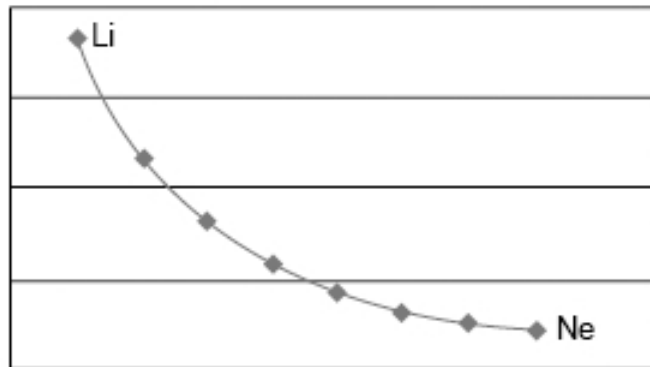
* Lanthanide series

Ce 140.12	Pr 140.9077	Nd 144.24	Pm (145)	Sm 150.4	Eu 151.96	Gd 157.25	Tb 158.9254	Dy 162.50	Ho 164.9304	Er 167.26	Tm 168.9342	Yb 173.04	Lu 174.967
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** Actinide series

Th 232.0381	Pa 231.0362	U 238.0289	Np 237.0482	Pu (244)	Am (243)	Cm (247)	Bk (247)	Cf (251)	Es (252)	Fm (257)	Md (258)	No (259)	Lr (260)
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The graph below shows the variation across the 2nd period of the periodic table of this property



- A. ionization energy
- B. electron affinity
- C. atomic radius
- D. electronegativity

Relative strength of attraction an atom has for electrons shared in chemical bonding
electronegativity increases

Relevance

δ^- - Is a bond nonpolar or polar ionic?
 δ^+
 $\text{H}-\text{C}-\text{H}$
 δ^-
 $\text{H}-\text{C}-\text{H}$
 δ^-
 What kind of intermolecular force?



- C - 2.5
- H - 2.1
- O - 3.5
- N - 3.0
- Cl - 3.0
- Br - 2.8
- F - 4.0
- S - 2.6
- Li, Na, Mg ~ 1.0

Periods	Groups	IA	IIA	IIIA	IVA	VA	VIA	VIIA	VIIIA
1		1	2						18
2		1	2	3	4	5	6	7	8
3		1	2	3	4	5	6	7	8
4		1	2	3	4	5	6	7	8
5		1	2	3	4	5	6	7	8
6		1	2	3	4	5	6	7	8
7		1	2	3	4	5	6	7	8

electronegativity decreases

Physical Properties
 Solubility
 δ^-
 $\text{H}_3\text{C}-\text{C}-\text{CH}_3$
 Nu:
 Reactivity

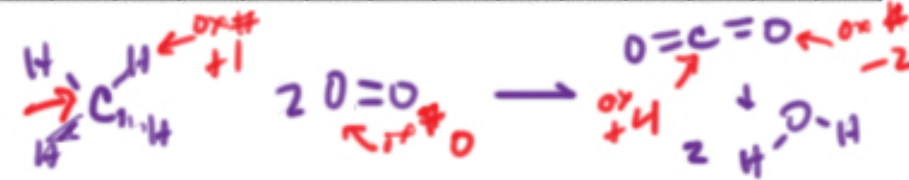
Oxidation Reduction
 $\text{ox H} -4$

*Lanthanide series

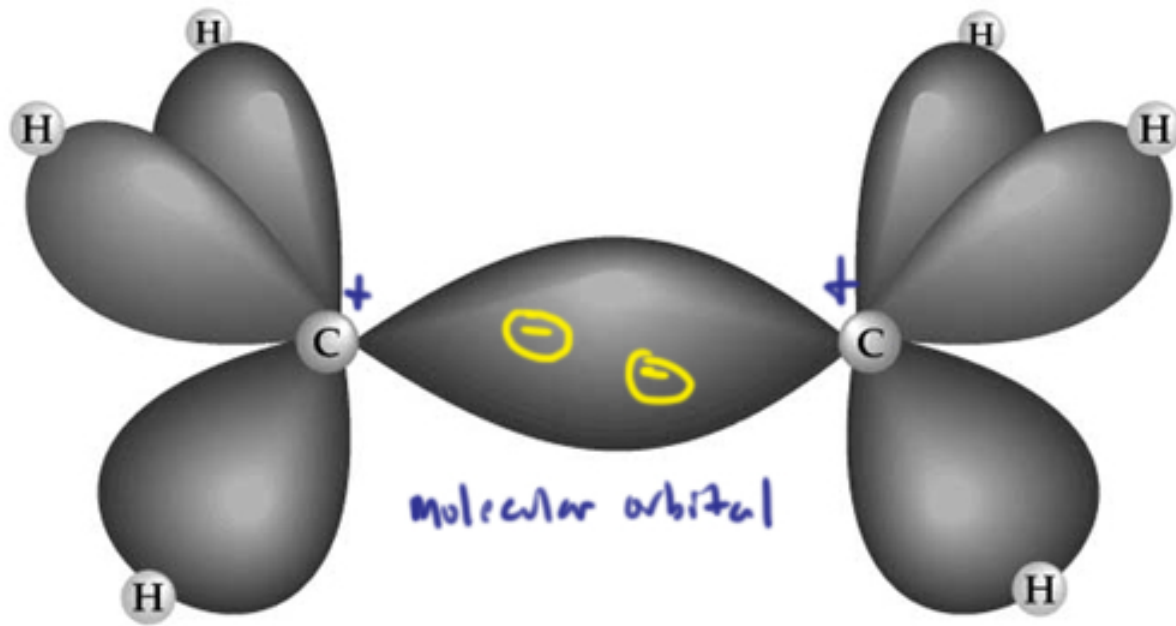
57	58	59	60	61	62	63	64	65	66	67	68	69	70	71
Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	

**Actinide series

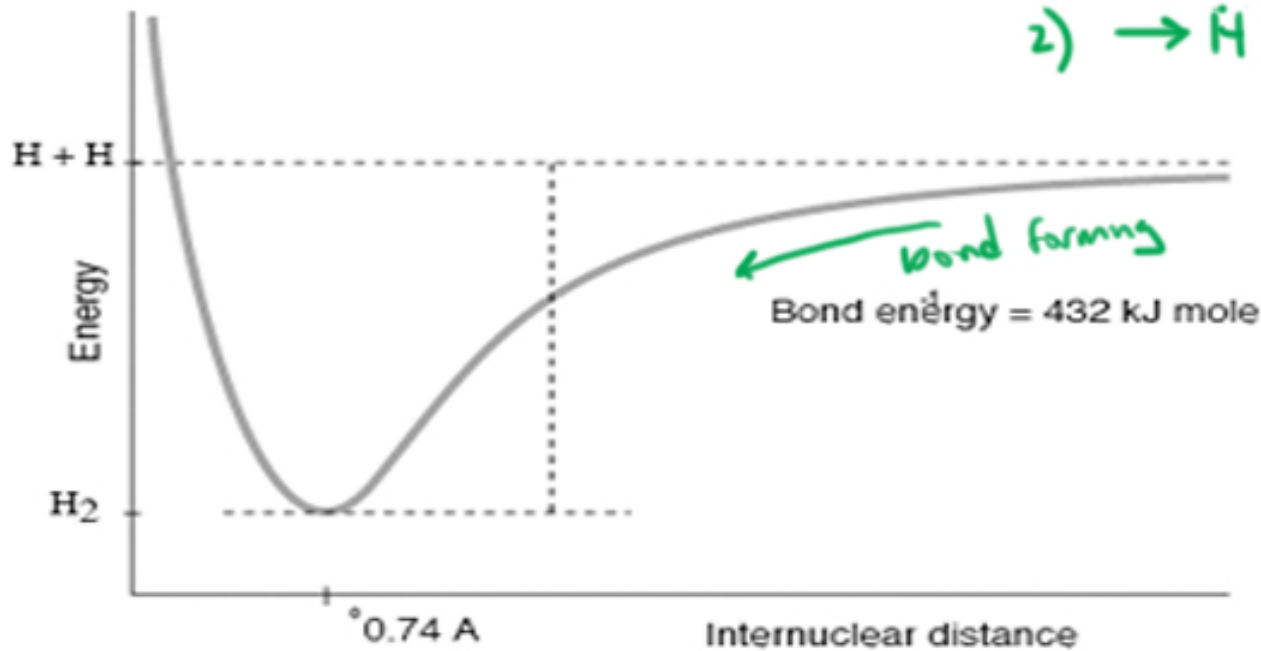
89	90	91	92	93	94	95	96	97	98	99	100	101	102	103
Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr	



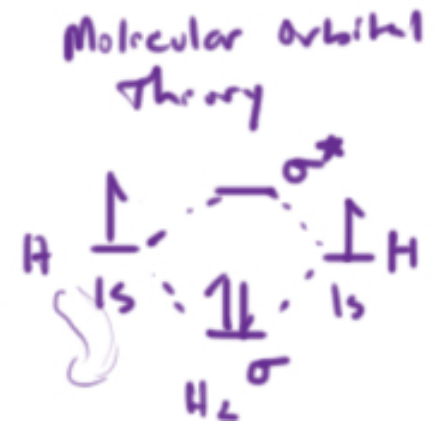
Covalent Bonding

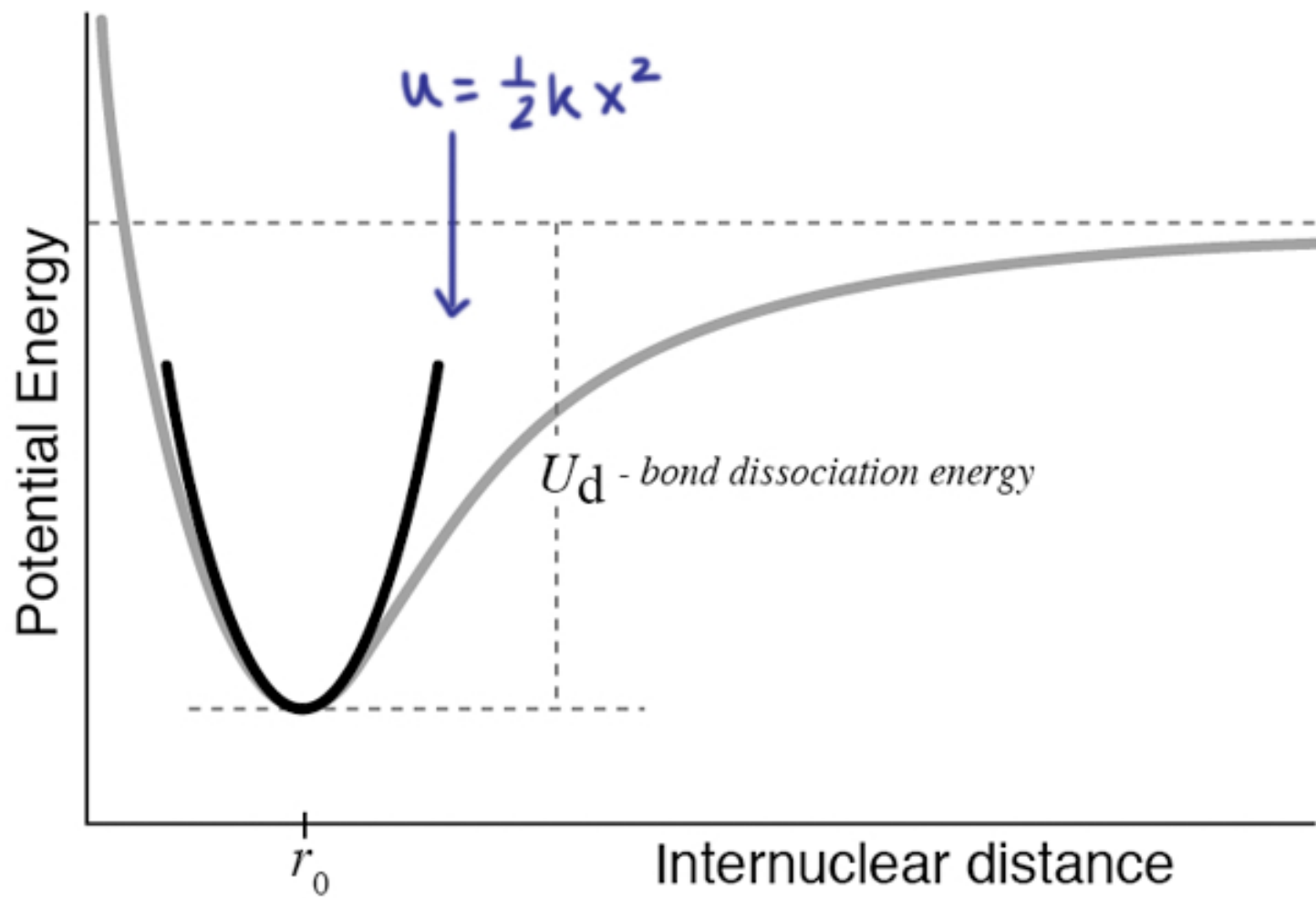


Ethane



↑ bond length
 $\text{Å} = 10^{-10} \text{ m}$ $10 \text{ Å} = 1 \text{ nm}$





Covalent bonds vibrate

- partition for thermal energy
- IR spectroscopy

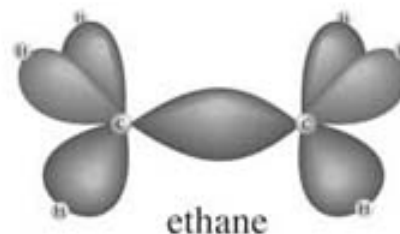


$$f = \frac{1}{2\pi} \sqrt{\frac{k}{\mu}}$$

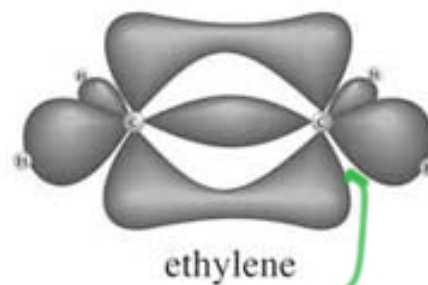
$$\mu = \frac{m_1 m_2}{m_1 + m_2}$$

The stretching vibrations along the bond axis of a C–H bond in ethane absorb infrared radiation of lower frequency than the IR radiation absorbed by a C–H bond of ethylene. Which of the following statements can be deduced from this evidence?

- a. The carbon-hydrogen bonds in ethylene are stronger than the carbon-hydrogen bonds in ethane
- b. Ethane has free rotation about the C–C bond axis
- c. The C–H bonds are shorter in ethane.
- d. The percent composition of ethane is greater for hydrogen.



C-H stretch
← 2990 cm⁻¹



C-H stretch
← 3010 cm⁻¹

greater
s character

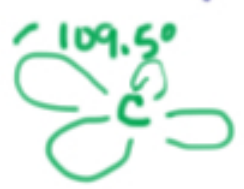
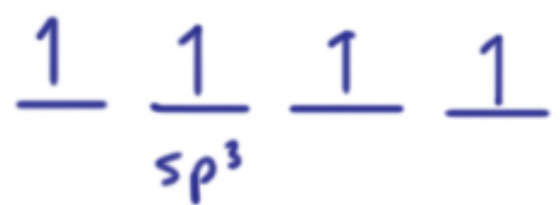
$f = \frac{1}{2\pi} \sqrt{\frac{k}{\mu}}$
 ← Spring constant
 ← bond strength

orbital hybridization

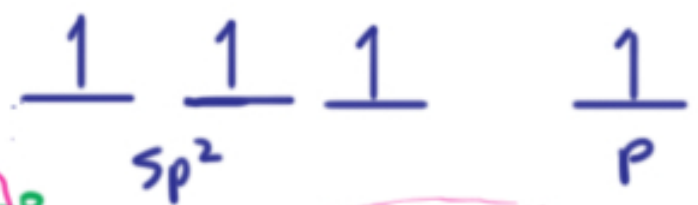
Carbon



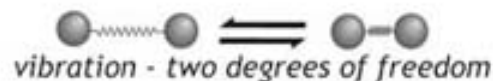
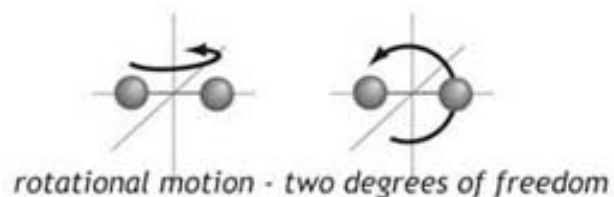
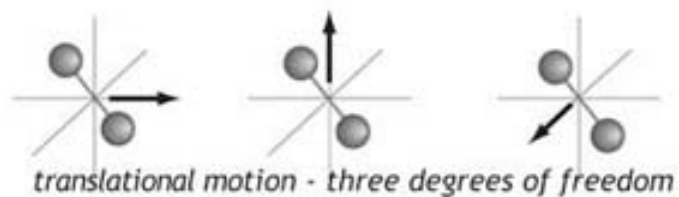
single bonds



double bond



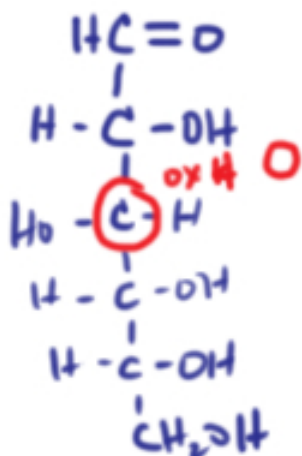
A monatomic gas molecule such as He possesses only kinetic energy deriving from its linear motion. A diatomic gas molecule, like Cl₂, in addition to translational motion, can also rotate and vibrate. What does this difference tell us?



- Helium is a noble gas.
- Chlorine has a higher molar heat capacity than helium.
- At a given temperature, helium molecules have greater average translational kinetic energy than chlorine molecules.
- The chlorine molecules have greater average translational kinetic

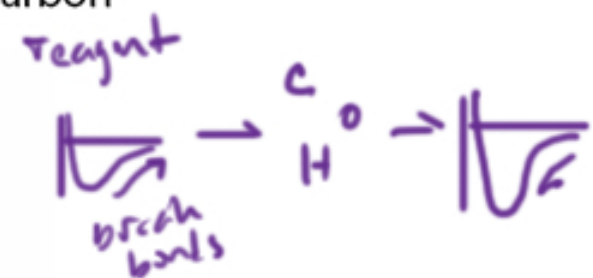
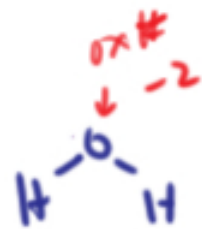
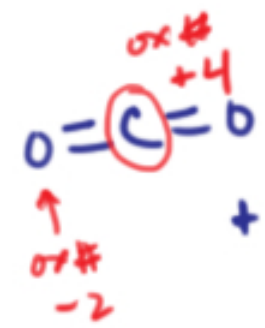
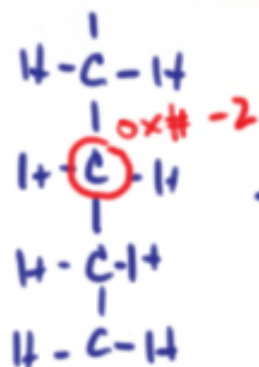
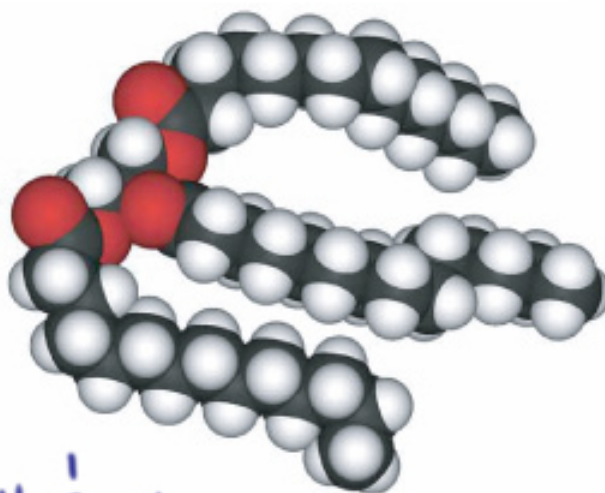
Heats of Combustion of Nutrient Molecules

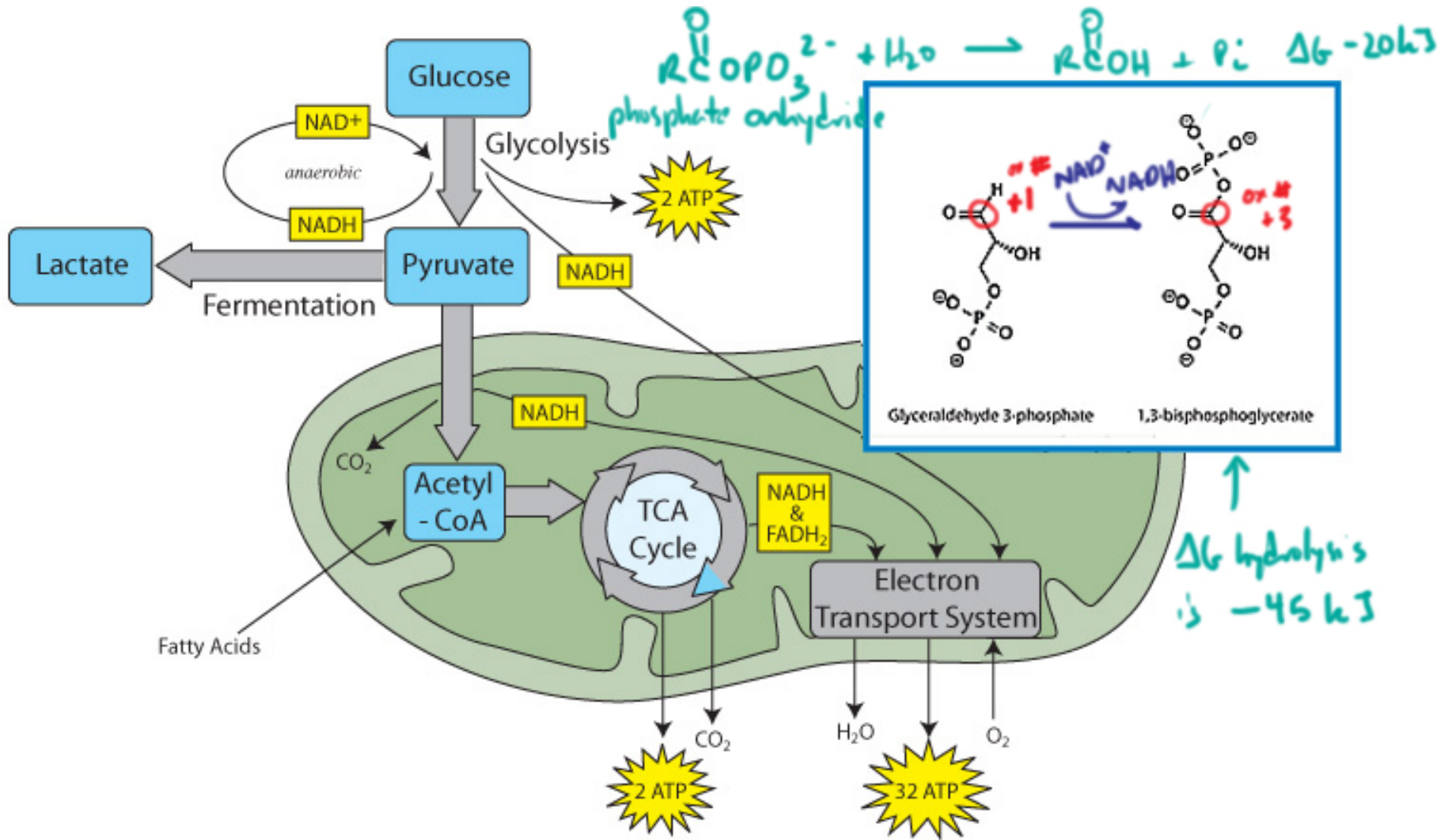
Glucose 466 kJ/mol carbon

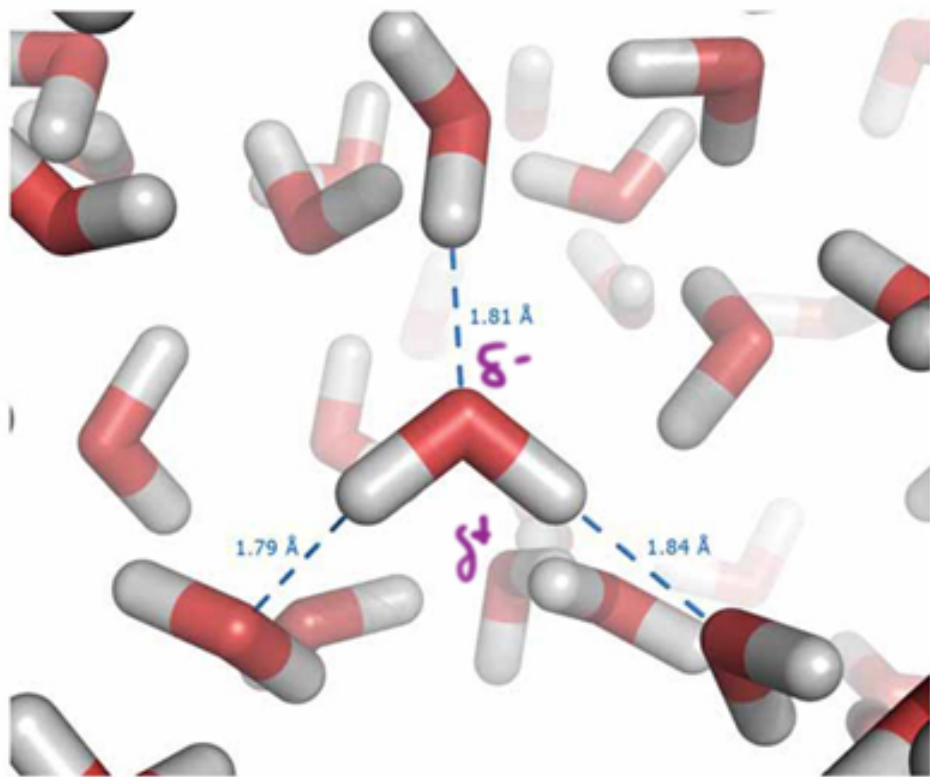


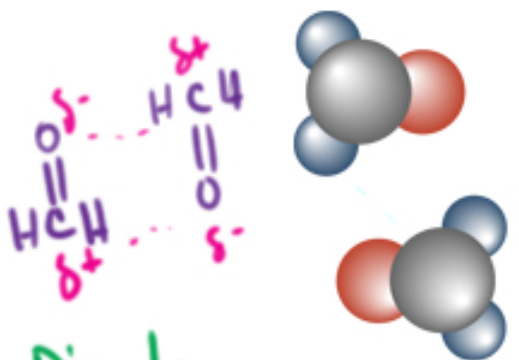
or

Triglyceride 626 kJ/mol carbon

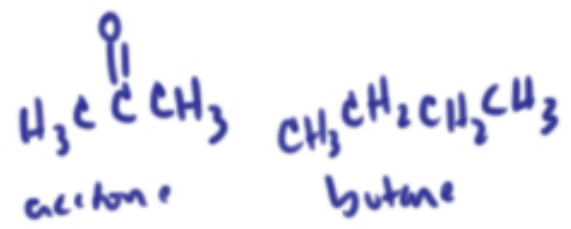




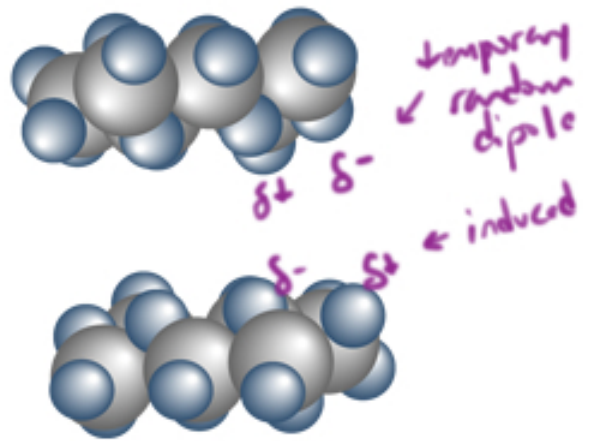




Dipole
Dipole
Stronger



H bonding
Strongest



Van der Waals
or
London dispersion
Weakest

Undissolved \leftrightarrow Dissolved

Like Dissolves Like

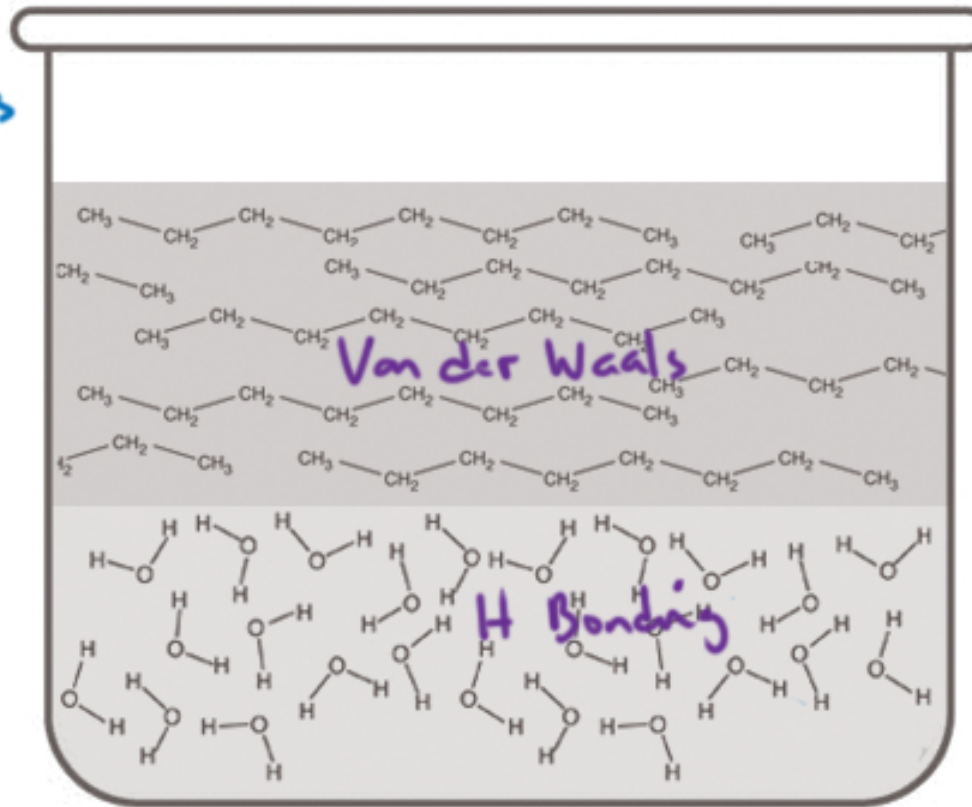
$\oplus \Delta G$
nonspontaneous

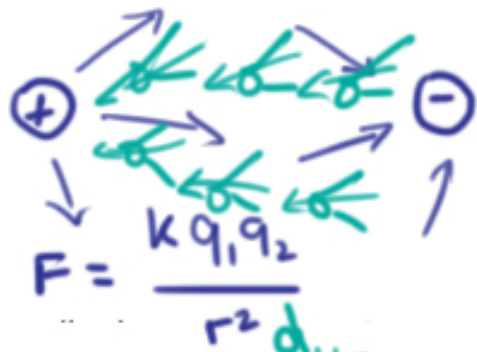
must be

$\oplus \Delta H$

because

$\oplus \Delta U$

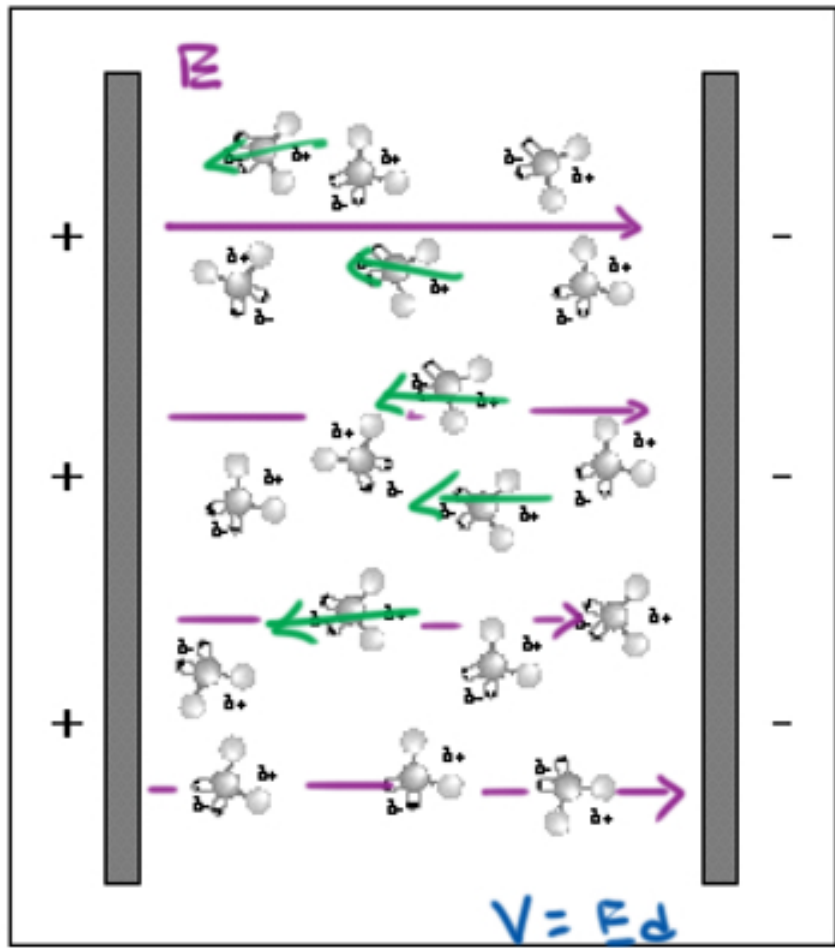
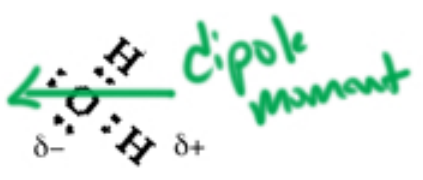




$$F = \frac{kq_1q_2}{r^2}$$

dielectric constant = 80

dipole moment = qd



A dielectric substance weakens an external field.

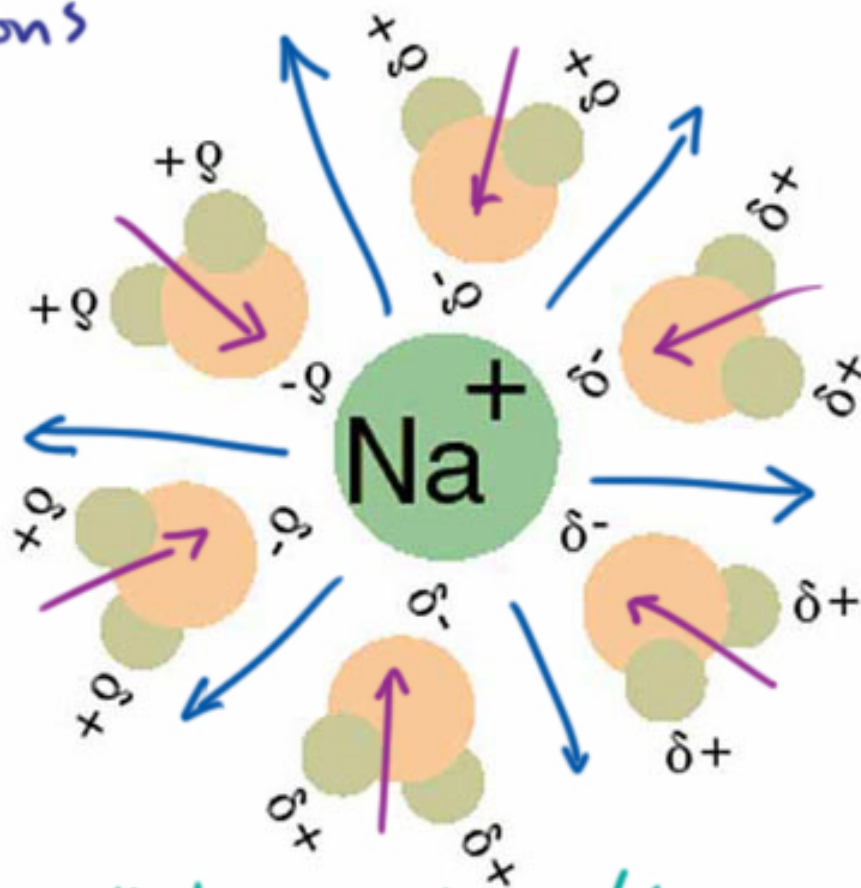
Increases the capacitance

$$C = \frac{Q}{V}$$

Water loves ions

- enthalpy of hydration

Ions love water



Hydration Sphere - (Solvation Shell)