CHEMISTRY

Chapter 10 LIQUIDS AND SOLIDS

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The Cooper Union

HW problems: 2, 11, 13, 17, 21, 25, 31, 43, 51, 58, 63, 65, 69

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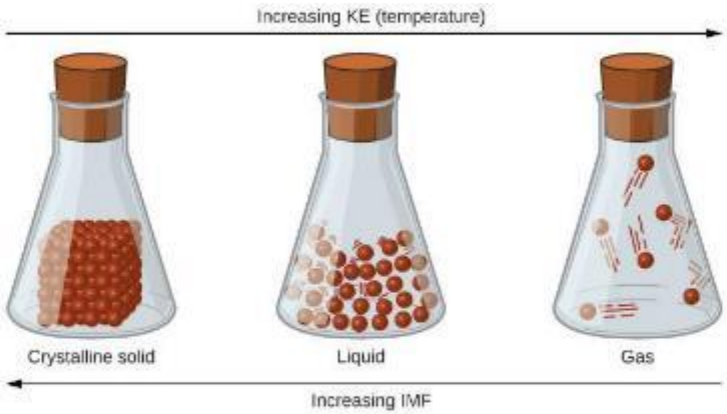
PHASES OF MATTER

- Don't forget KMT
- A *phase* is a mechanically separate, homogeneous part of a heterogeneous system. (dictionary.com)




(a)


(b)

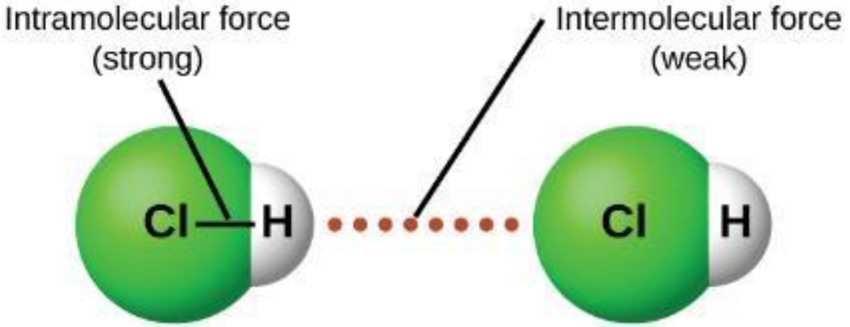
State of Matter	Volume/Shape	Density	Compressibility	Motion of Molecules
Gas	Assumes the volume and shape of its container	Low	Very compressible	Very free motion
Liquid	Has a definite volume but assumes the shape of its container	High	Only slightly compressible	Slide past one another freely
Solid	Has a definite volume and shape	High	Virtually incompressible	Vibrate about fixed positions

CH. 10 OUTLINE

- 10.1 Intermolecular Forces
- 10.2 Properties of Liquids
- 10.3 Phase Transitions
- 10.4 Phase Diagrams
- ~~10.5 The Solid Phase of Matter~~
- ~~10.6 Lattice Structures in Crystalline Solids~~

INTER VS INTRAMOLECULAR FORCES

- Intermolecular forces are attractive forces between molecules.
- Intramolecular forces hold atoms together in a molecule. (ie- bonds)
- Generally, intermolecular forces are much weaker than intramolecular forces.
  - 41 kJ to vaporize 1 mole of water (inter)
  - 930 kJ to break all O-H bonds in 1 mole of water (intra)
- Measures of intermolecular forces
  - boiling point (DHvap)
  - melting point (DHfus)
  - also DHsub



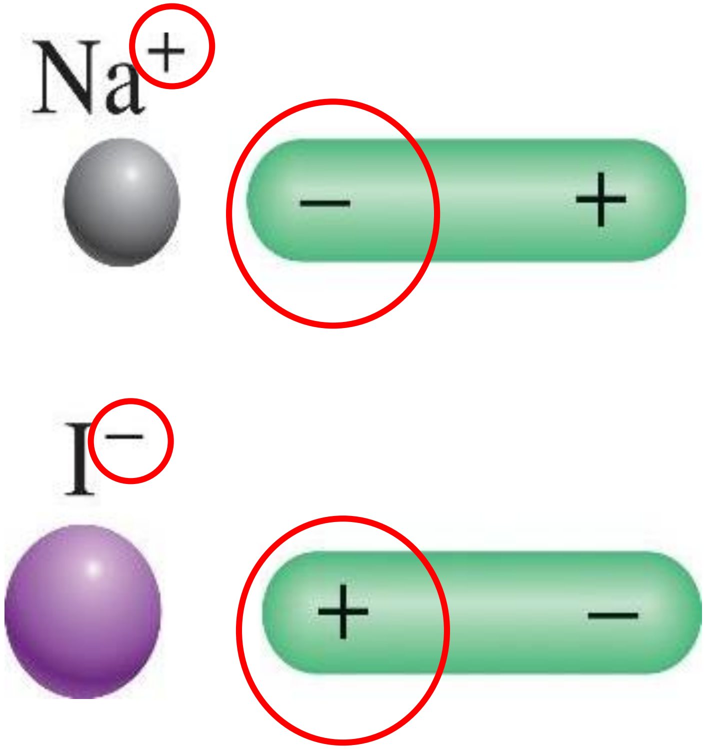
TYPES OF INTERMOLECULAR FORCES

- In order of decreasing strength:
- Ion-dipole (chapter 11)
- Dipole-dipole
  - Hydrogen bonding
- London/Dispersion

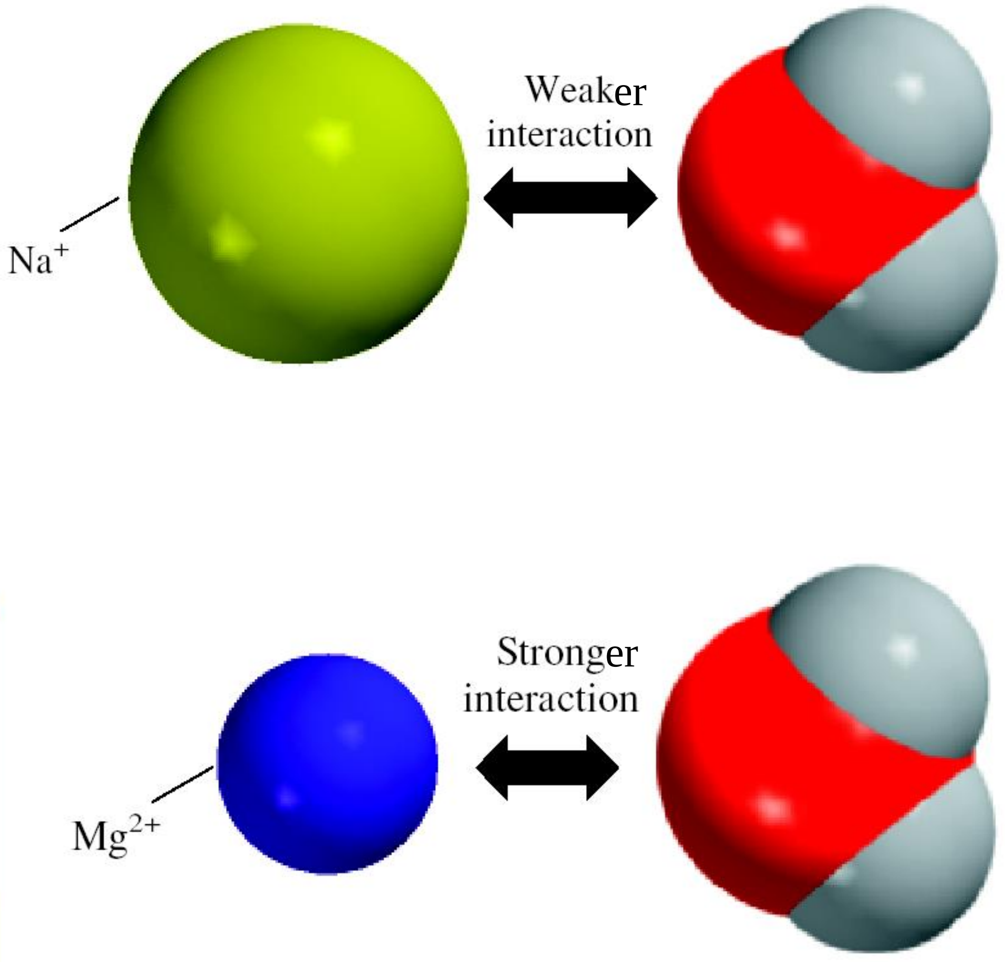
- van der Waals forces are a *group* of intermolecular forces
  - Sadly, the group varies from text to text

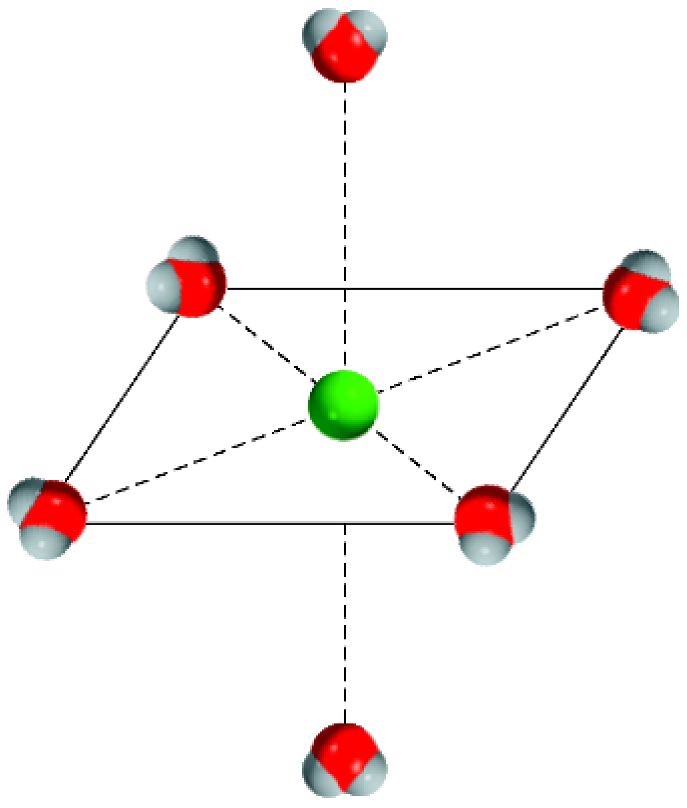
ION-DIPOLE FORCES (CHAPTER 11.2)

- Attractive forces between an ion and a polar molecule



WATER-ION INTERACTIONS - SOLVATION

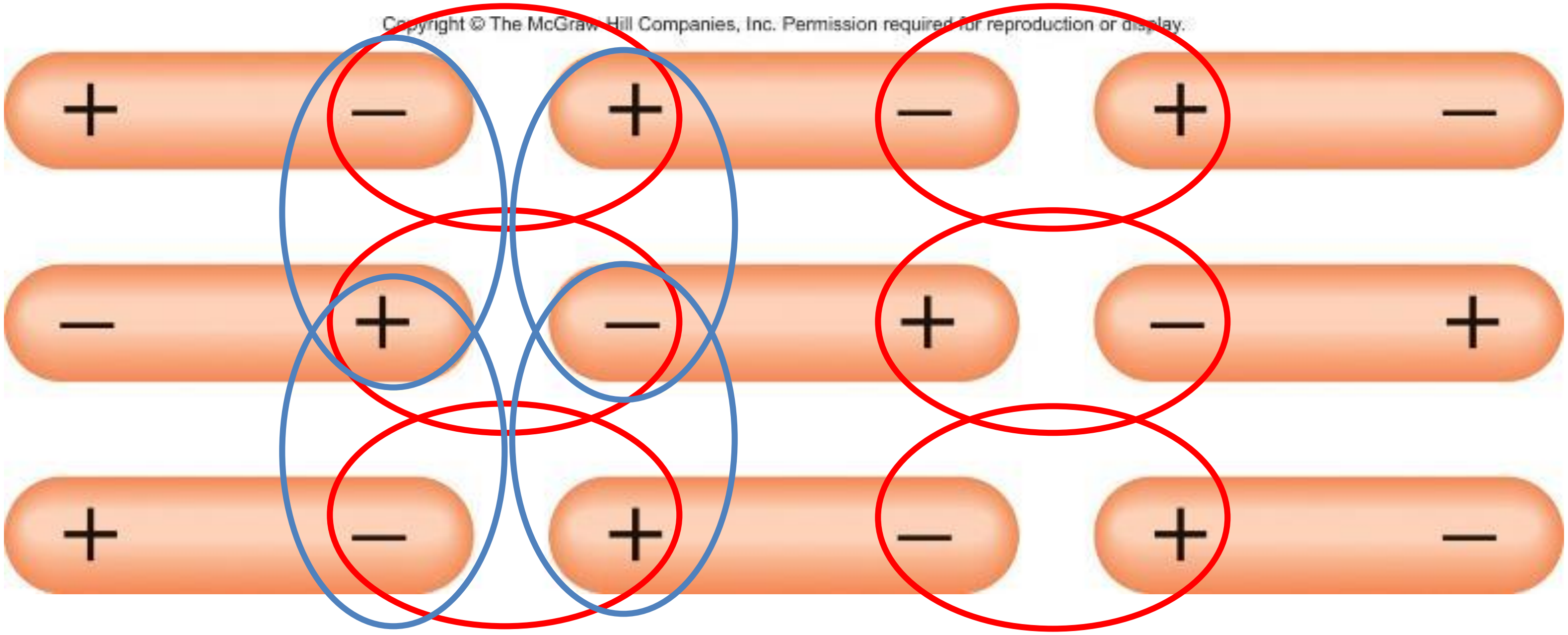




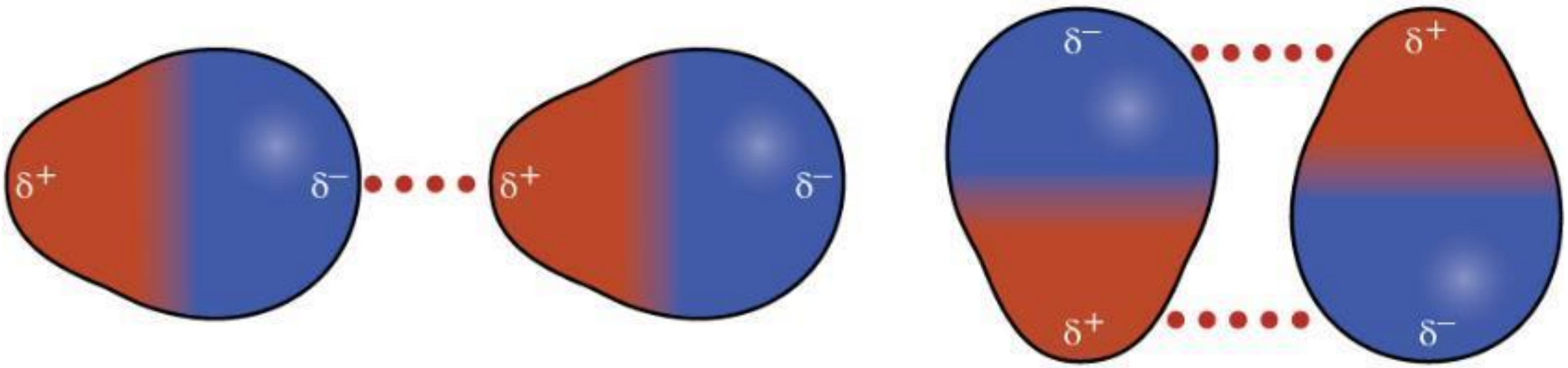
DIPOLE-DIPOLE FORCES

- Attractive forces between polar molecules

Orientation of polar molecules in a solid



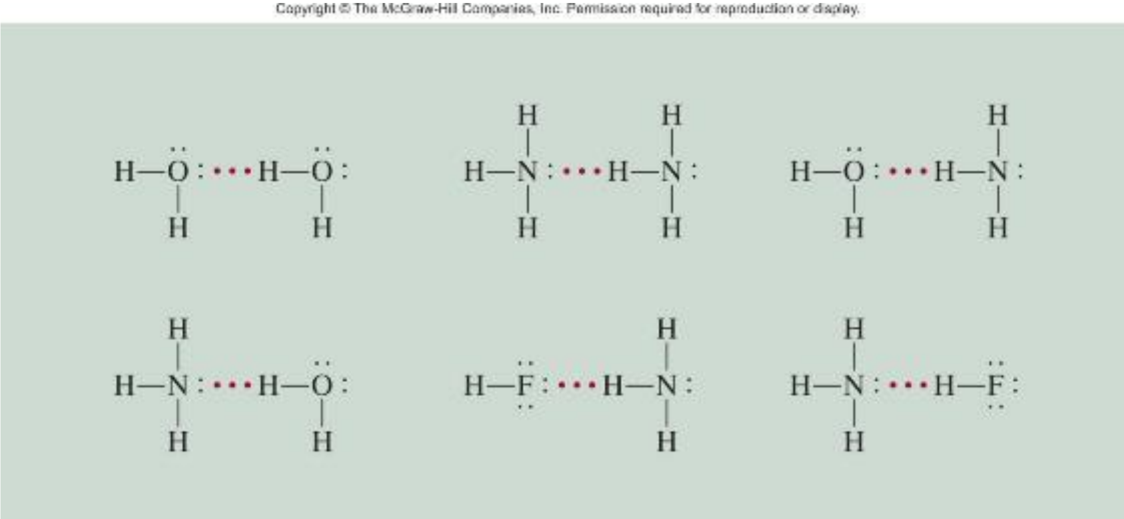
DIPOLE-DIPOLE (CONT'D) FIG 10.9

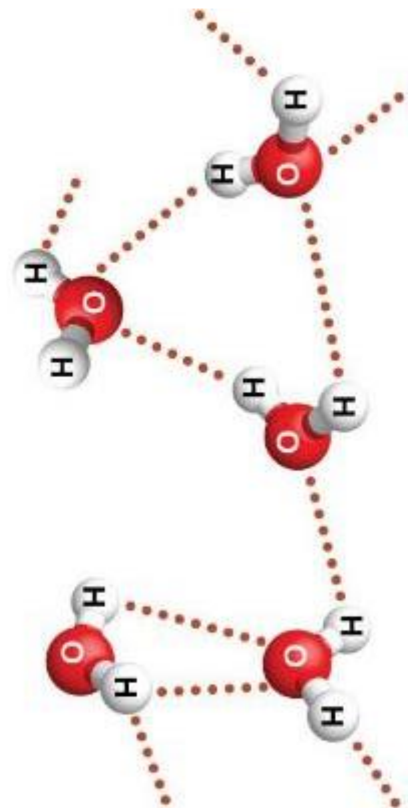


- This image shows two arrangements of polar molecules, such as HCl, that allow an attraction between the partial negative end of one molecule and the partial positive end of another.
- Compare HCl (MW= 36.46g/mol; BP=188K) to F_2 (MW=38g/mol; BP=85K)

HYDROGEN BONDING

- The hydrogen “bond” is a special dipole-dipole interaction between the hydrogen atom in a polar N-H, O-H, or F-H bond and the lone pair of electrons on a small, electronegative (O, N, or F) atom.

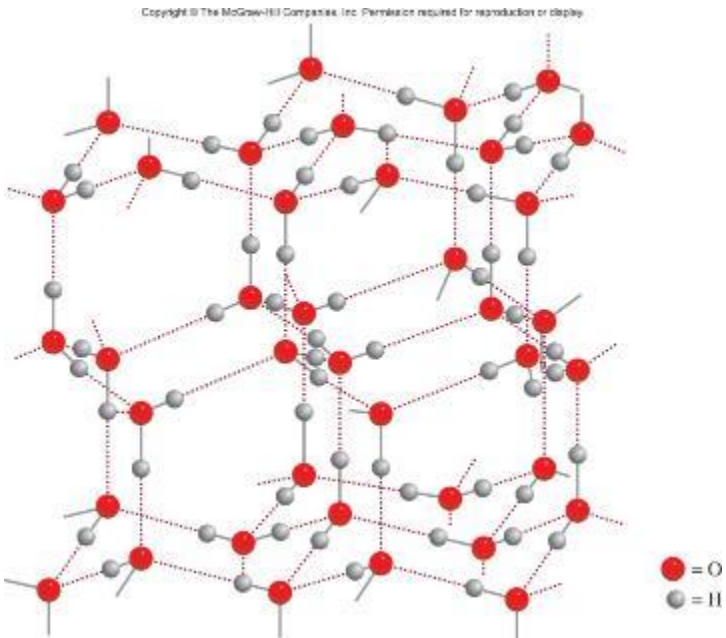




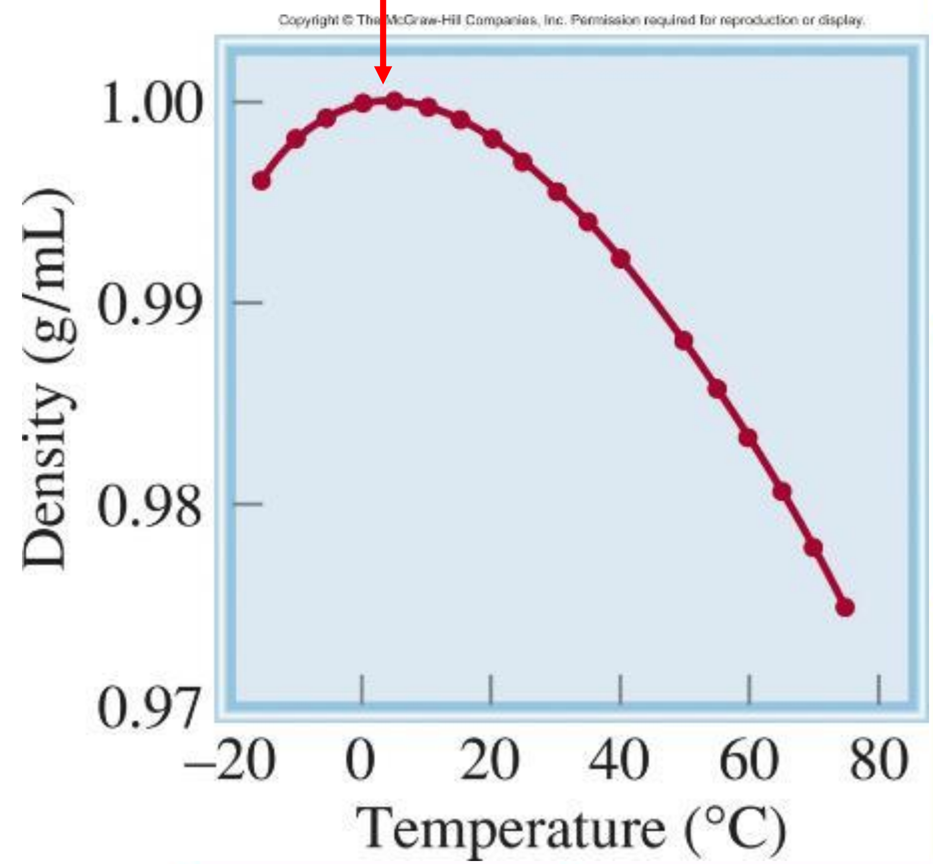
- May be intra- or intermolecular.

WATER

- Unique in that its solid is less dense than its liquid.



max density = $4^{0}C$



Get your laundry clean, bright and fresh without using harsh detergents!
GREEN CLEAN
Forget using expensive detergents, harmful bleach and antibacterial soaps in your wash. With this revolutionary eco laundry ball, you don't need them! It utilizes pure physical principles to wash clothes — more than 80 types of minerals & negative ions that are emitted by the minerals to divide large water molecules into smaller ones. This allows the water to more effectively penetrate clothing fibers to lift dirt & stains. Works with all laundry machines & lasts for up to 1000 washes.
NO CHEMICALS
Lasts up to 1000 washes!
Compare At: $49.95
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Eco Laundry Ball
Item No. TB-21355
$14.99
*Reduced price available with purchase of a regular priced item.
† CA buyers see other side of form for details.
ORDER ANYTHING FROM THIS CATALOG AND GET THE ECO BALL FOR ONLY:
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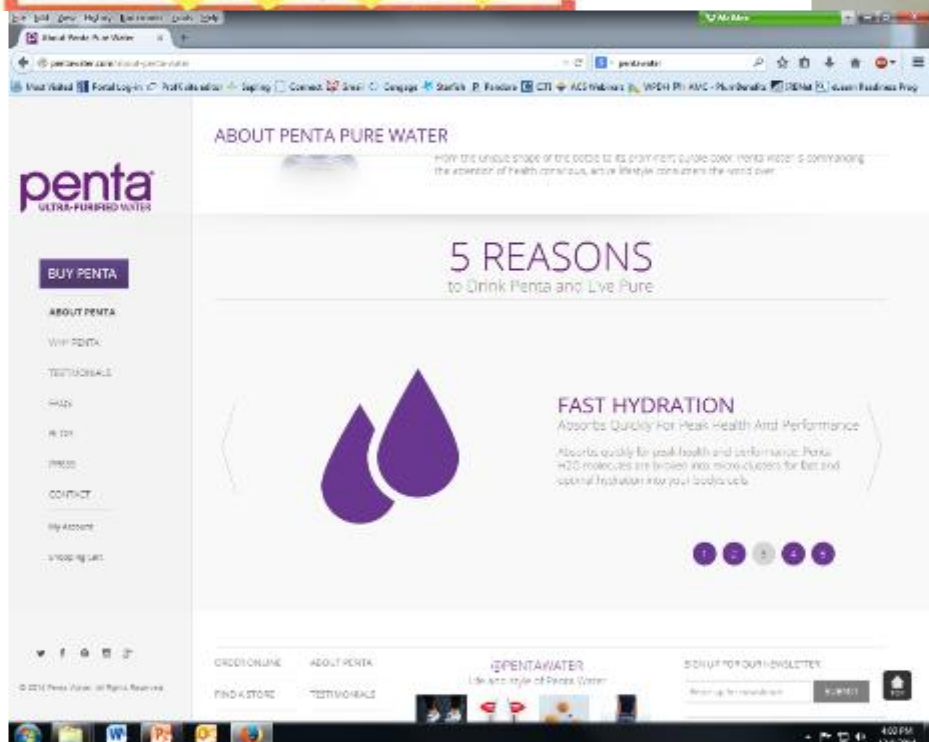
Ask operator for other specials too!



ABOUT PENTA PURE WATER
penta
ULTRA-PURIFIED WATER
BUY PENTA
ABOUT PENTA
5 REASONS
to Drink Penta and Live Pure
FAST HYDRATION
Absorbs Quickly For Peak Health And Performance
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JOHN ELLIS WATER DISCOVERY
VIDEO PROOF
Norman Rockwell
and Other American Icons
These are people that influenced my life in New Rochelle, NY where Norman Rockwell lived for 25 years and where my family lived for 3 generations.
We all knew and loved the man in spite of a book trashing him in another attempt to destroy everything that is great about America! I am writing a book with a rebuttal that includes the untold stories about many others that shaped our country.
Did you ever wonder what happened to over 100 signed letters from FDR, that Harvard wanted for their archives?
Most of these people I met in my parents living room: Dr. Norman Vincent Peale, James Cash Penney, Lowell Thomas, Charles E. Wilson (Chairman of GE. FDR appointed him head of the War Production Board WW2), Carrie Chapman Catt (Woman Suffragist), Dr. James E. West (Chief Scout Executive, Boy Scouts of America), William Frank Snyder (FDR's lawyer and close friend, who also had polio, wrote his will and handled his financial affairs including Mrs. Delano, complaining to my mother: "The Roosevelt's are using my pool!"). "Buffalo Bob" Smith (It's Howdy Doody Time!). C.L. Lowes: (My grandfather started BOND BREAD. Buying trainloads of flour for 50 plants, he waited for the price of flour to go UP so farmers could make a fair profit...he was unique! General Baking Co became General Host..."Twinkies") Richard Ellis (my brother, commercial Real Estate) and many others!
After my father died, Dr. Peale said the eulogy and inspired me to increase water properties back to what it was before "The Flood" (living to Biblical ages). After "The Flood" they didn't live as long!
Since I am the first person in history to do it, should be ample proof that it had to come from divine inspiration! With an Engineering Degree that includes Steam Plant Design, I increased the Hydrogen Bond Angle (HBA) in ordinary water from 104 to 114 degrees, confirmed by scientists at Los Alamos Nuclear Lab and Lawrence Livermore to The Washington Times.
The Washington Post (on our website): "10,000 people per day" traveling to obtain water from my countertop machines, even adding water to a well with miraculous results! Dr. G. Abraham MD UCLA: "Nothing is even close for measurable Blood Flow with a 114 HBA!" At 84, MEASURE 3000% more ENERGY in your drinking water (Video)!! 13 Patents 332 FDA Tests
johnellis.com/measure
THE SATURDAY EVENING POST
Gilbert de Daunant (Prince Rainier's cousin):"I just walked 40 blocks and I am 94! Send another E5 to Monaco!"
THE FLOOD REVISITED
ORDER A MACHINE 845.754.8696
LISTEN TO A RECORDING 800.433.9553
tercuresanything.com/measure

Just add oil

What makes it special is Bulletproof's patented nano particles. Asprey has concocted XCT Oil, which is coconut oil that has been triple-distilled to extract triglycerides. They're then mixed with Vitamin E. All told, there's 2 grams of fat in each 16-ounce bottle.
Daily News 8/6/15

cess. The oil helps the water do its job better because cells are more likely to take in H2O that has a tiny bit of fat in it, he says.

The Bulletproof Diet inventor is entering uncharted waters

BY JACQUELINE CUTLER
NEW YORK DAILY NEWS

Oil and water don't mix — so why are there droplets of fat in the newest bottle of H2O?

Because the Silicon Valley techie who mixed butter with coffee and created a diet he calls "Bulletproof" put them there. He thinks his new drink — yes, it's called FATwater — is better than regular water.

"My whole career in Silicon Valley has been about disruptive technology," says Dave Asprey, creator of FATwater and a cloud-computing pioneer. "This is a disruptive technology for beverages."

The secret ingredient in FATwater is teeny droplets of fat extracted from coconut oil in Asprey's proprietary process. The oil helps the water do its job better because cells are more likely to take in H2O that has a tiny bit of fat in it, he says.

Meanwhile, the fats in the oil provide a temporary energy boost and do not get stored as body fat in the way sugar does, he adds.

Besides, it's only 2 grams of saturated fat — the equivalent of two squares of Chocolove dark.

"The oils enhance thermogenesis, which is a fancy word for 'fat burning,'" says Asprey, 42. "They get burned as energy and have an appetite-suppression effect. It's not like we put in sunflower oil or canola."

For now, Asprey is selling FATwater only at his Bulletproof Coffee Shop in Santa Monica, Calif., and at an L.A. natural foods store. But he has plans to expand nationally.

TASTE KITCHEN

Nutritionists say he shouldn't rush — this oil is of the snake variety.

"It is just getting crazier and crazier," says Rochelle Sirota, a dietitian and nutritionist. "What is the need? Coconut water can be very hydrating because of the electrolytes, but I do not get this whole thing."

Nutritionists at Brown & Medina Nutrition in Manhattan also questioned FATwater's claims, saying in a statement that the small amount of fat diluted in the water "would most likely not have an impact on fat burn."

There is "no research on the fat being more hydrating," the statement continued.

The country's sole water sommelier, Martin Riese, who offers 20 mineral and spring waters at Ray's & Stark Bar in Los Angeles, was aware of FATwater — and doesn't think much of it.

"Water should not have any calories, and this has 20," he says. "This, I say, is a 'near water' product. I believe water should come from nature and not a factory."

Though Asprey is not the first to extract the oil, he is the first to mix it in water, patent it and market it.

Research, smesearch, he suggests.

He cites his creation of Bulletproof Coffee as evidence that conventional wisdom is wrong and that everything — even nature itself — can be improved upon.

"Biohacking is taking control of the environment around you so you have control of your biology," he says.

"So you are less stressed and recover better and are a nicer person. I am making it easier for people to make those little changes and feel good all the time."

We sent a bottle of lemon and berry flavors of FATwater into the Daily News Taste Kitchen — and about the nicest thing anyone said is that FATwater is an acquired taste.

One reporter thought the berry tasted like "liquid soap," while another thought the lemon was "like Crystal Light not fully diluted."

Two testers actually shook with revulsion. But one took a long sip, swallowed and gave FATwater its highest praise: "You know what? It's not that bad."

Tech wiz-turned-biohacker Dave Asprey

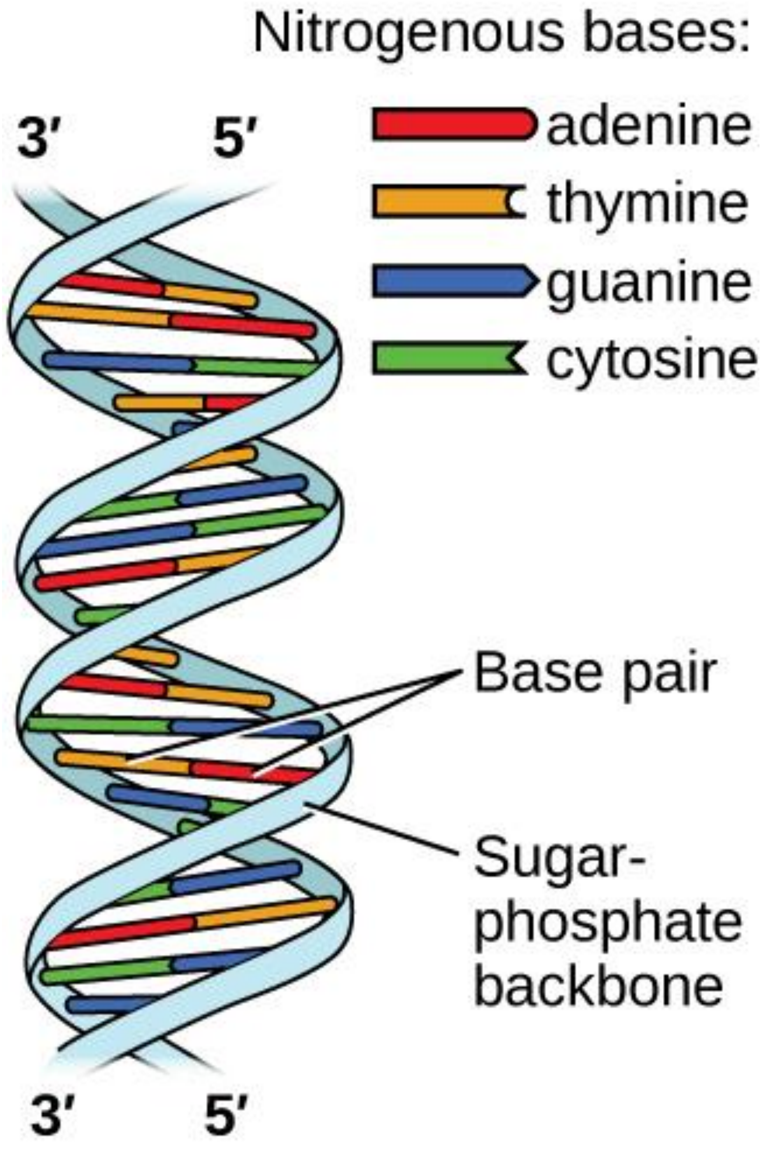
DRIPPING WITH HEALTH CLAIMS

GATORADE VS. FATWATER

Here's how 16 ounces of two hydrating beverages compare:

GATORADE		FATWATER
Formulated in 1965 by a University of Florida lab after the Florida Gators football coach asked for a drink to replace fluids that athletes lose when training in severe heat.	ORIGIN	Made by Dave Asprey, creator of the Bulletproof Diet, known for its emphasis on butter and coffee. It contains droplets of coconut oil.
$1.98 for a 128-ounce bottle	PRICE	$3.95 per 16-ounce bottle
100	CALORIES	20
28g	CARBS	1g
60 mg potassium	ELECTROLYTES	0g
28g	SUGAR	0g

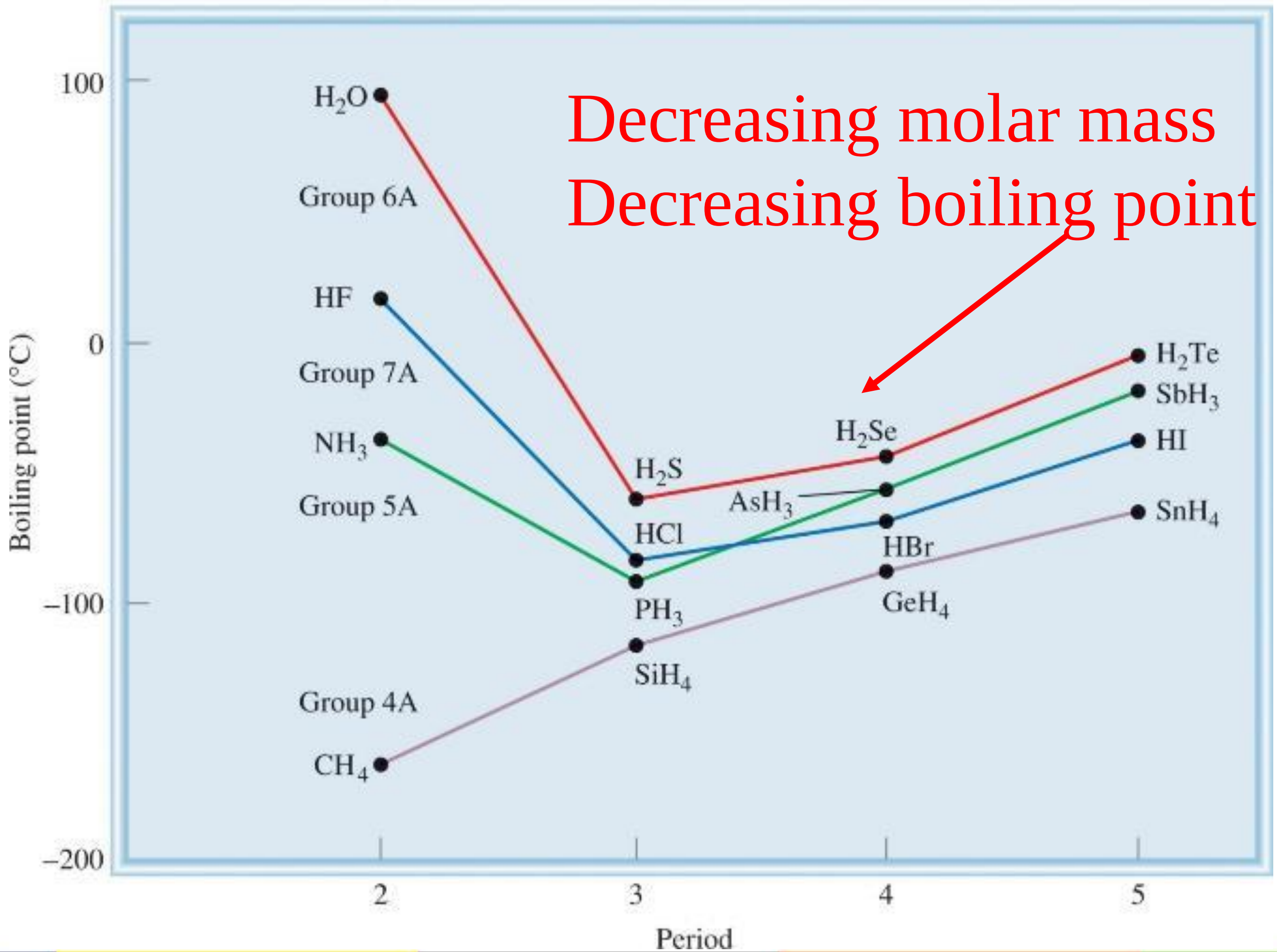
DNA - FIGURE 10.13



- Two separate DNA molecules form a double-stranded helix in which each base pair is held together by hydrogen bonding.
- A and T share two hydrogen bonds, C and G share three. (credit: modification of work by Jerome Walker, Dennis Myts)

H-BONDING EFFECT ON BP (~FIG 10.12)

- Typically, BP increases with molecular weight due to increased dispersion forces....except...

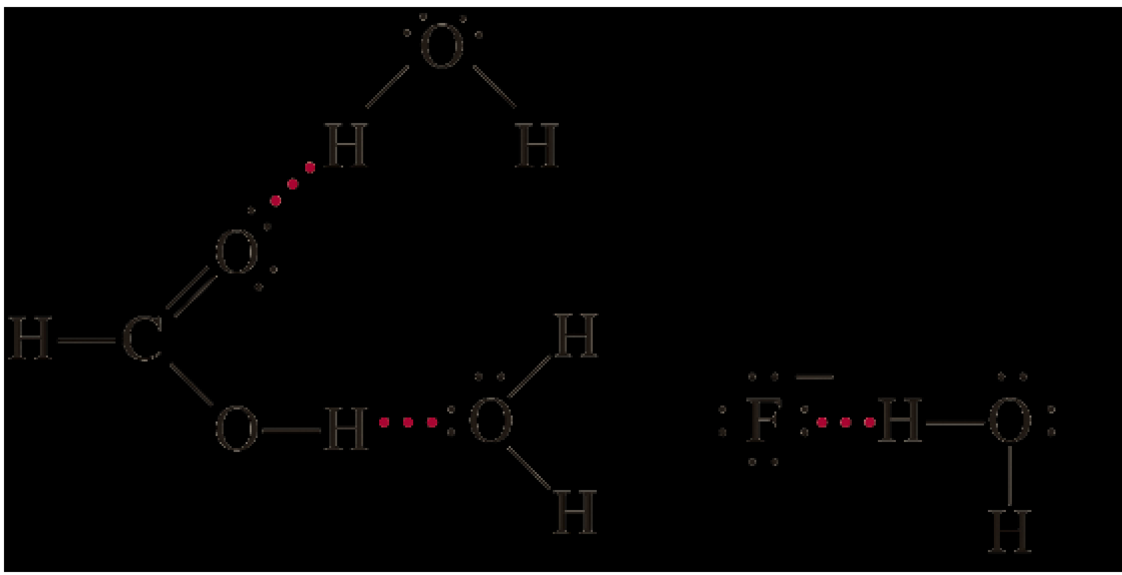


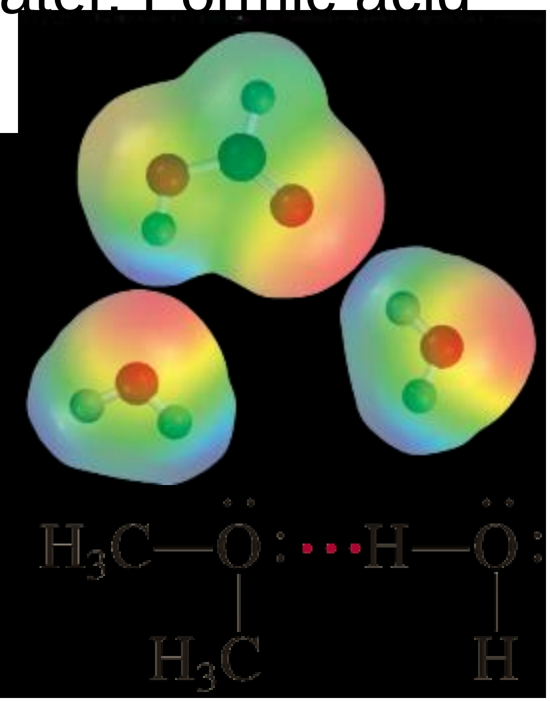
QUESTION 11.2

- Which of the following can form hydrogen bonds with water? With itself?
- CH_3OCH_3
- CH_4
- F_2
- HCOOH
- Na^+

ANSWER 11.2

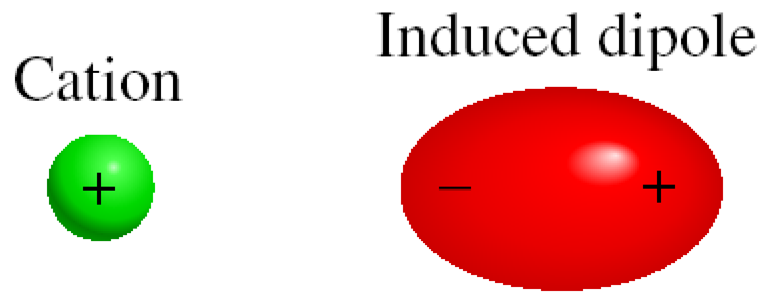
- ***Strategy*** A species can form hydrogen bonds with water if it contains one of the three small, electronegative elements (F, O, or N) and/or it has a H atom bonded to one of these three elements.
- ***Solution*** There are no electronegative elements (F, O, or N) in either CH_4 or Na^+. Therefore, only CH_3OCH_3, F_2, and HCOOH can form hydrogen bonds with water. Formic acid can do it 2 ways.



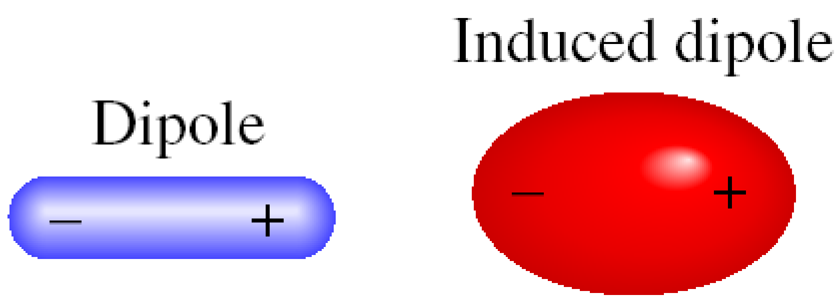


(LONDON) DISPERSION FORCES

- Attractive forces that arise as a result of temporary dipoles (induced or instantaneous) in atoms or molecules



ion-induced dipole interaction



dipole-induced dipole interaction

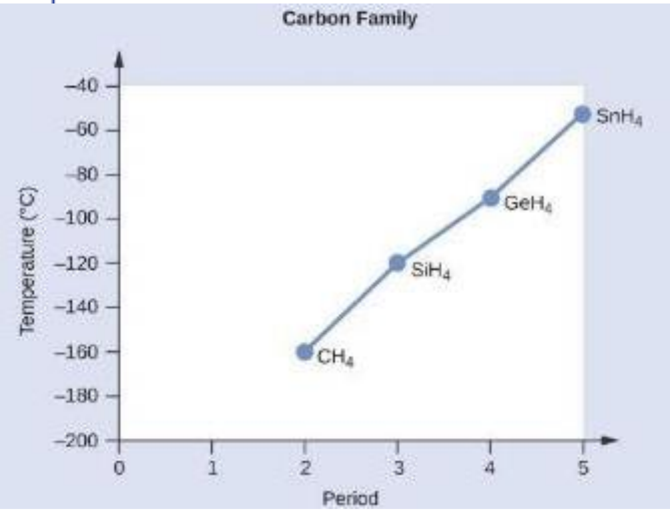
DISPERSION FORCES (CONT'D)

- Larger and heavier atoms and molecules are more *polarizable* and exhibit stronger dispersion forces than do smaller and lighter atoms and molecules.

Melting and Boiling Points of the Halogens

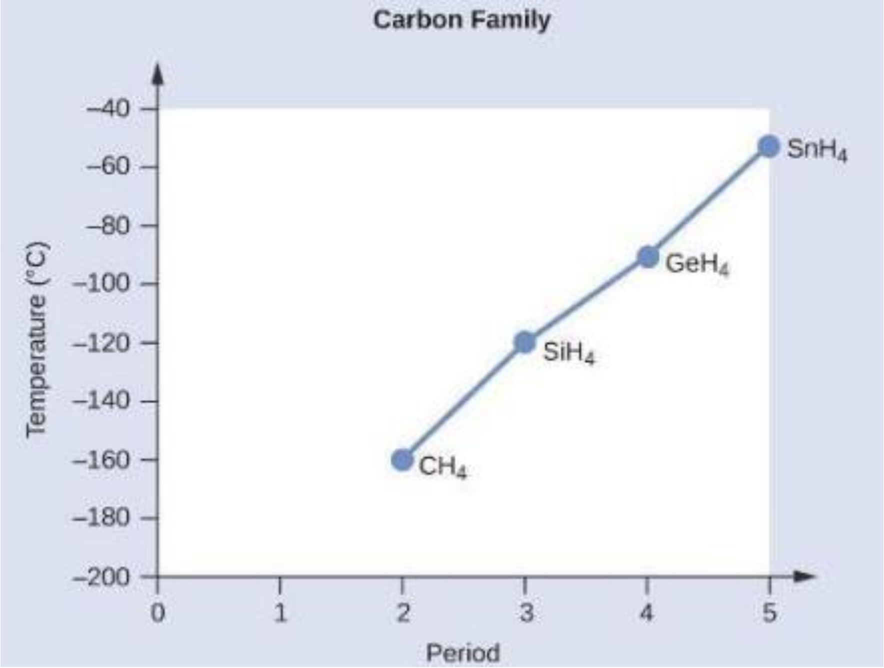
Halogen	Molar Mass	Atomic Radius	Melting Point	Boiling Point
fluorine, F_2	38 g/mol	72 pm	53 K	85 K
chlorine, Cl_2	71 g/mol	99 pm	172 K	238 K
bromine, Br_2	160 g/mol	114 pm	266 K	332 K
iodine, I_2	254 g/mol	133 pm	387 K	457 K
astatine, At_2	420 g/mol	150 pm	575 K	610 K

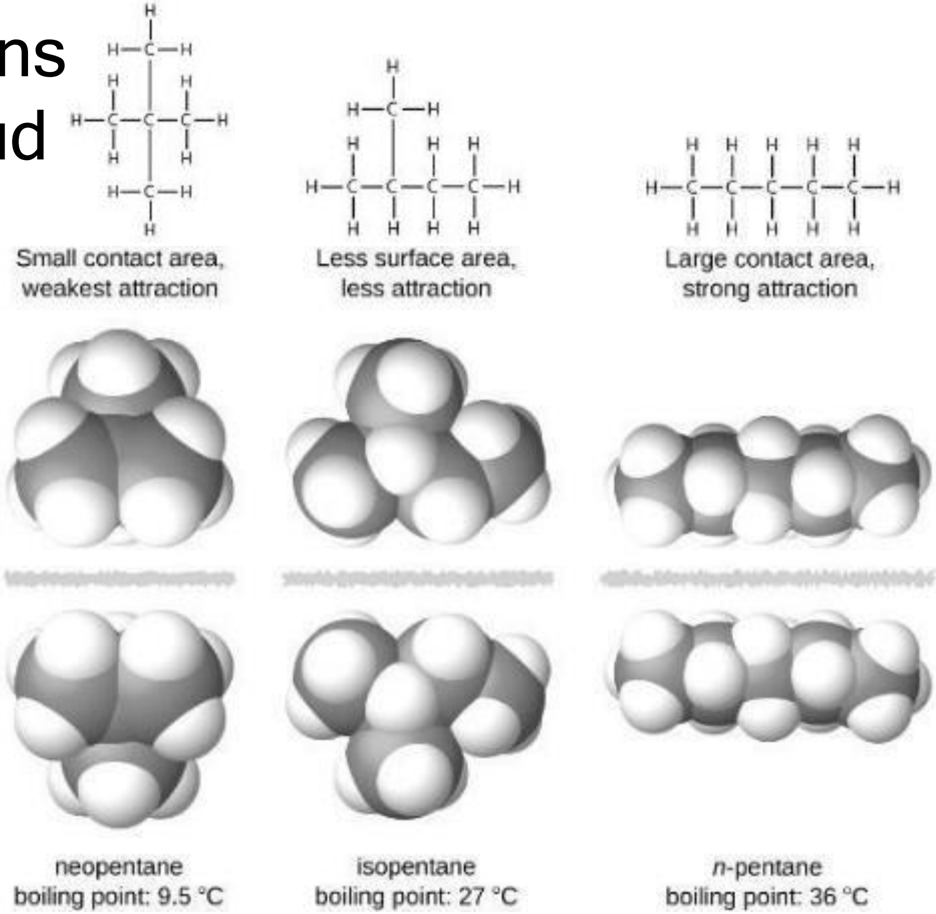
Table 10.1



DISPERSION FORCES (CONT'D)

- Polarizability is the ease with which the electron distribution in the atom or molecule can be distorted.
- Polarizability increases with:
  - greater number of electrons
  - more diffuse electron cloud





QUESTION

- Which has the higher BP, N_2 or CO?

QUESTION

What type(s) of intermolecular forces exist between the following pairs of molecules?

(a) HBr and H_2O

(b) Cl_2 and CBr_4

(c) I_2 and NO_3^-

(d) NH_3 and C_6H_6

ANSWER

- ***Strategy*** Classify the species into three categories: ionic, polar (possessing a dipole moment), and nonpolar. Keep in mind that dispersion forces exist between *all* species.

- ***Solution***

(a) Both HBr and H_2O are polar molecules. Therefore, the intermolecular forces present are dipole-dipole forces, as well as dispersion forces.

(b) Both Cl_2 and CBr_4 are nonpolar, so there are only dispersion forces between these molecules.

(c) I_2 is a homonuclear diatomic molecule and therefore nonpolar, so the forces between it and the ion are ion-induced dipole forces and dispersion forces.

- (d) NH_3 is polar, and C_6H_6 is nonpolar. The forces are dipole-induced dipole forces and dispersion forces.

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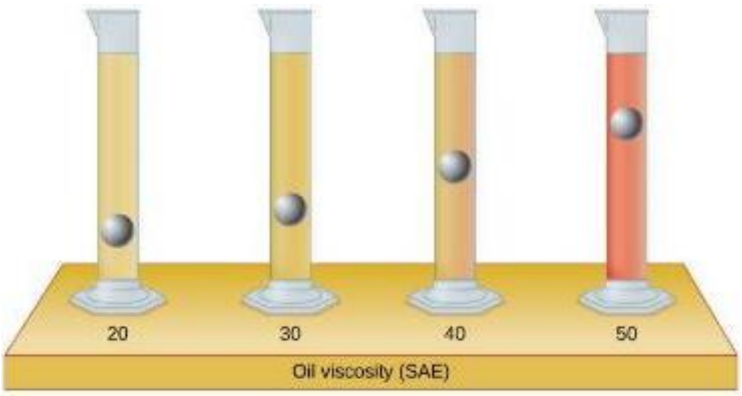
VISCOSITY

- Viscosity is a measure of a fluid's resistance to flow.
- Strong intermolecular forces = high viscosity
- Lower T = higher viscosity



Viscosities of Common Substances at 25 °C

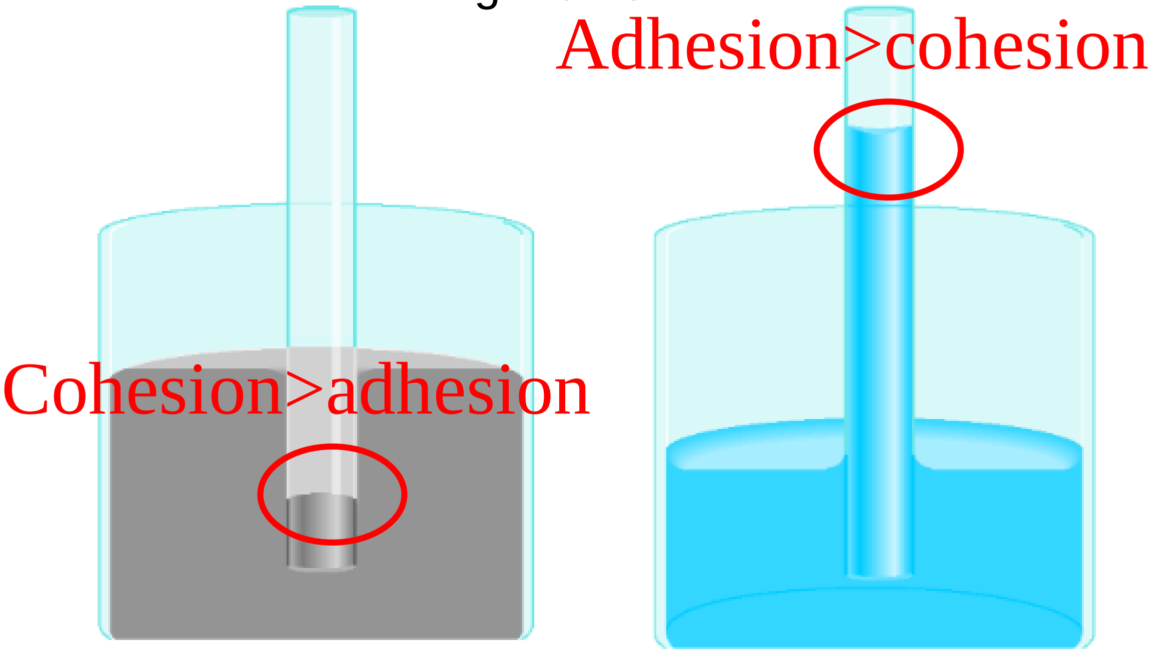
Substance	Formula	Viscosity (mPa·s)
water	H_2O	0.890
mercury	Hg	1.526
ethanol	C_2H_5OH	1.074
octane	C_8H_{18}	0.508
ethylene glycol	$CH_2(OH)CH_2(OH)$	16.1
honey	variable	~2,000–10,000
motor oil	variable	~50–500

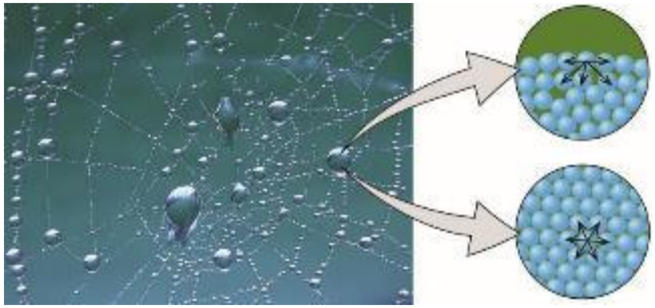
Table 10.2

ADHESION AND COHESION

- **Cohesion** is the intermolecular attraction between like molecules
  - Responsible for round water droplets
- **Adhesion** is an attraction between unlike molecules
  - Responsible for capillary action

~Fig. 10.18

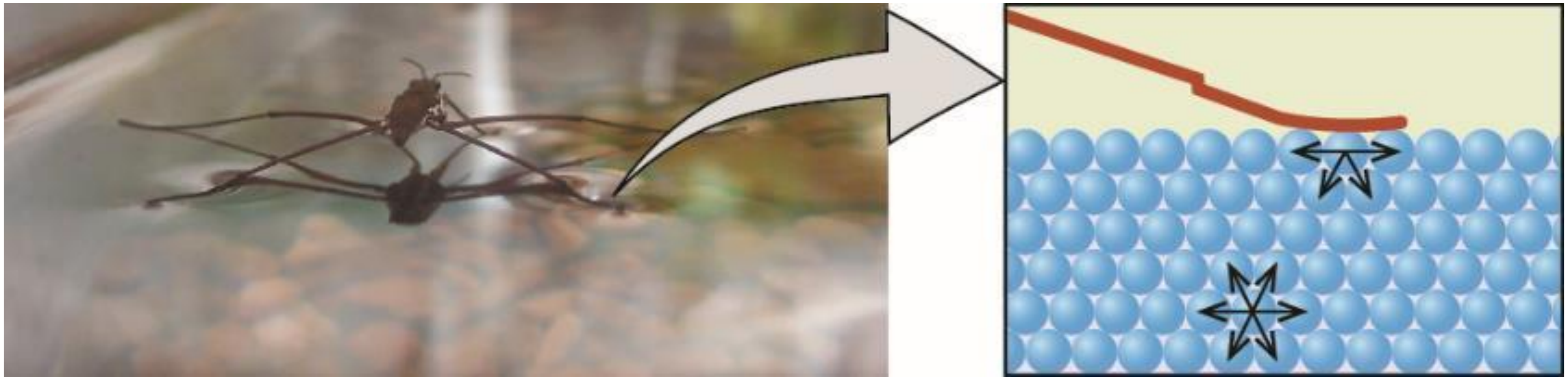




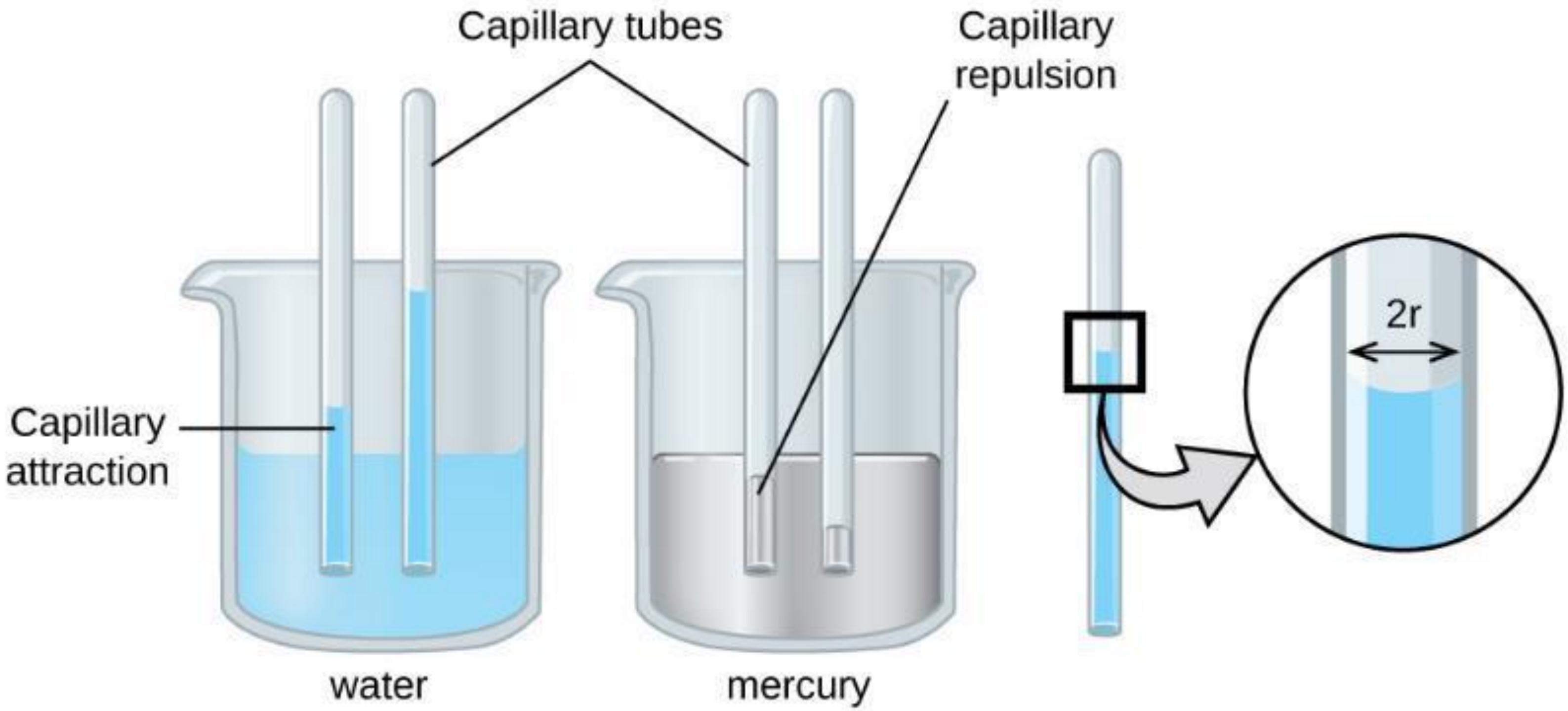
Attractive forces result in a spherical water drop that minimizes surface area; cohesive forces hold the sphere together; adhesive forces keep the drop attached to the web. (credit photo: modification of work by “OliBac”/Flickr)

SURFACE TENSION

- Surface tension is the amount of energy required to stretch or increase the surface of a liquid by a unit area.
- Strong intermolecular forces = High surface tension



CAPILLARY ACTION (FIGURE 10.20)



- Depending upon the relative strengths of adhesive and cohesive forces, a liquid may rise (such as water) or fall (such as mercury) in a glass capillary tube. The extent of the rise (or fall) is directly proportional to the surface tension of the liquid and inversely proportional to the density of the liquid and the radius of the tube.
- We will not do the math on page 535

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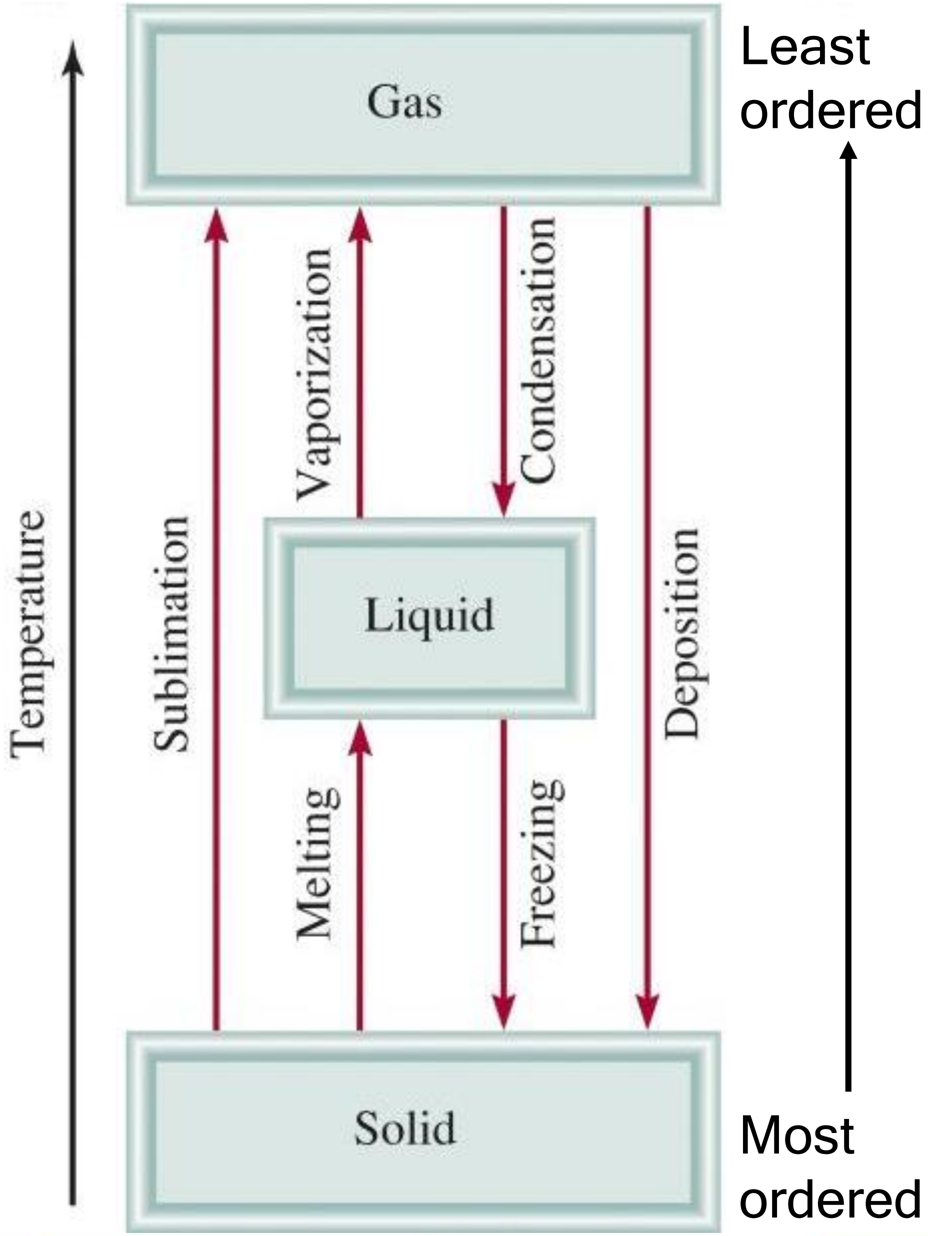
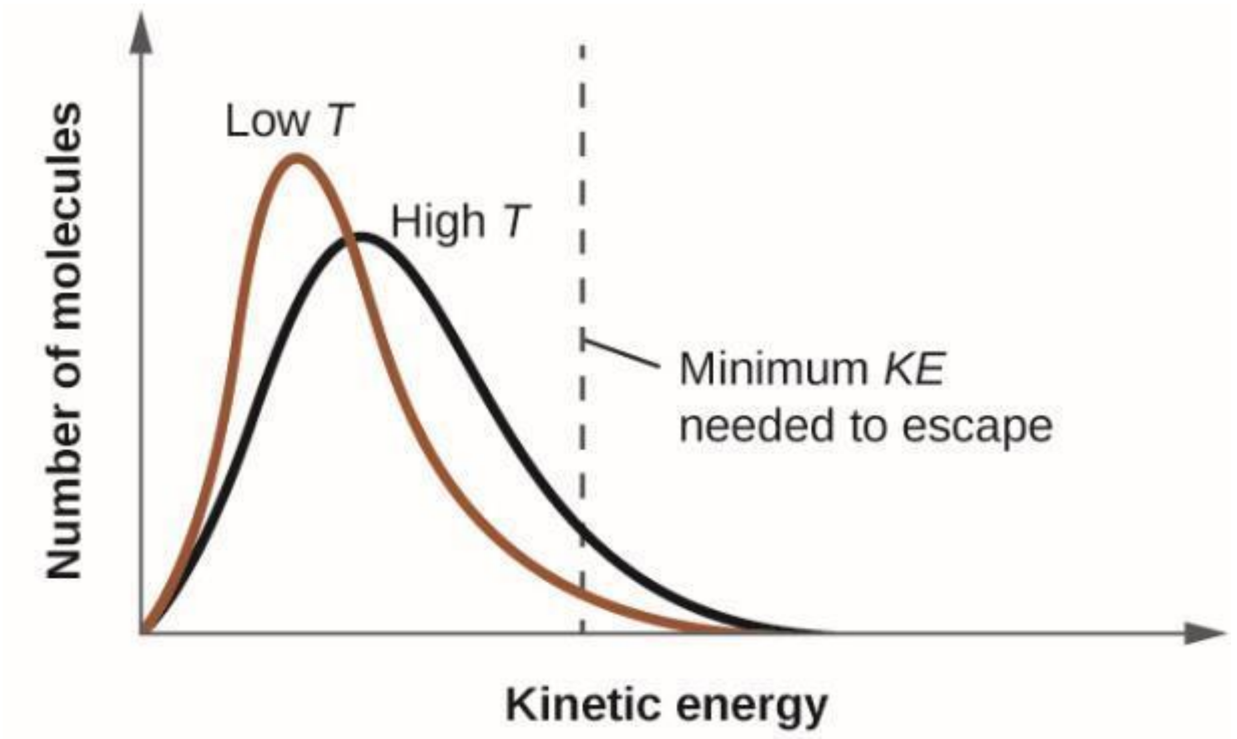
PHASE CHANGES



EFFECT OF T ON KE

- Remember, hotter is faster



- Temperature affects the distribution of kinetic energies for the molecules in a liquid. At the higher temperature, more molecules have the necessary kinetic energy, KE, to escape from the liquid into the gas phase.

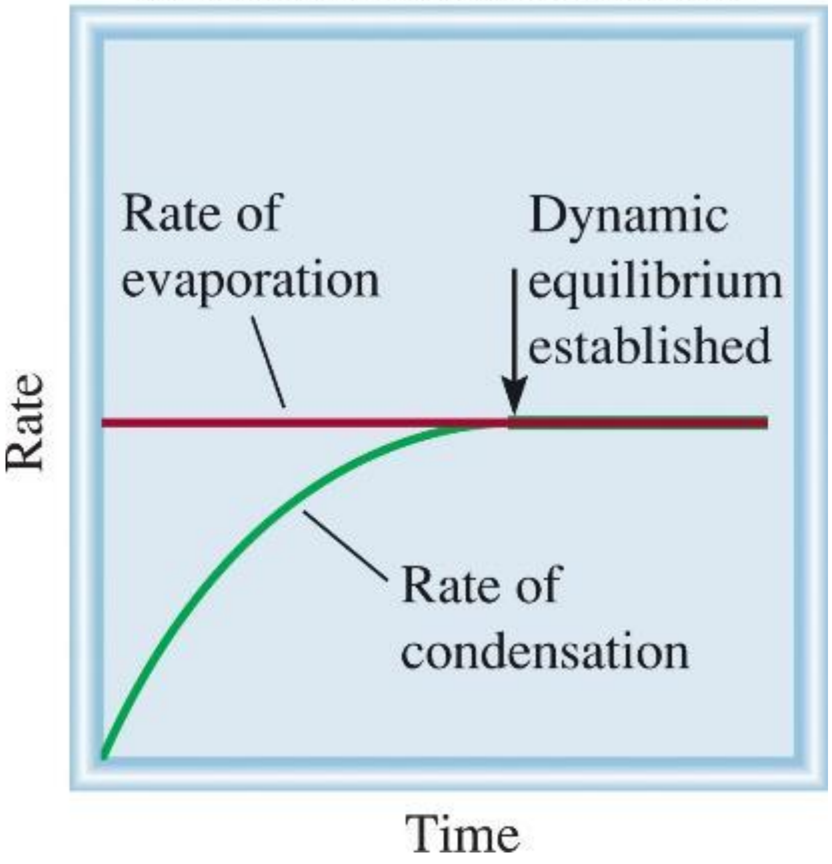
DYNAMIC EQUILIBRIUM & VAPOR PRESSURE

- The equilibrium vapor pressure is the vapor pressure measured when a dynamic equilibrium exists between condensation and evaporation

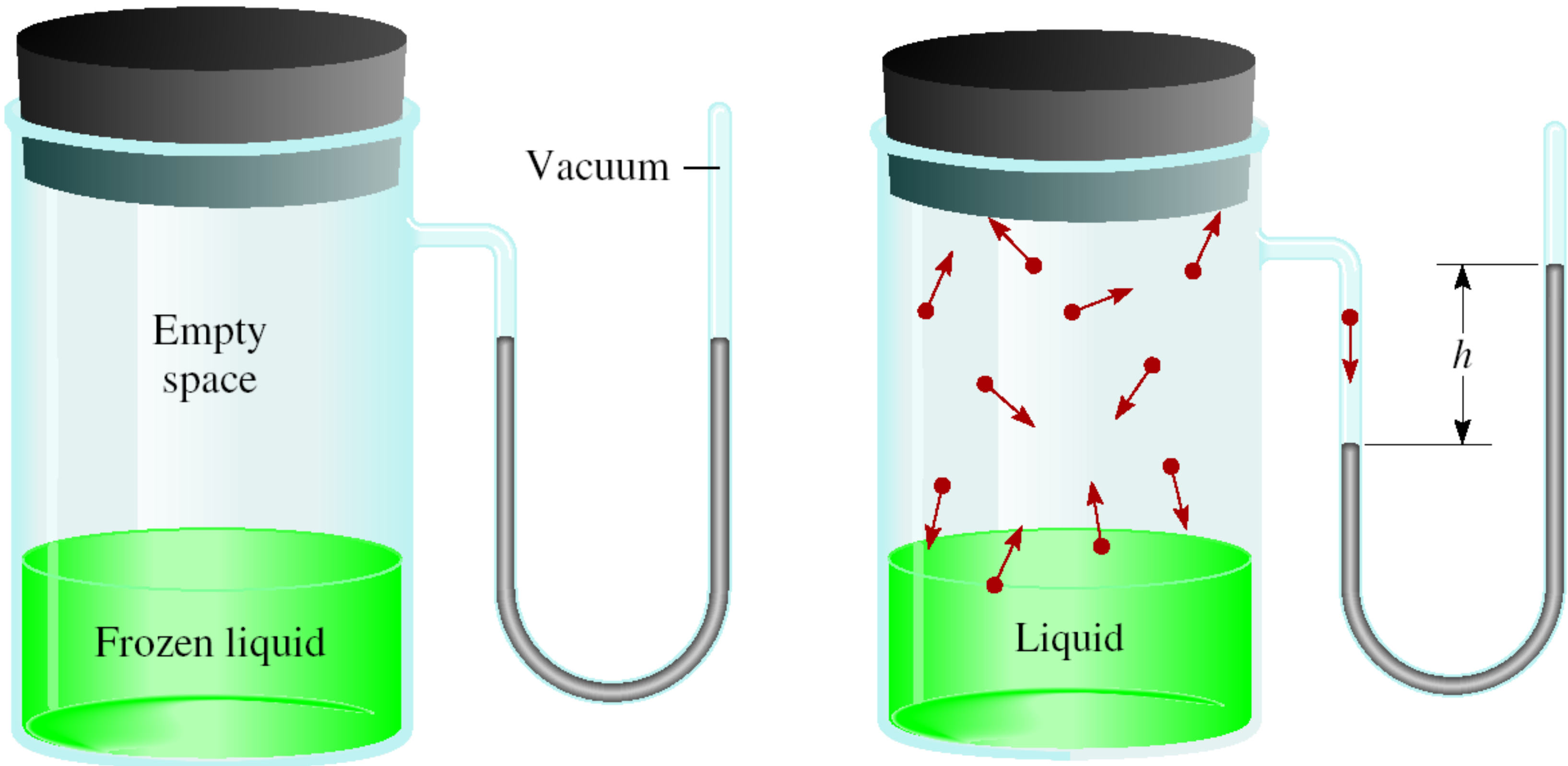
$$H_2O\ (l) \rightleftharpoons H_2O\ (g)$$

Dynamic equilibrium

Rate of condensation = Rate of evaporation



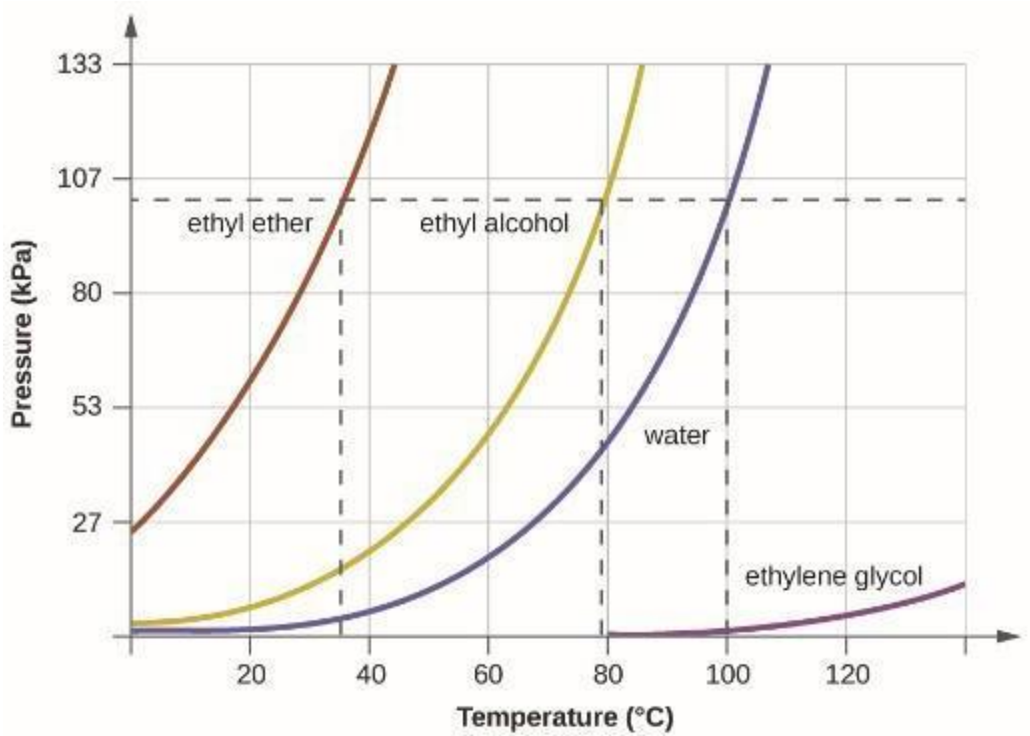
MEASURING VP (~FIG 10.22 (NOT GOOD))



- In a closed container, **dynamic equilibrium** is reached when the rate of molecules escaping from the liquid to become the gas eventually equals the rate of gas molecules entering the liquid. When this equilibrium is reached, the vapor pressure of the gas is constant, although the vaporization and condensation processes continue.

BOILING POINT

- The *boiling point* is the temperature at which the (equilibrium) vapor pressure of a liquid is equal to the external pressure.
- The *normal boiling point* is the temperature at which a liquid boils when the external pressure is 1 atm.



- The boiling points of liquids are the temperatures at which their equilibrium vapor pressures equal the pressure of the surrounding atmosphere. Normal boiling points are those corresponding to a pressure of 1 atm (101.3 kPa.)

QUESTION

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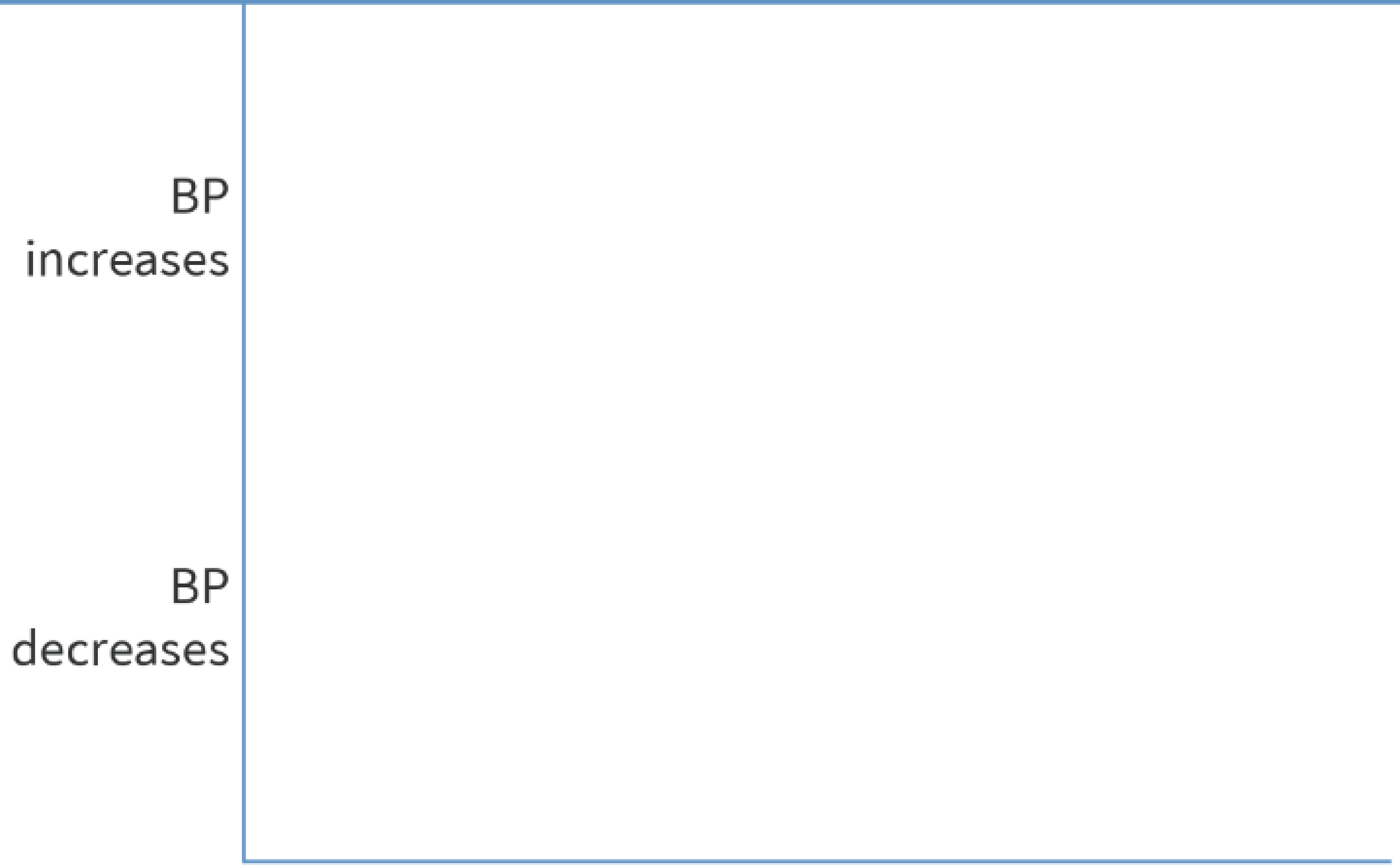
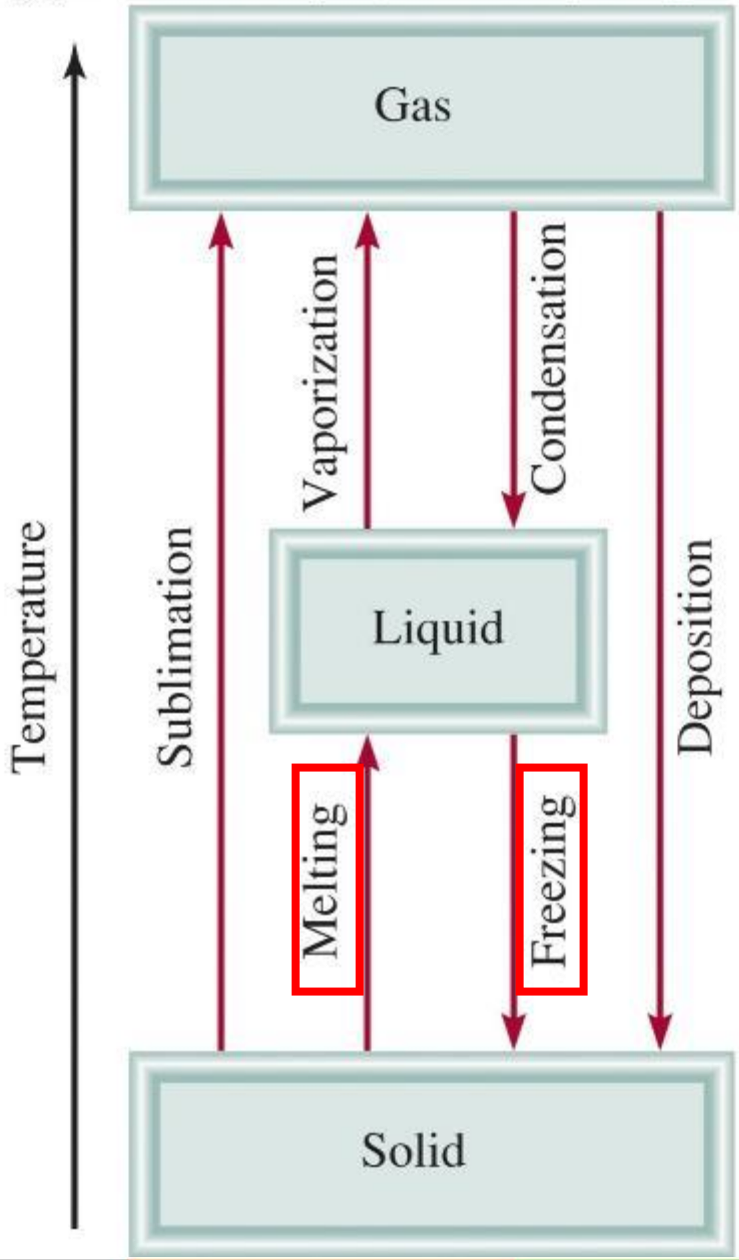
What happens to the BP of a liquid at lower external pressure?



SOLID-LIQUID EQUILIBRIA

- The *melting point* of a solid or the *freezing point* of a liquid is the temperature at which the solid and liquid phases coexist in equilibrium.

$$H_2O\ (s) \rightleftharpoons H_2O\ (l)$$

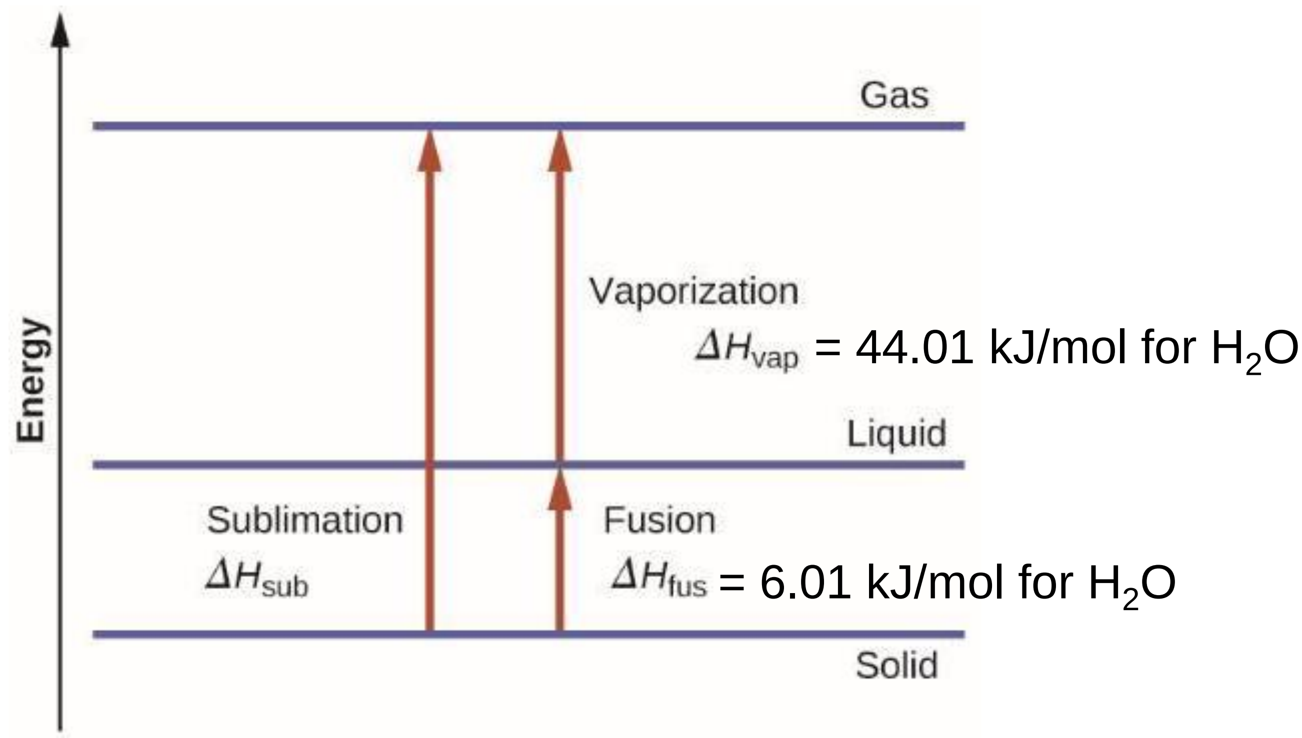


ENTHALPY OF PHASE CHANGES

- Just as it takes (or releases) energy to heat (or cool) a liquid, it takes/releases energy to change a phase.
- Yes, we skipped the thermo chapter…

$$\Delta H_{sub} = \Delta H_{fus} + \Delta H_{vap}$$

(Hess' law)



RELATING VP AND ΔH

- Molar heat of vaporization (ΔH_{vap}) is the energy required to vaporize 1 mole of a liquid at its boiling point.

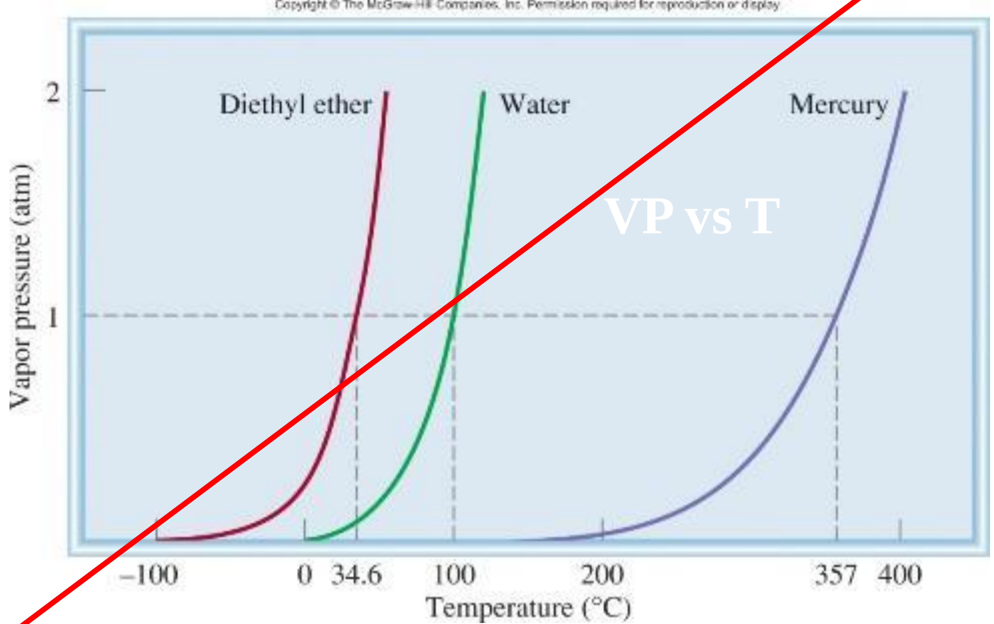
P = (equilibrium) vapor pressure

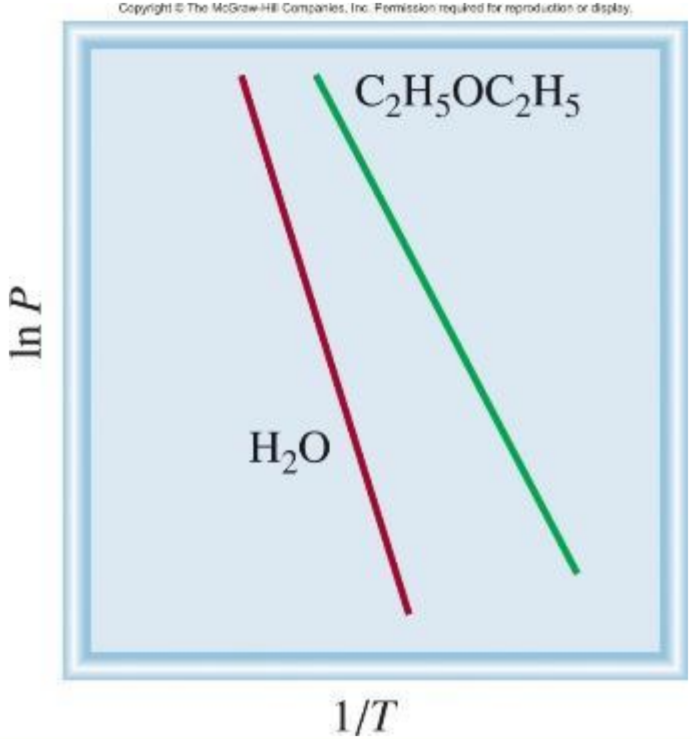
T = temperature (K)

R = gas constant (8.314 J/K•mol)

<u>Clausius-Clapeyron equation</u>

$$\ln P = -\frac{\Delta H_{vap}}{RT} + \ln A$$





CLAUSIUS-CLAPEYRON EQUATION

- At two temperatures:

$$\ln \frac{P_1}{P_2} = \frac{\Delta H_{\text{vap}}}{R}\left(\frac{1}{T_2} - \frac{1}{T_1}\right)$$

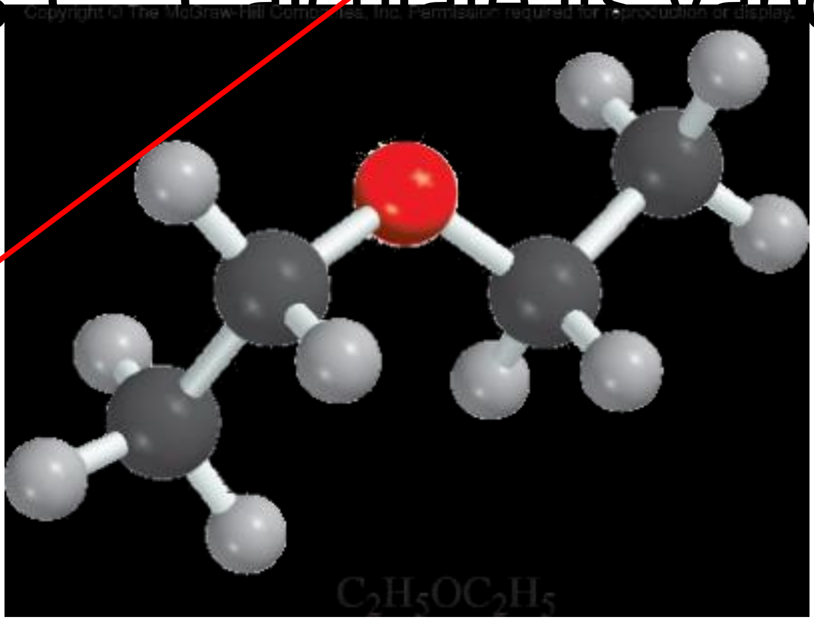
or

$$\ln \frac{P_1}{P_2} = \frac{\Delta H_{\text{vap}}}{R}\left(\frac{T_1 - T_2}{T_1 T_2}\right)$$

QUESTION

- Diethyl ether is a volatile, highly flammable organic liquid that is used mainly as a solvent.

- The vapor pressure of diethyl ether is 401 mmHg at 18°C. Calculate its vapor pressure at 32°C.



ANSWER

- ***Strategy*** We are given the vapor pressure of diethyl ether at one temperature and asked to find the pressure at another temperature. Therefore, we need Equation (11.5).

- ***Solution*** Table 11.6 tells us that ΔH_{vap} = 26.0 kJ/mol. The data are

$$P_1 = 401 \text{ mmHg} \qquad P_2 = ?$$
$$T_1 = 18°\text{C} = 291 \text{ K} \qquad T_2 = 32°\text{C} = 305 \text{ K}$$

- From Equation (11.5) we have

$$\ln \frac{401}{P_2} = \frac{26{,}000 \text{ J/mol}}{8.314 \text{ J/K} \cdot \text{mol}} \left[\frac{291 \text{ K} - 305 \text{ K}}{(291 \text{ K})(305 \text{ K})} \right]$$
$$= -0.493$$

ANSWER (CONT'D)

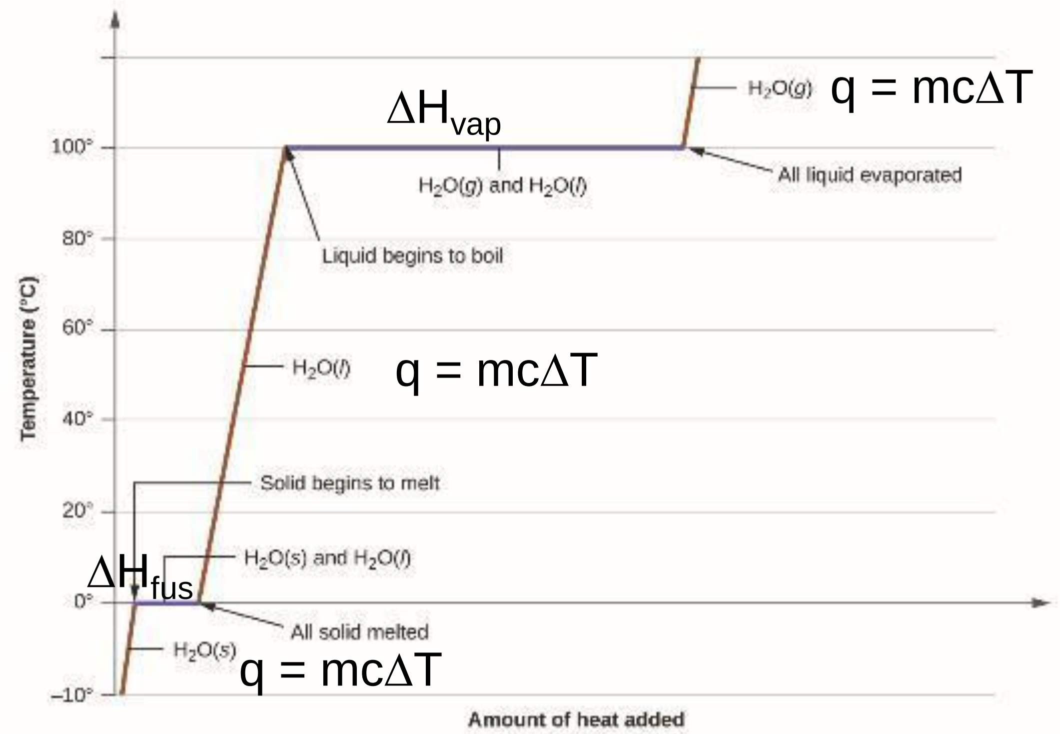
- Taking the antilog of both sides (see Appendix 4), we obtain

$$\frac{401}{P_2} = e^{-0.493} = 0.611$$

- Hence
    - P_2 = 656 mmHg

- ***Check*** We expect the vapor pressure to be greater at the higher temperature. Therefore, the answer is reasonable.

HEATING CURVE



- A typical heating curve for a substance depicts changes in temperature that result as the substance absorbs increasing amounts of heat. Plateaus in the curve (regions of constant temperature) are exhibited when the substance undergoes phase transitions.

QUESTION

- Calculate the amount of energy (in kilojoules) needed to heat 346 g of liquid water from 0°C to 182°C.

- Assume that the specific heat of water is 4.184 J/g•°C over the entire liquid range and that the specific heat of steam is 1.99 J/g•°C.

ANSWER

- ***Strategy*** The heat change (q) at each stage is given by $q = mc\Delta t$ (see p. 546), where *m* is the mass of water, c is the specific heat, and Δt is the temperature change.
- If there is a phase change, such as vaporization, then q is given by $n\Delta H_{vap}$, where *n* is the number of moles of water.
- ***Solution***
- *Step 1: Heating water from 0°C to 100°C*

$$\begin{aligned} q_1 &= ms\Delta t \\ &= (346\ \text{g})(4.184\ \text{J/g} \cdot {}^\circ\text{C})(100^\circ\text{C} - 0^\circ\text{C}) \\ &= 1.45 \times 10^5\ \text{J} \\ &= 145\ \text{kJ} \end{aligned}$$

ANSWER (CONT'D)

- *Step 2: Evaporating 346 g of water at 100°C (a phase change)*
  On p. 541 we see ΔH_{vap} = 40.79 kJ/mol for water, so

$$q_2 = 346 \cancel{\text{g H}_2\text{O}} \times \frac{1 \cancel{\text{mol H}_2\text{O}}}{18.02 \cancel{\text{g H}_2\text{O}}} \times \frac{40.79 \text{ kJ}}{1 \cancel{\text{mol H}_2\text{O}}}$$

$$= 783 \text{ kJ}$$

- *Step 3: Heating steam from 100°C to 182°C*

$$\begin{aligned} q_3 &= ms\Delta t \\ &= (346 \text{ g})(1.99 \text{ J/g} \cdot {}^\circ\text{C})(182^\circ\text{C} - 100^\circ\text{C}) \\ &= 5.65 \times 10^4 \text{ J} \\ &= 56.5 \text{ kJ} \end{aligned}$$

ANSWER (CONT'D)

- The overall energy required is given by

$$\begin{aligned} q_{\text{overall}} &= q_1 + q_2 + q_3 \\ &= 145 \text{ kJ} + 783 \text{ kJ} + 56.5 \text{ kJ} \\ &= 985 \text{ kJ} \end{aligned}$$

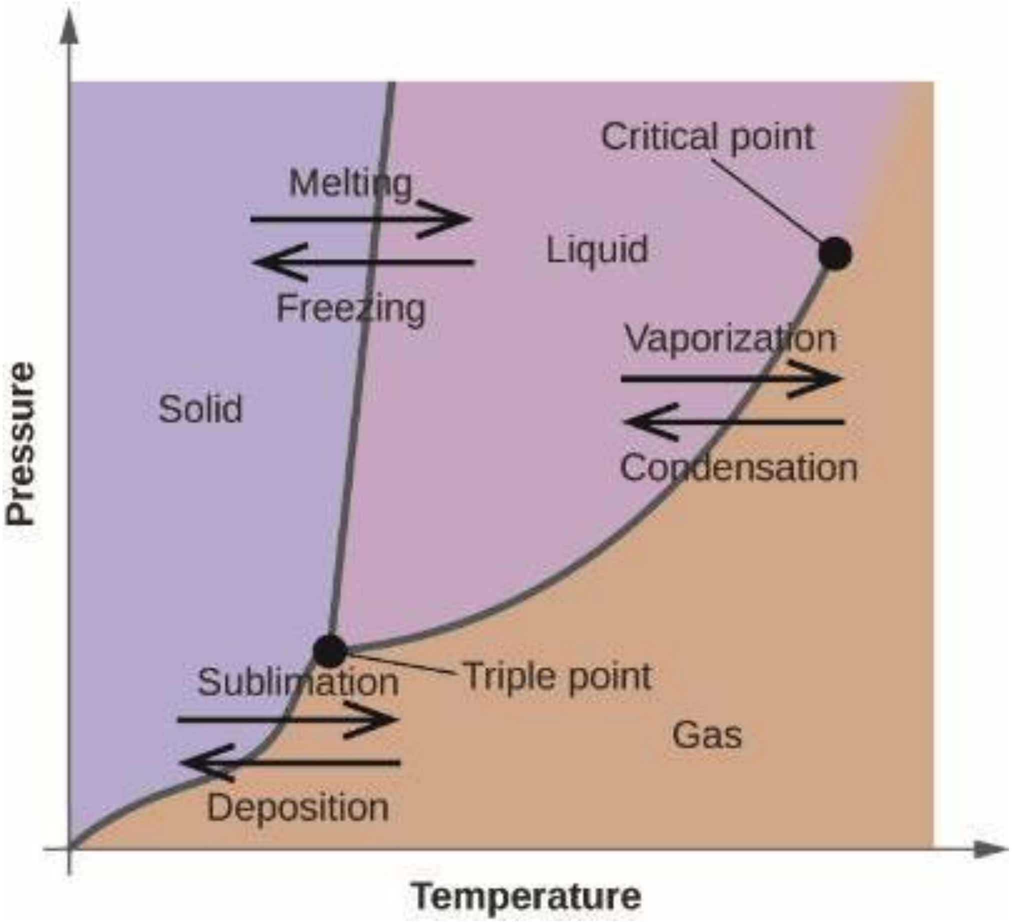
- ***Check*** All the *q*s have a positive sign, which is consistent with the fact that heat is absorbed to raise the temperature from 0°C to 182°C. Also, as expected, much more heat is absorbed during the phase transition.

CH. 10 OUTLINE

- 10.1 Intermolecular Forces
- 10.2 Properties of Liquids
- 10.3 Phase Transitions
- **10.4 Phase Diagrams**
- ~~10.5 The Solid Phase of Matter~~
- ~~10.6 Lattice Structures in Crystalline Solids~~

11.9 PHASE DIAGRAM

- A phase diagram summarizes the conditions at which a substance exists as a solid, liquid, or gas.



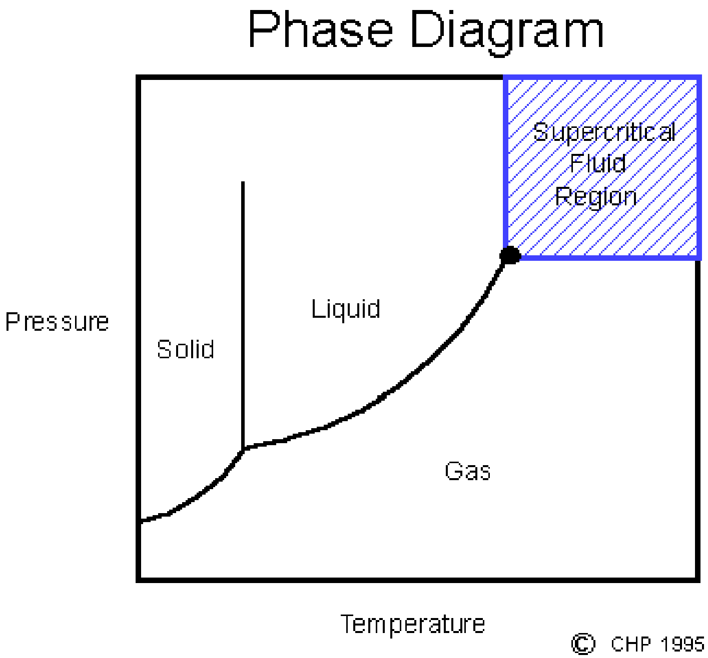
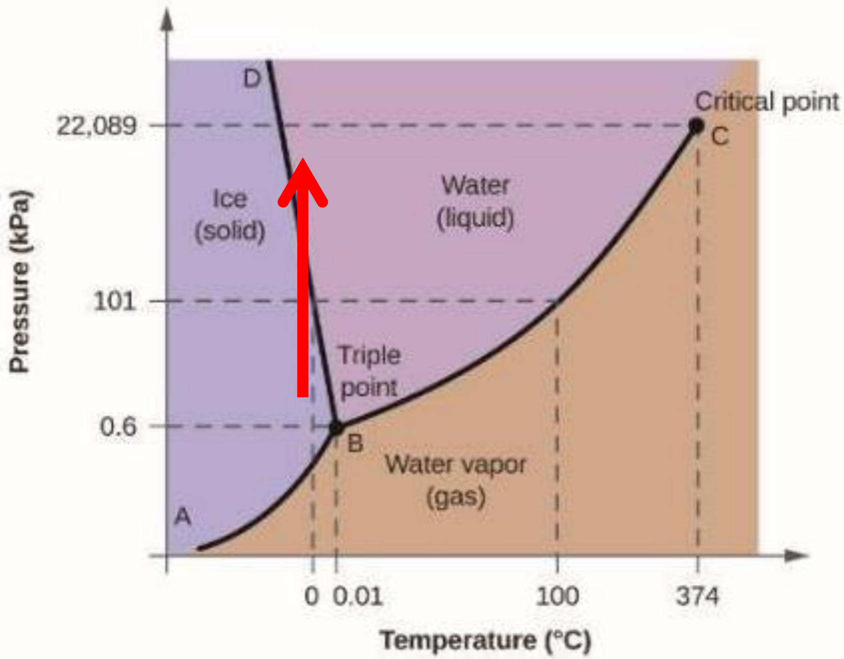
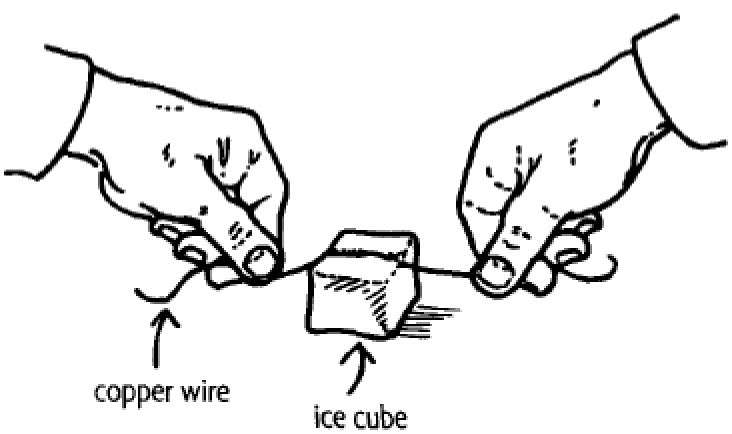


FIGURE 10.32

- Freeze-dried foods, like this ice cream, are dehydrated by sublimation at pressures below the triple point for water. (credit: “lwao”/Flickr)

REGELATION OF ICE/WATER





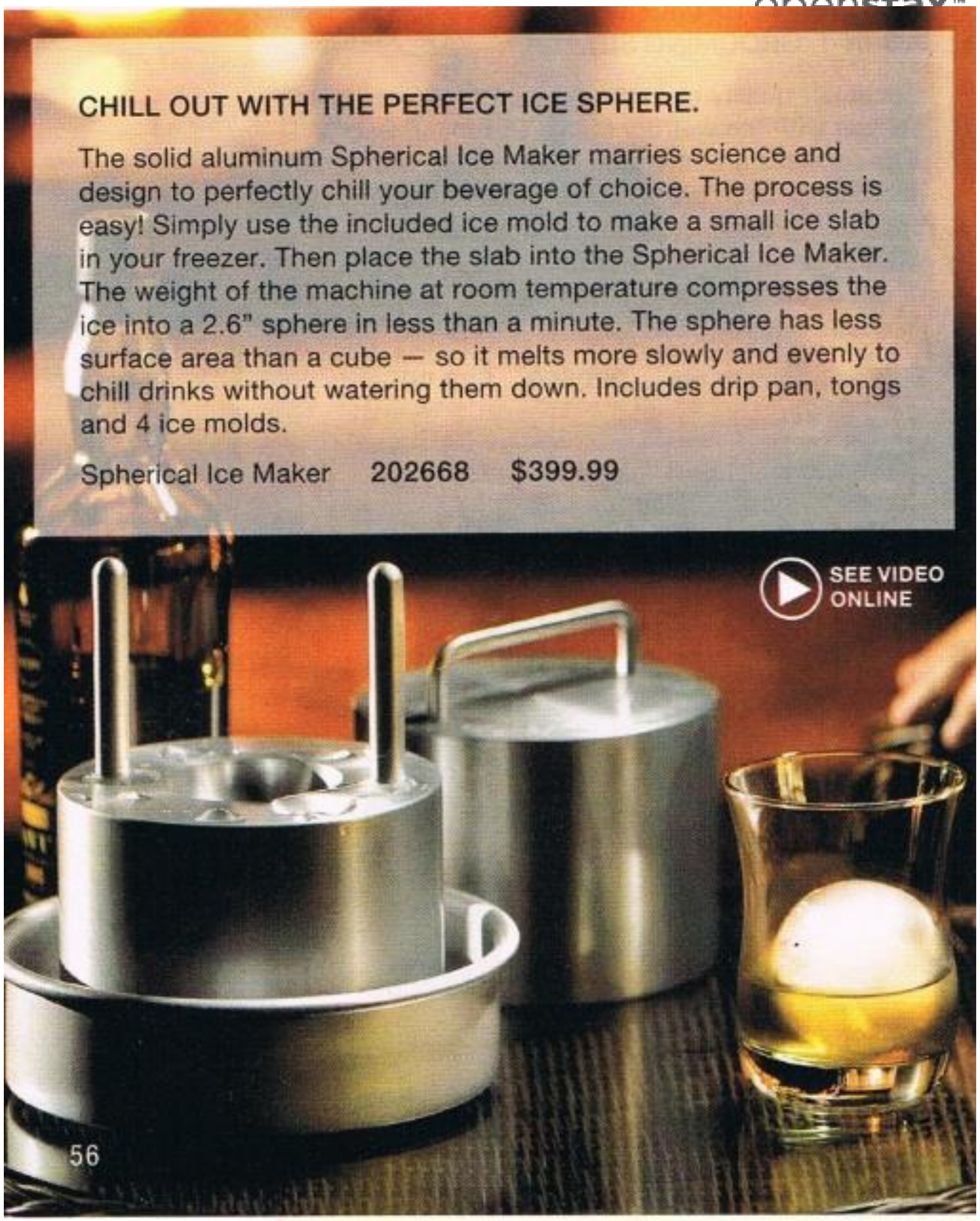
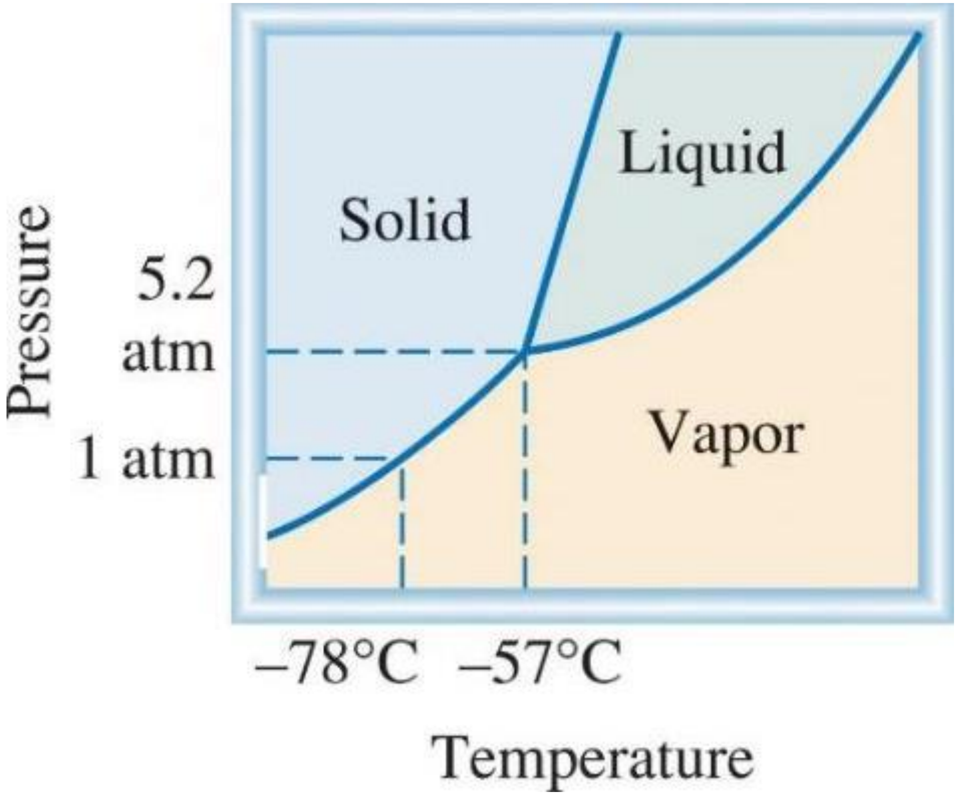


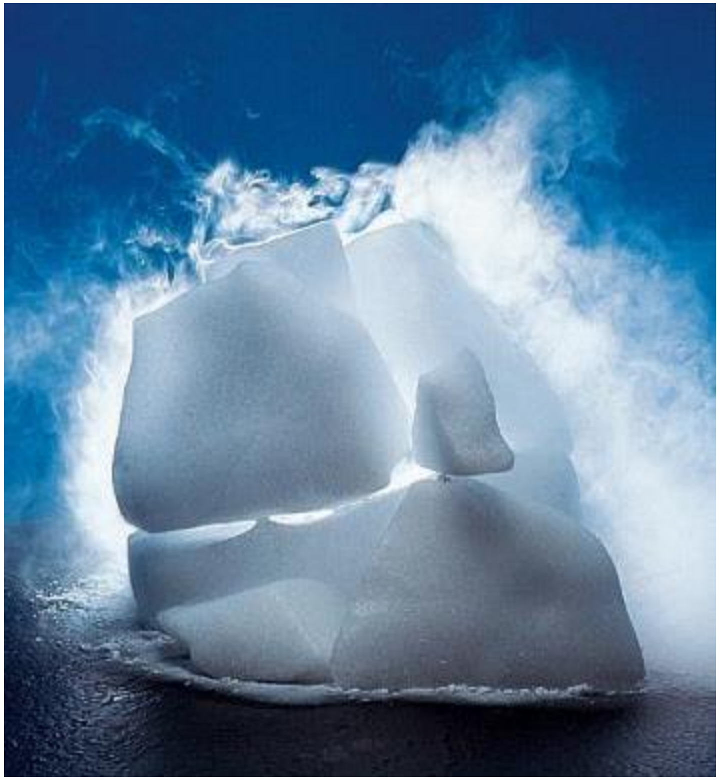
FIGURE 10.33

- The immense pressures beneath glaciers result in partial melting to produce a layer of water that provides lubrication to assist glacial movement. This satellite photograph shows the advancing edge of the Perito Moreno glacier in Argentina. (credit: NASA)

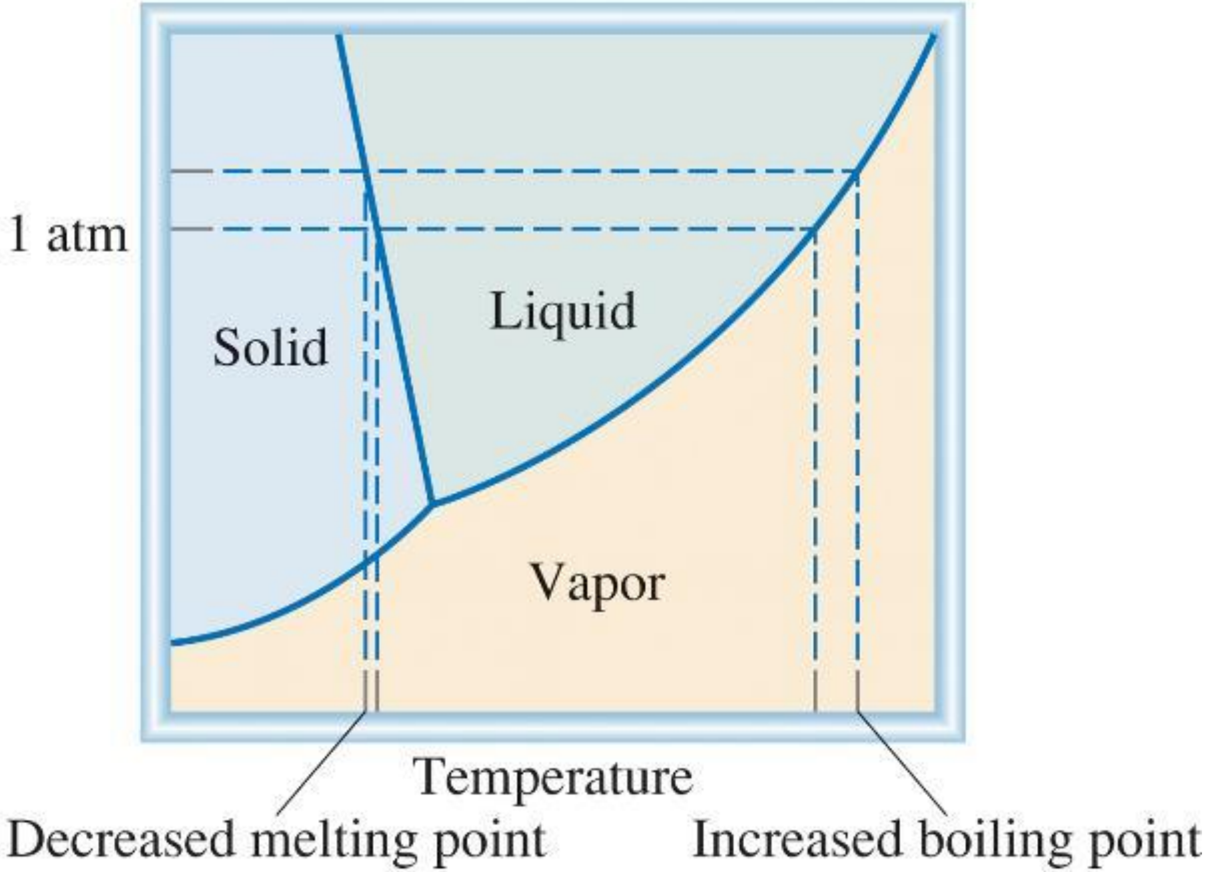
PHASE DIAGRAM OF CO_2

- At 1 atm CO_2 (*s*) → CO_2 (*g*)





P VS BP AND MP



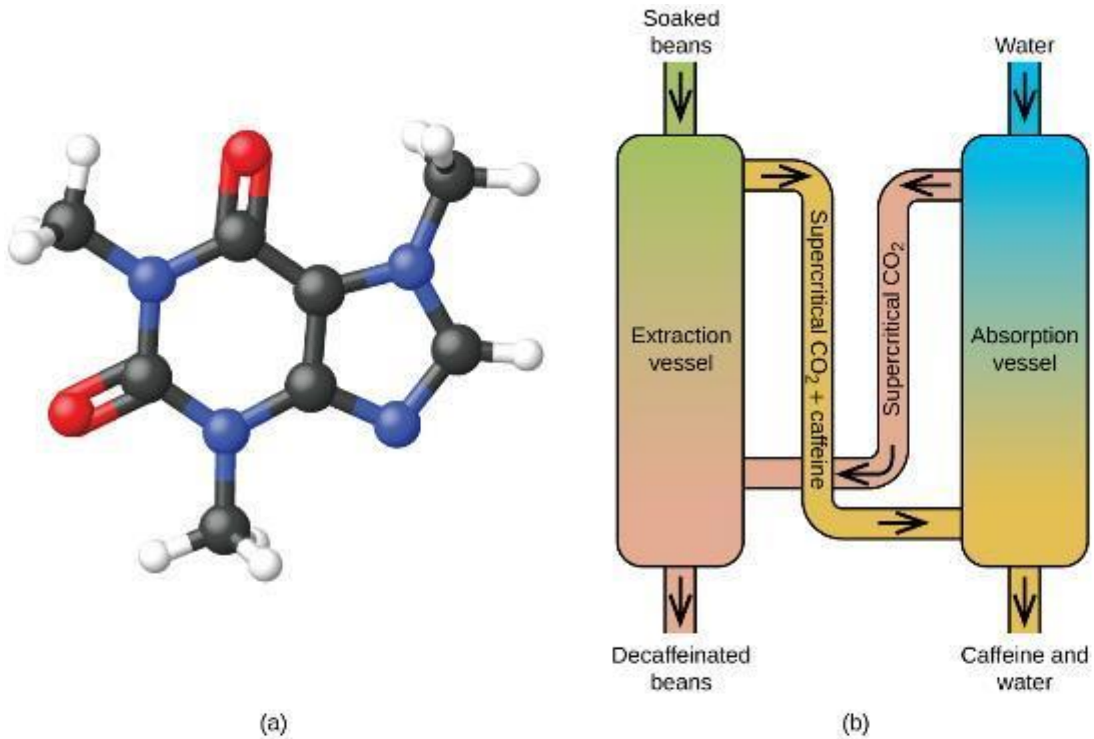
1 atm
Solid
Liquid
Vapor
Temperature
Decreased melting point
Increased boiling point

CRITICAL T AND P

- The *critical temperature* (T_c) is the temperature above which the gas cannot be made to liquefy, no matter how great the applied pressure.
- The *critical pressure* (P_c) is the minimum pressure that must be applied to bring about liquefaction at the critical temperature.

Substance	T_c (°C)	P_c (atm)
Ammonia (NH_3)	132.4	111.5
Argon (Ar)	−186	6.3
Benzene (C_6H_6)	288.9	47.9
Carbon dioxide (CO_2)	31.0	73.0
Diethyl ether ($C_2H_5OC_2H_5$)	192.6	35.6
Ethanol (C_2H_5OH)	243	63.0
Mercury (Hg)	1462	1036
Methane (CH_4)	−83.0	45.6
Molecular hydrogen (H_2)	−239.9	12.8
Molecular nitrogen (N_2)	−147.1	33.5
Molecular oxygen (O_2)	−118.8	49.7
Sulfur hexafluoride (SF_6)	45.5	37.6
Water (H_2O)	374.4	219.5

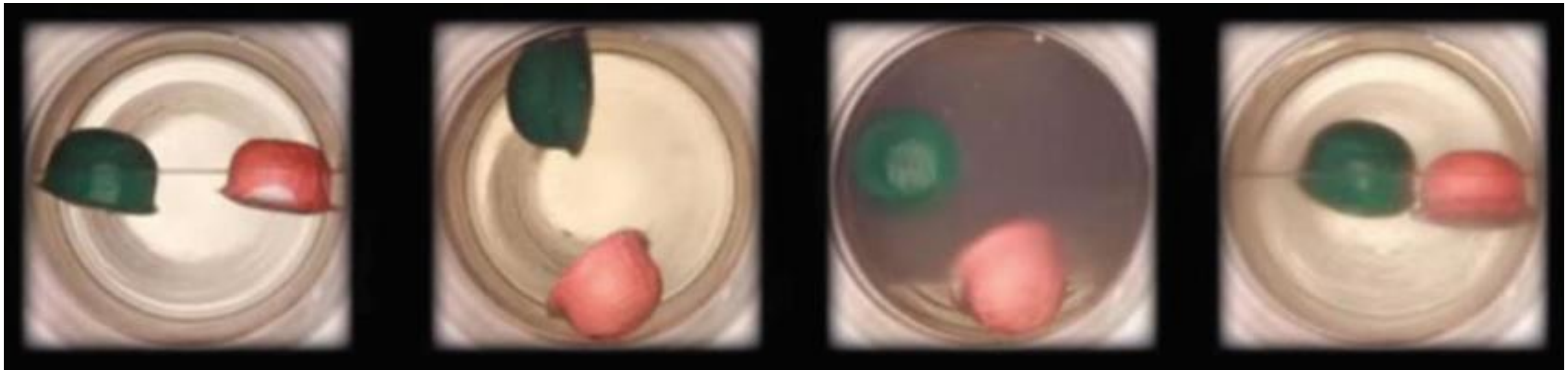
FIGURE 10.36



(a) Caffeine molecules have both polar and nonpolar regions, making it soluble in solvents of varying polarities.

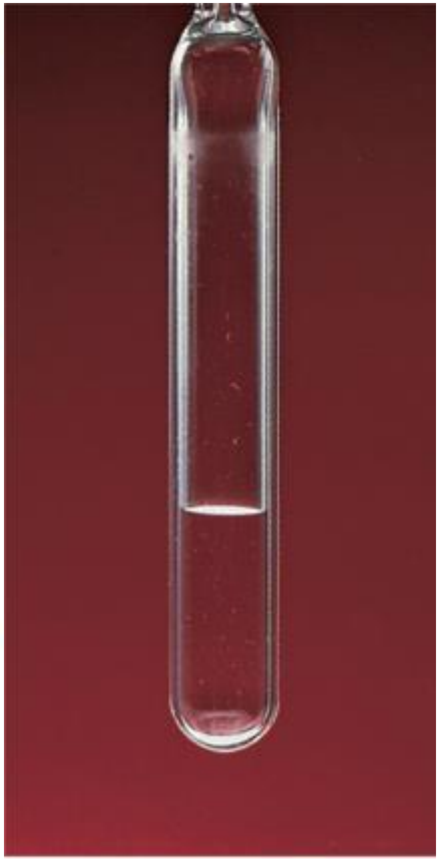
(b) The schematic shows a typical decaffeination process involving supercritical carbon dioxide.

FIGURE 10.35



- (a) A sealed container of liquid carbon dioxide slightly below its critical point is heated, resulting in (b) the formation of the supercritical fluid phase. Cooling the supercritical fluid lowers its temperature and pressure below the critical point, resulting in the reestablishment of separate liquid and gaseous phases (c and d). Colored floats illustrate differences in density between the liquid, gaseous, and supercritical fluid states. (credit: modification of work by “mrmrobin”/YouTube)

CRITICAL PHENOMENON OF SF_6



$T < T_c$

$T > T_c$

$T \sim T_c$

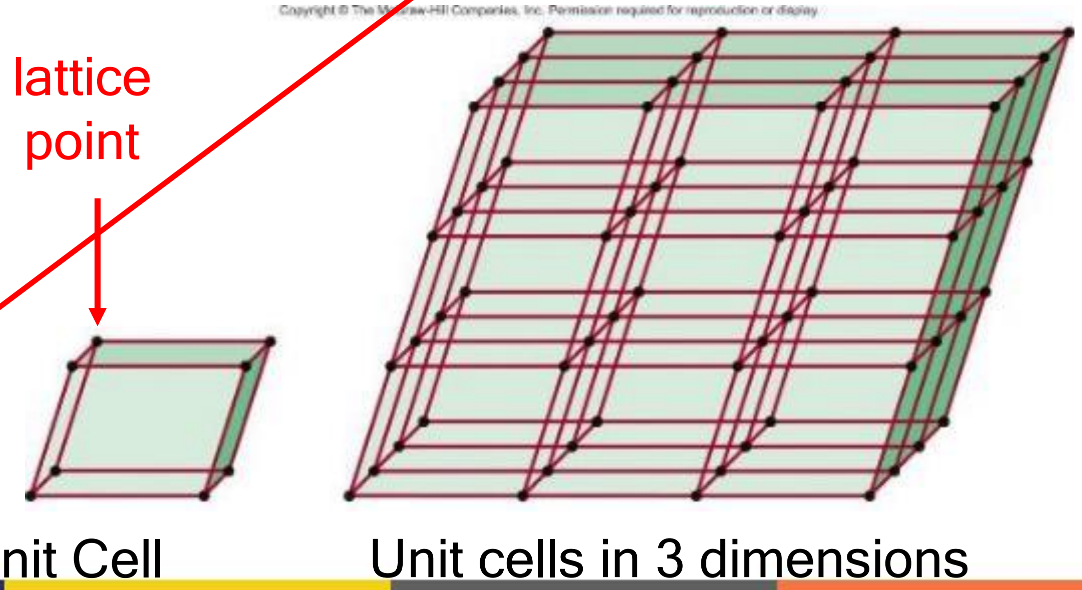
$T < T_c$

CH. 10 OUTLINE

- 10.1 Intermolecular Forces
- 10.2 Properties of Liquids
- 10.3 Phase Transitions
- 10.4 Phase Diagrams
- ~~10.5 The Solid Phase of Matter~~
- ~~10.6 Lattice Structures in Crystalline Solids~~

SOLIDS

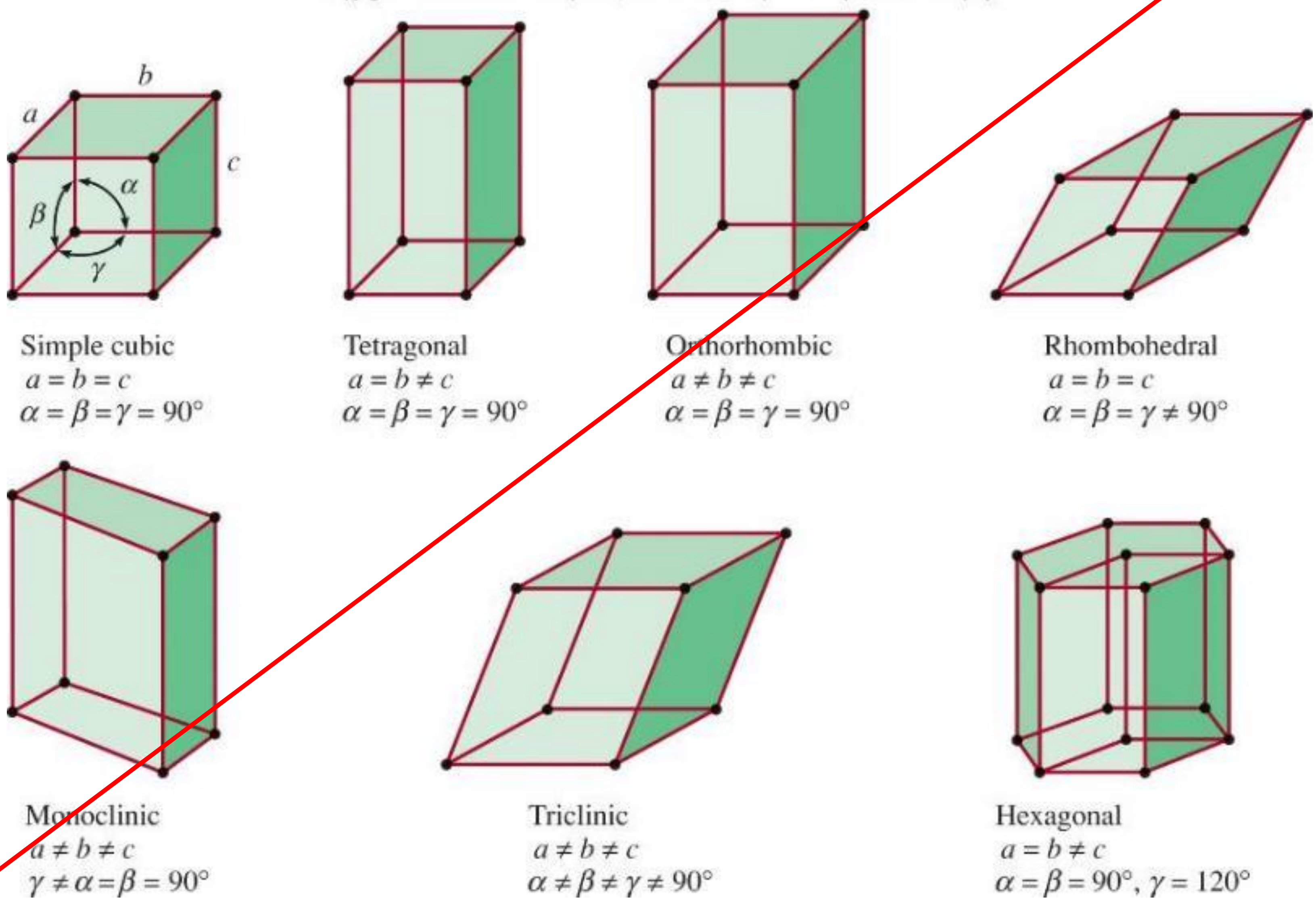
- A CRYSTALLINE SOLID possesses rigid and long-range order. In a crystalline solid, atoms, molecules or ions occupy specific (predictable) positions.
- An AMORPHOUS SOLID does not possess a well-defined arrangement and long-range molecular order.
- A UNIT CELL is the basic repeating structural unit of a crystalline solid.

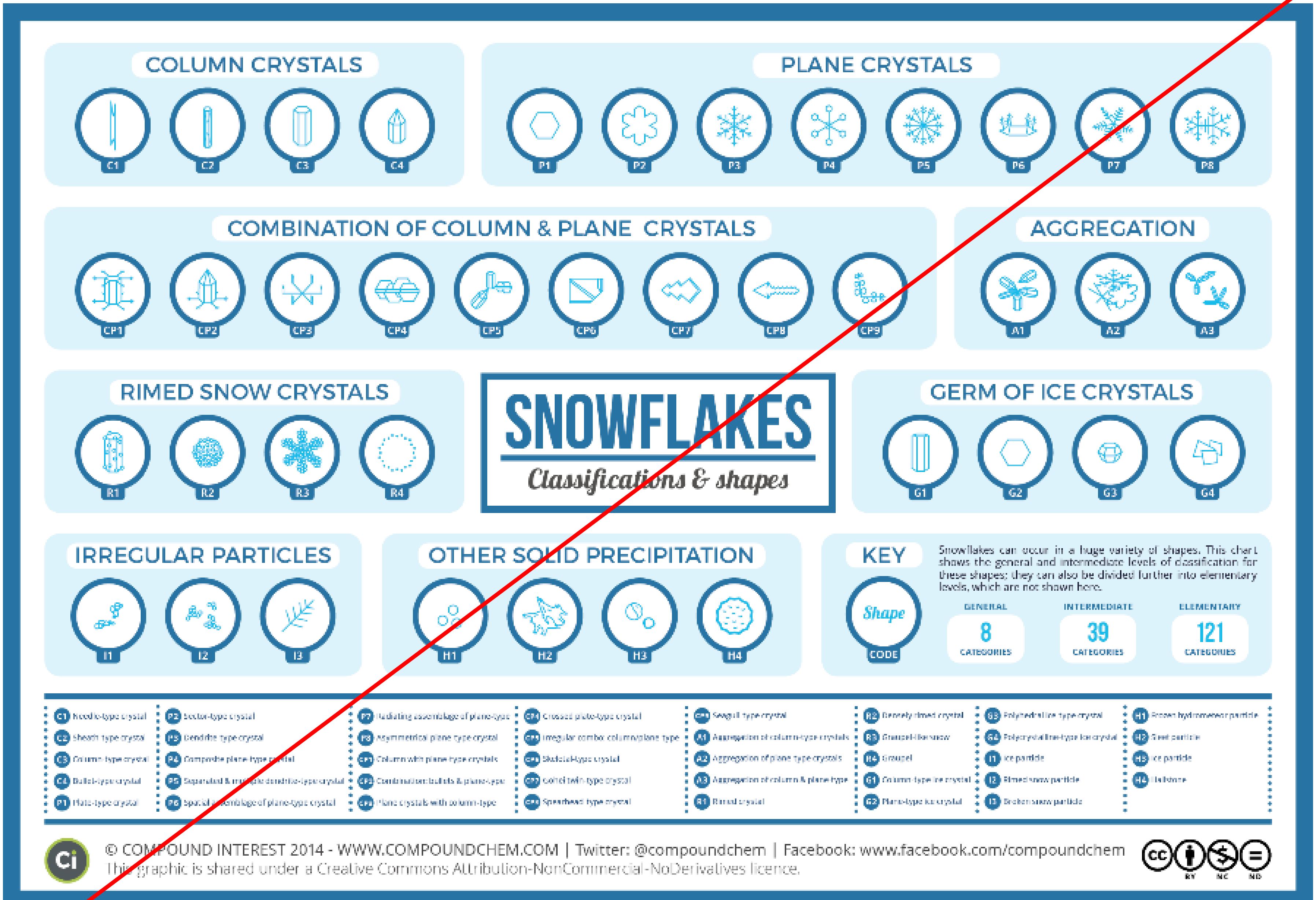


At lattice points:

- Atoms
- Molecules
- Ions

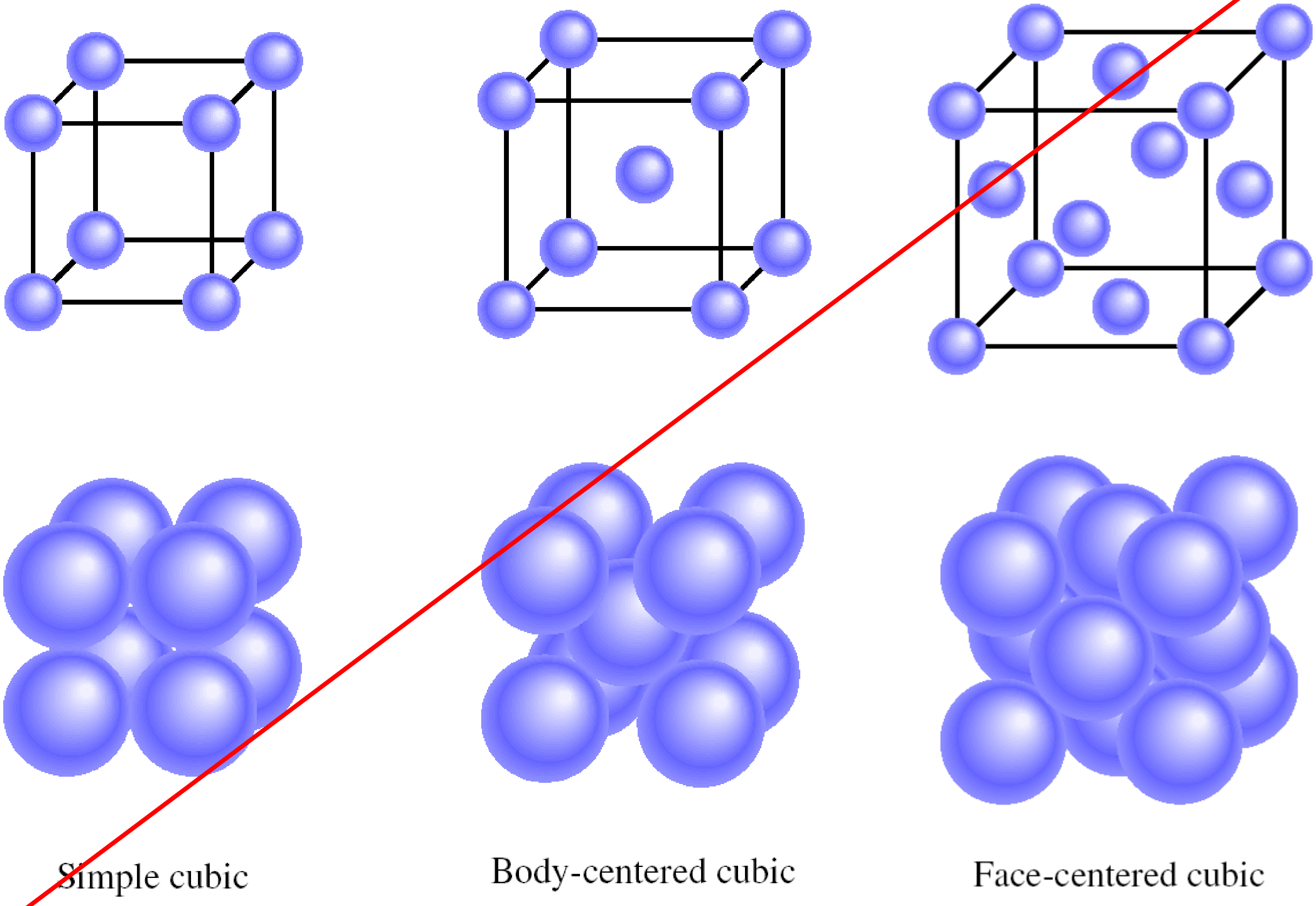
SEVEN BASIC TYPES OF UNIT CELLS



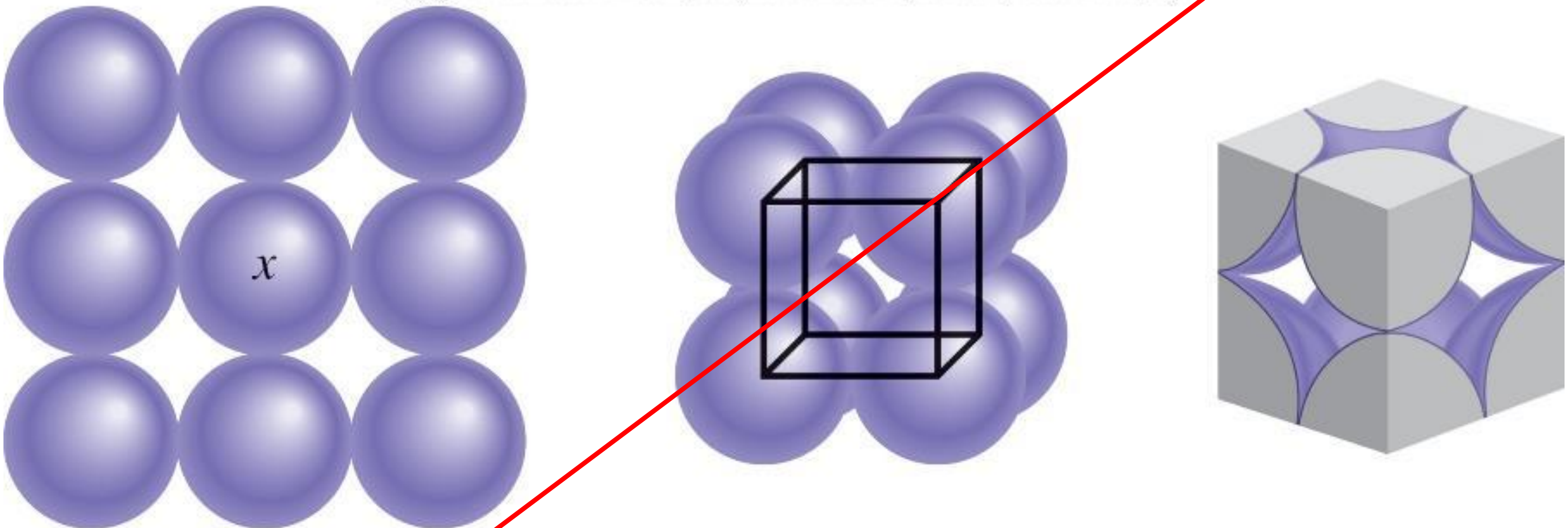


http://www.compoundchem.com/2014/12/10/snowflakes/

THREE SUB-TYPES OF CUBIC UNIT CELLS

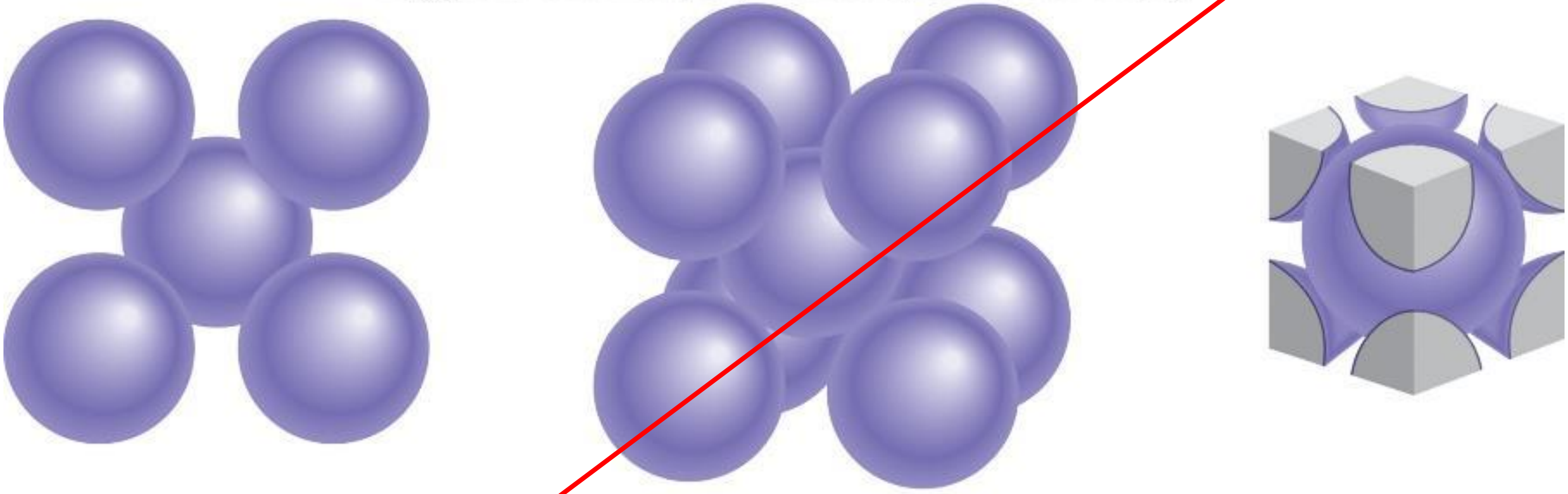


SIMPLE CUBIC UNIT CELLS



(a) (b) (c)

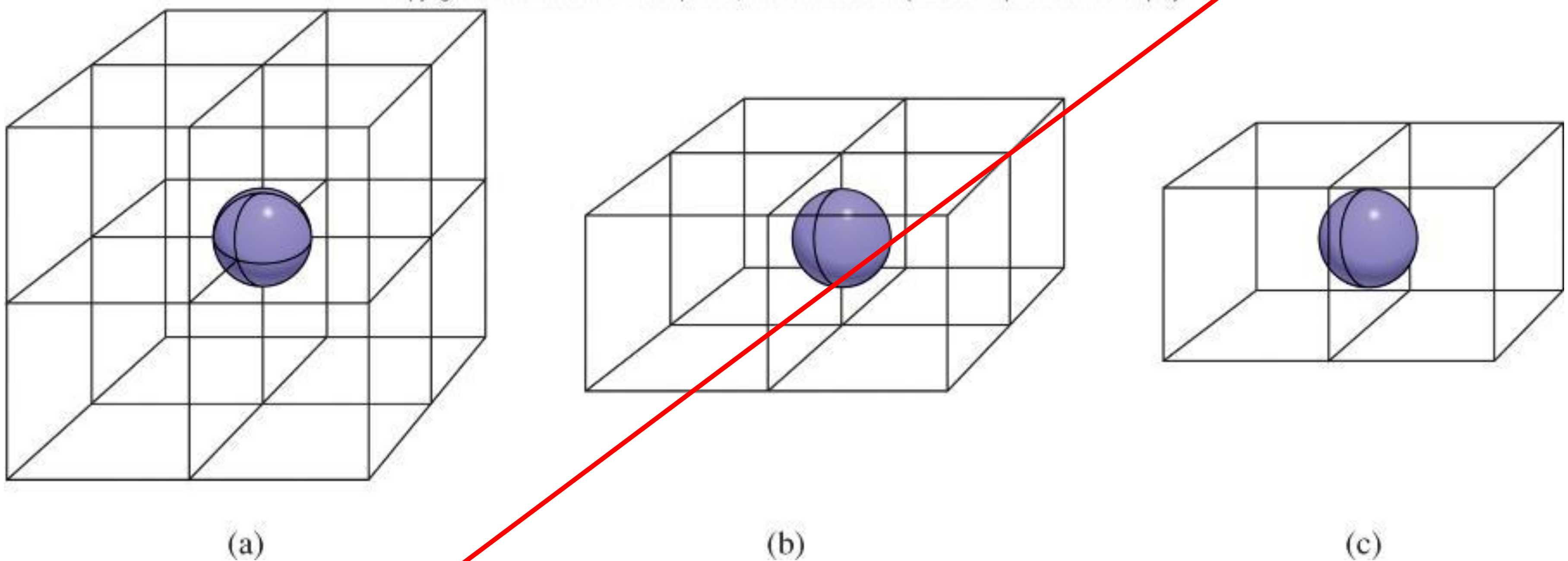
BODY-CENTERED CUBIC (BCC) UNIT CELLS



(a) (b) (c)

ATOMIC POSITIONS IN CELLS

- Corner, edge-centered and face-centered atoms

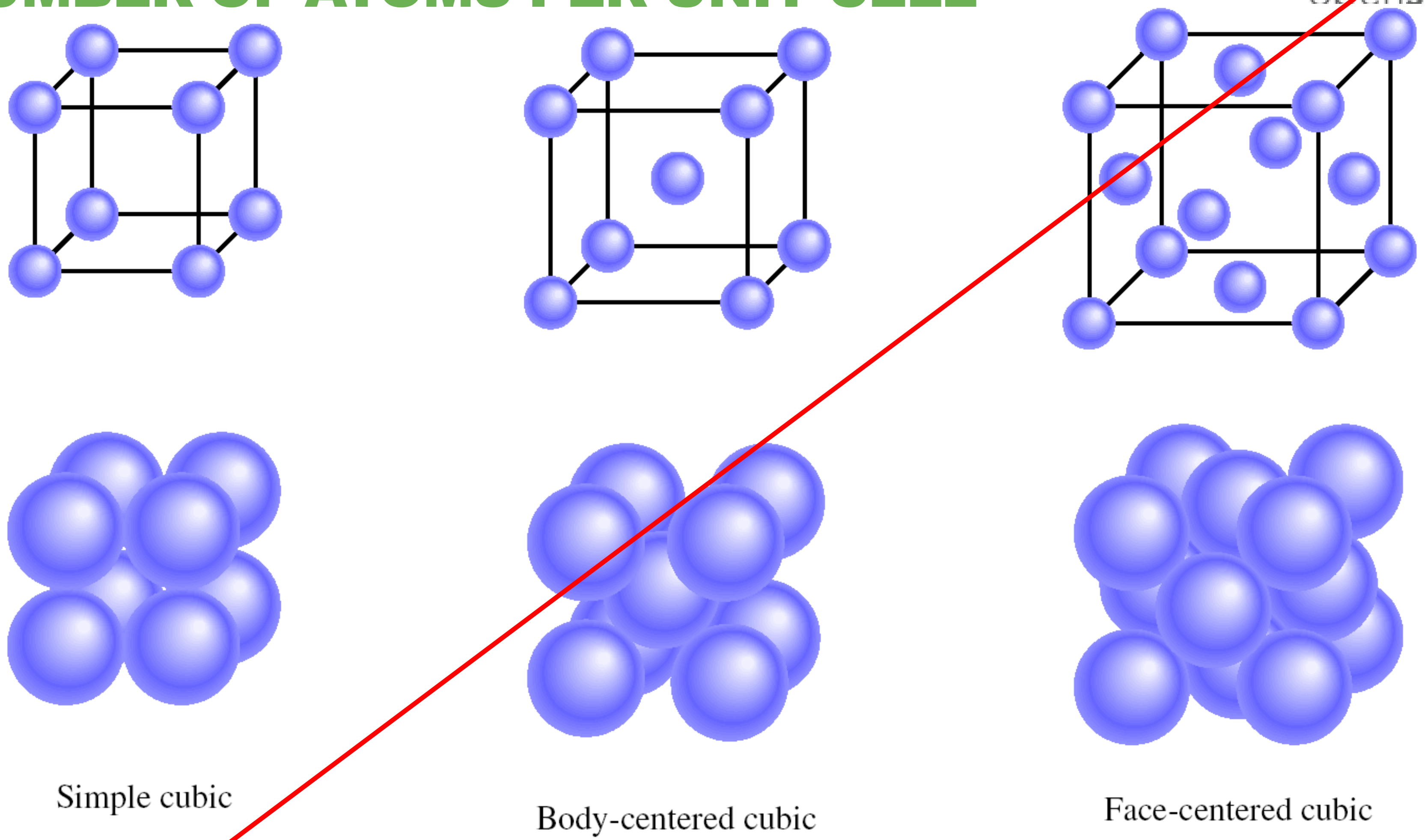


Shared by 8 unit cells

Shared by 4 unit cells

Shared by 2 unit cells

NUMBER OF ATOMS PER UNIT CELL

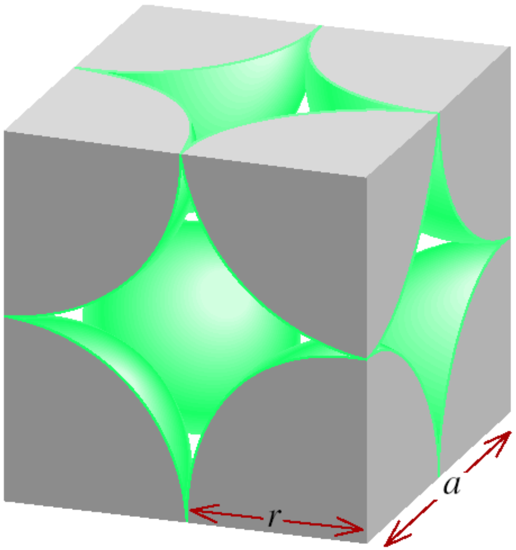


1 atom/unit cell (8 x 1/8 = 1)

2 atoms/unit cell (8 x 1/8 + 1 = 2)

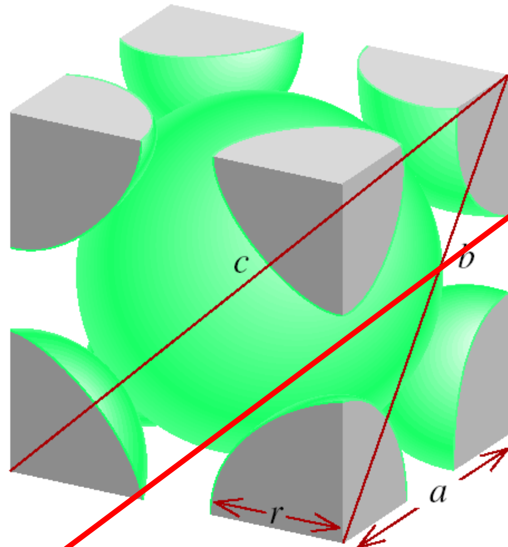
4 atoms/unit cell (8 x 1/8 + 6 x 1/2 = 4)

EDGE LENGTH VS. ATOMIC RADIUS



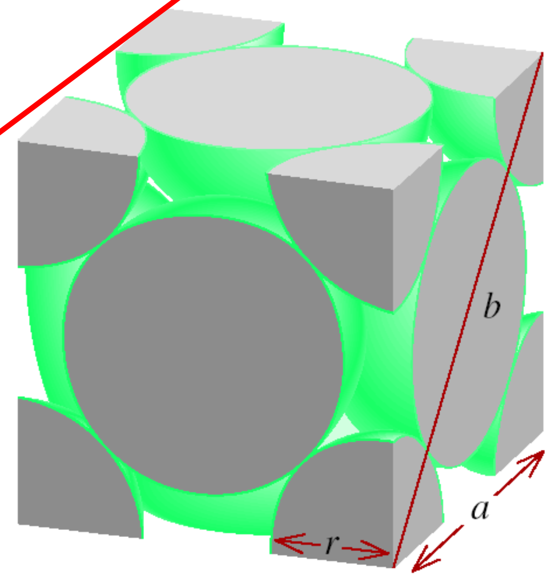
scc

$$a = 2r$$



bcc

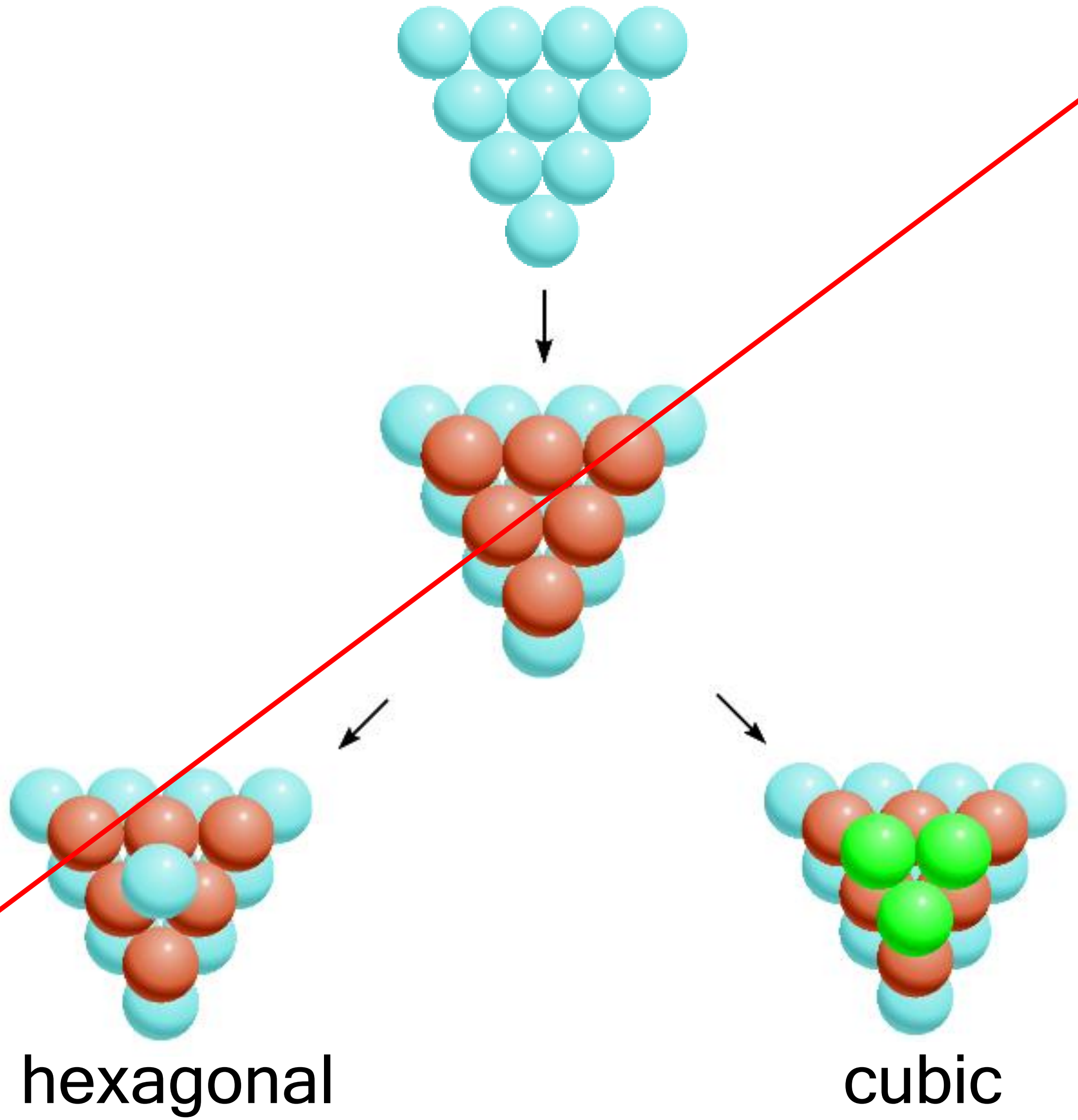
$$\begin{aligned} b^2 &= a^2 + a^2 \\ c^2 &= a^2 + b^2 \\ &= 3a^2 \\ c &= \sqrt{3}a = 4r \\ a &= \frac{4r}{\sqrt{3}} \end{aligned}$$



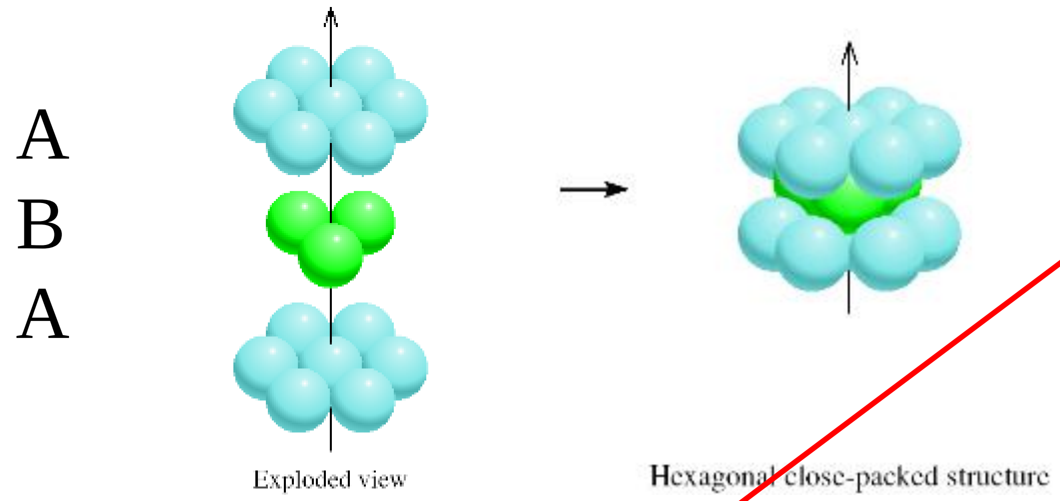
fcc

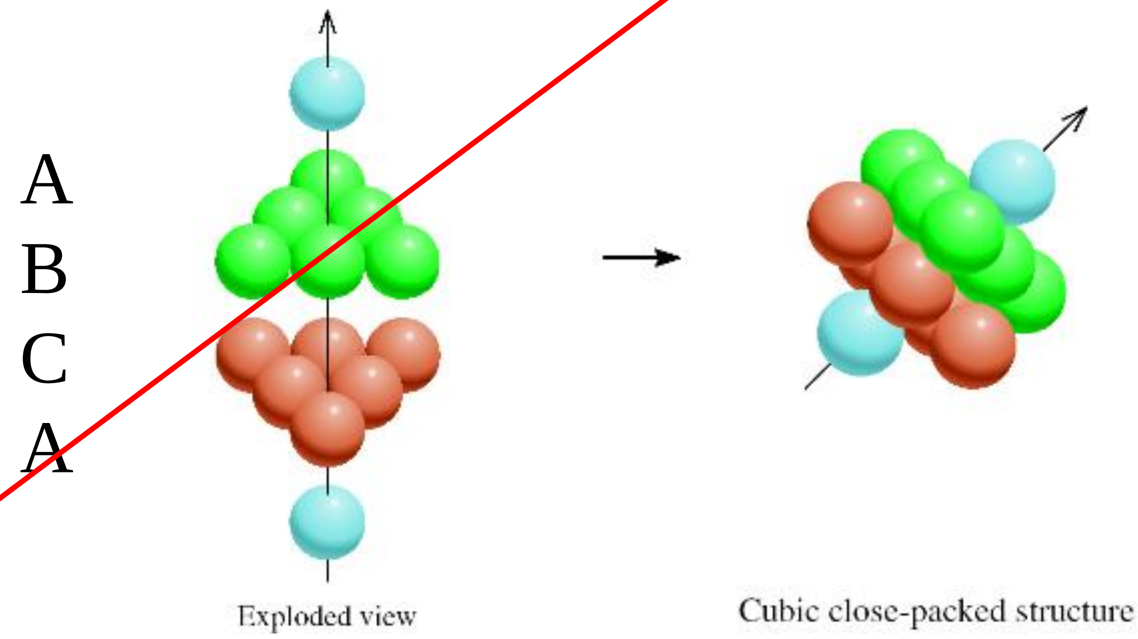
$$\begin{aligned} b &= 4r \\ b^2 &= a^2 + a^2 \\ 16r^2 &= 2a^2 \\ a &= \sqrt{8}r \end{aligned}$$

HEXAGONAL AND CUBIC CLOSE PACKING



HCP AND CCC (CONT'D)





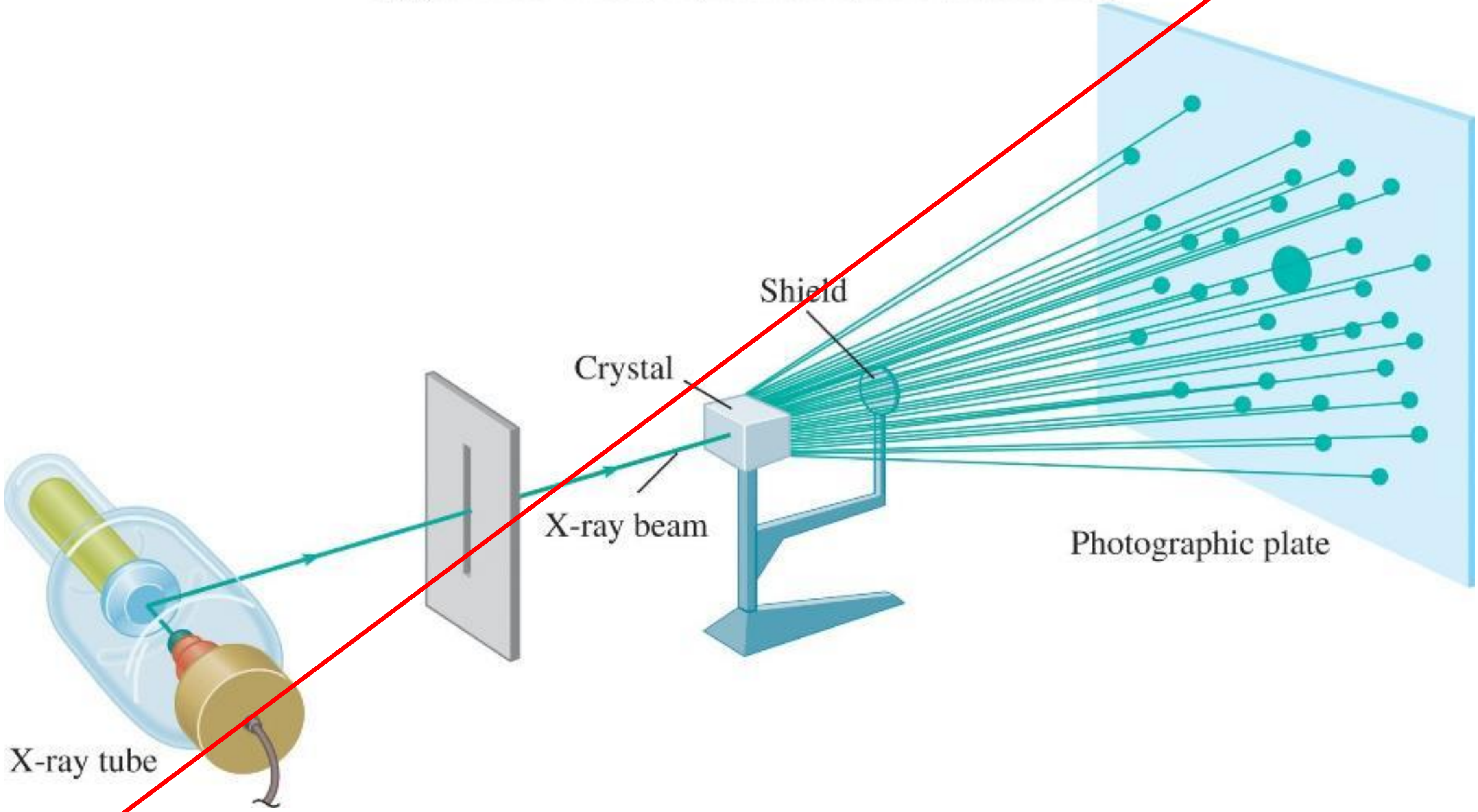
CHEMISTRY 151 - KOLACK

Chapter 11

Sections 11.5 – 11.7

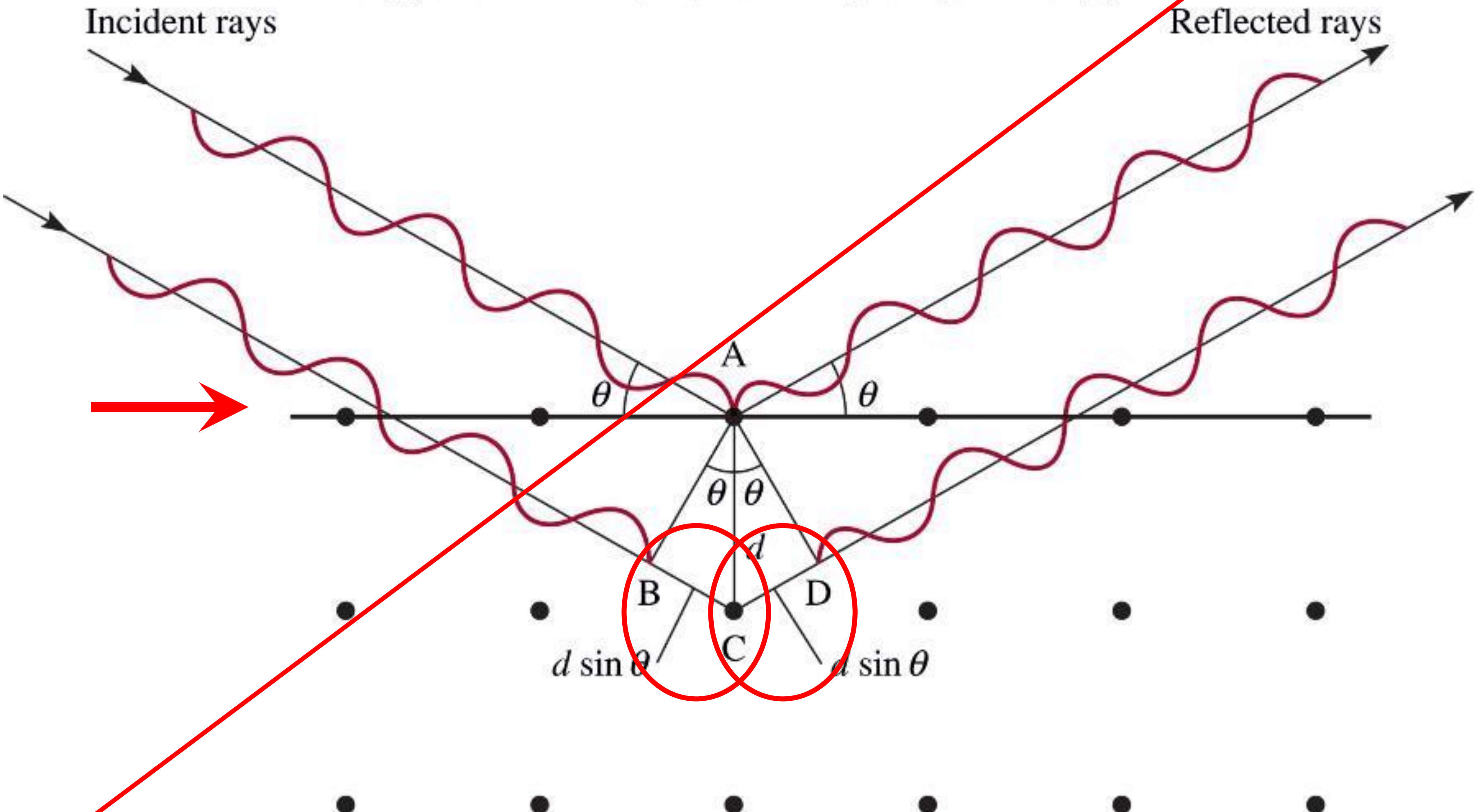
Intermolecular Forces – Liquids and Solids

X-RAY DIFFRACTION



X-RAY DIFFRACTION (CONT'D)

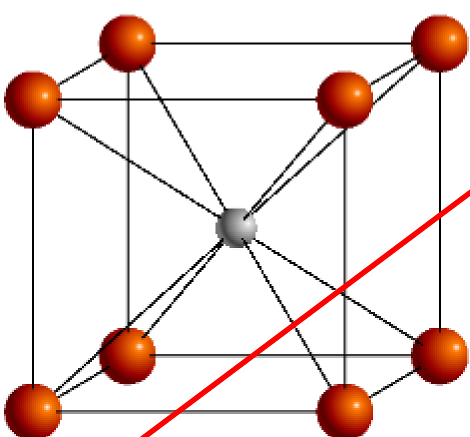
Reflection of X-rays from two layers of atoms



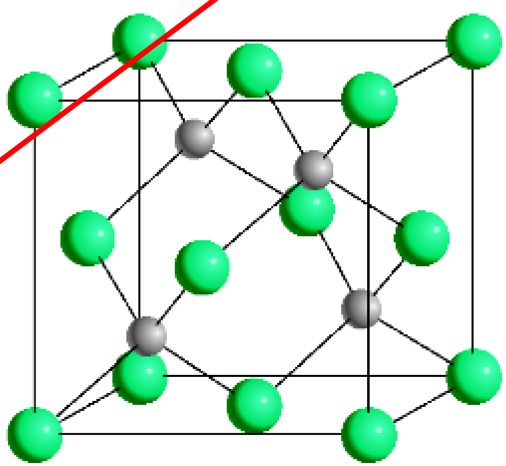
Extra distance = $BC + CD = 2d \sin\theta = n\lambda$ (Bragg Equation)

TYPES OF CRYSTALS – IONIC

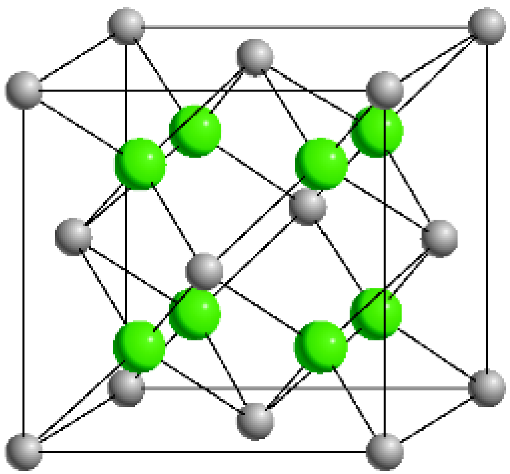
- Lattice points occupied by cations and anions
- Held together by electrostatic attraction
- Hard, brittle, high melting point
- Poor conductor of heat and electricity



$CsCl$



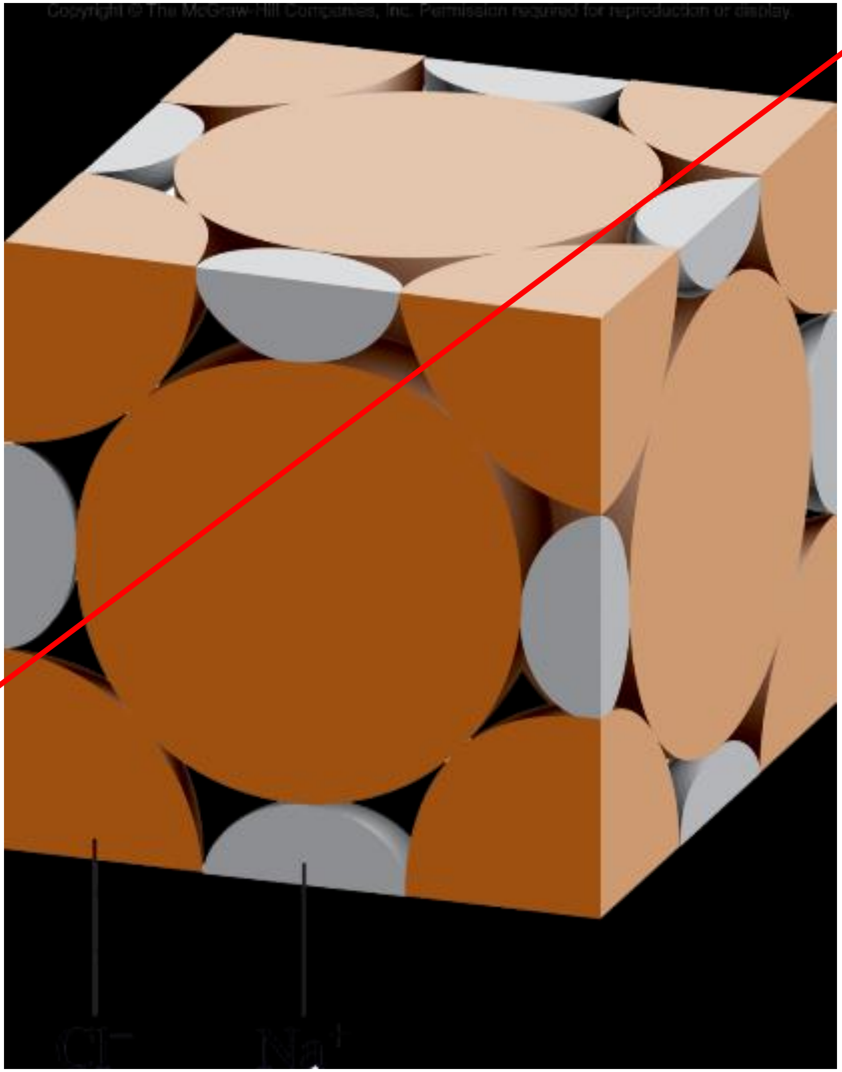
ZnS



CaF_2

QUESTION

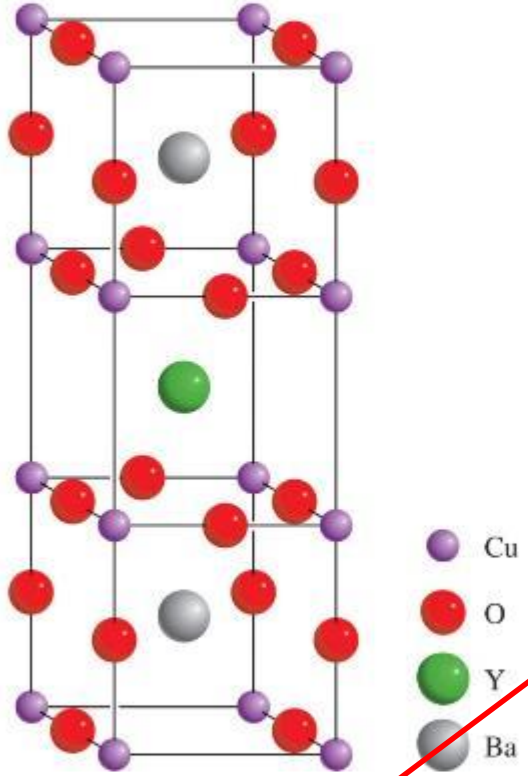
- How many Na^+ and Cl^- ions are in each NaCl unit cell?

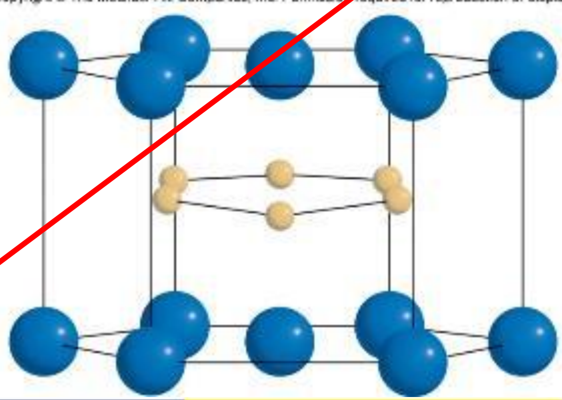


ANSWER

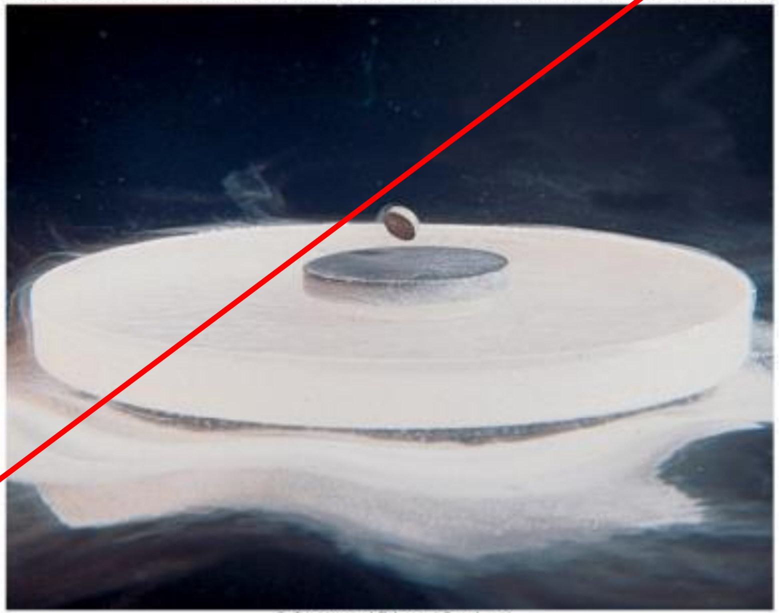
- ***Solution*** NaCl has a structure based on a face-centered cubic lattice. One whole Na^+ ion is at the center of the unit cell, and there are twelve Na^+ ions at the edges. Because each edge Na^+ ion is shared by four unit cells, the total number of Na^+ ions is $1 + (12 \times \frac{1}{4}) = 4$.
- Similarly, there are six Cl^- ions at the face centers and eight Cl^- ions at the corners. Each face-centered ion is shared by two unit cells, and each corner ion is shared by eight unit cells, so the total number of Cl^- ions is $(6 \times \frac{1}{2}) + (8 \times 1/8) = 4$. Thus, there are four Na^+ ions and four Cl^- ions in each NaCl unit cell.
- ***Check*** This result agrees with sodium chloride's empirical formula.

SUPERCONDUCTORS





MgB_2



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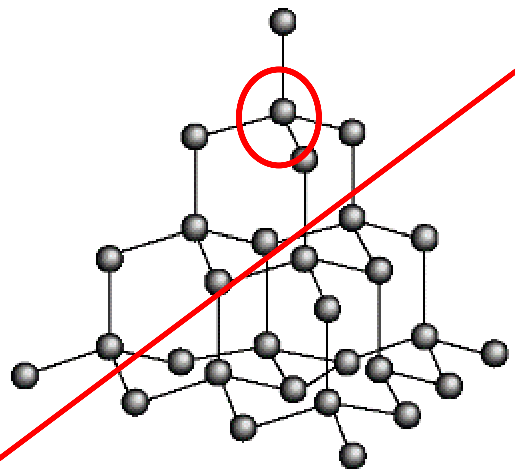
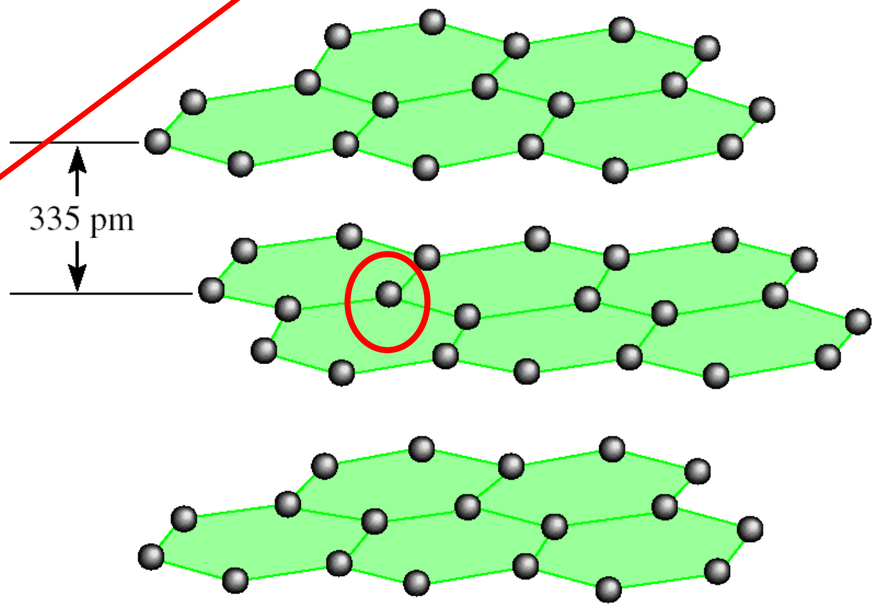
COVALENT CRYSTALS

- Lattice points occupied by atoms
- Held together by covalent bonds
- Hard, high melting point
- Poor conductors of heat and electricity

carbon atoms



diamond

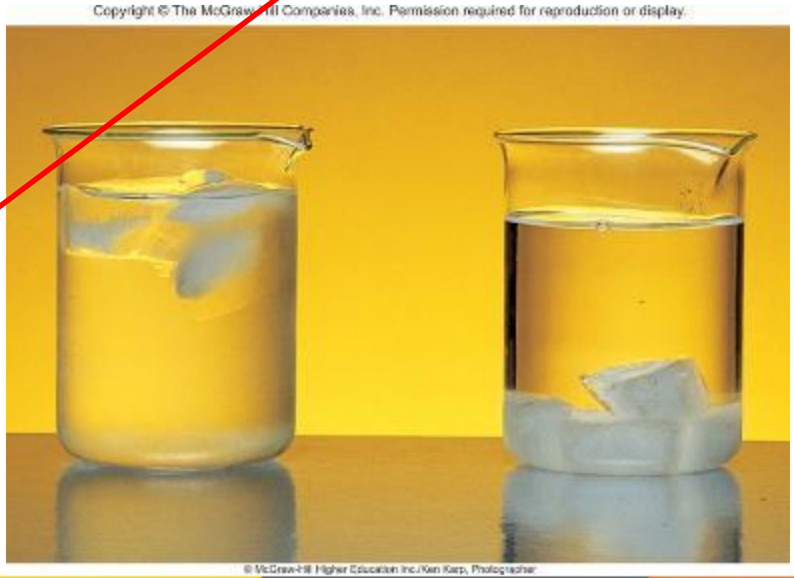


graphite

MOLECULAR CRYSTALS

- Lattice points occupied by molecules
- Held together by intermolecular forces
- Soft, low melting point
- Poor conductors of heat and electricity

water



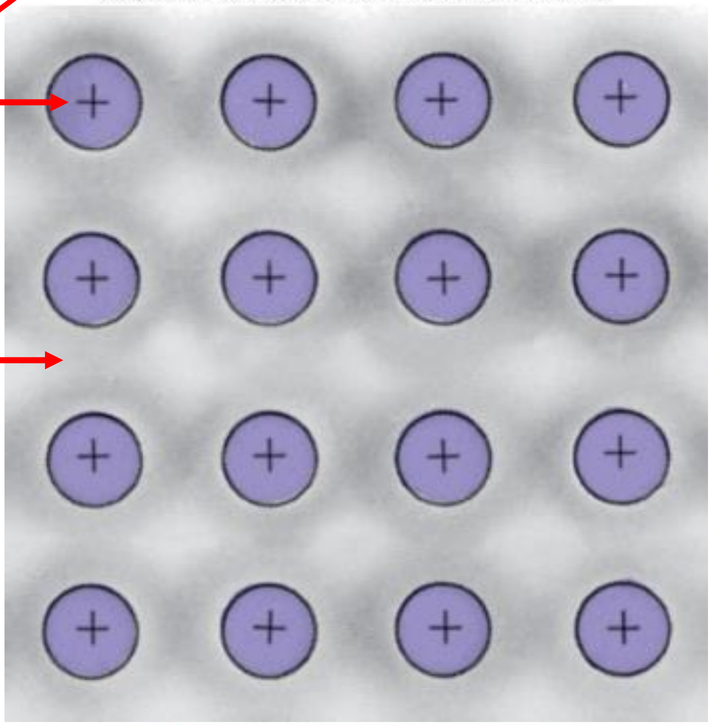
benzene

METALLIC CRYSTALS

- Lattice points occupied by metal atoms
- Held together by metallic bonds
- Soft to hard, low to high melting point
- Good conductors of heat and electricity

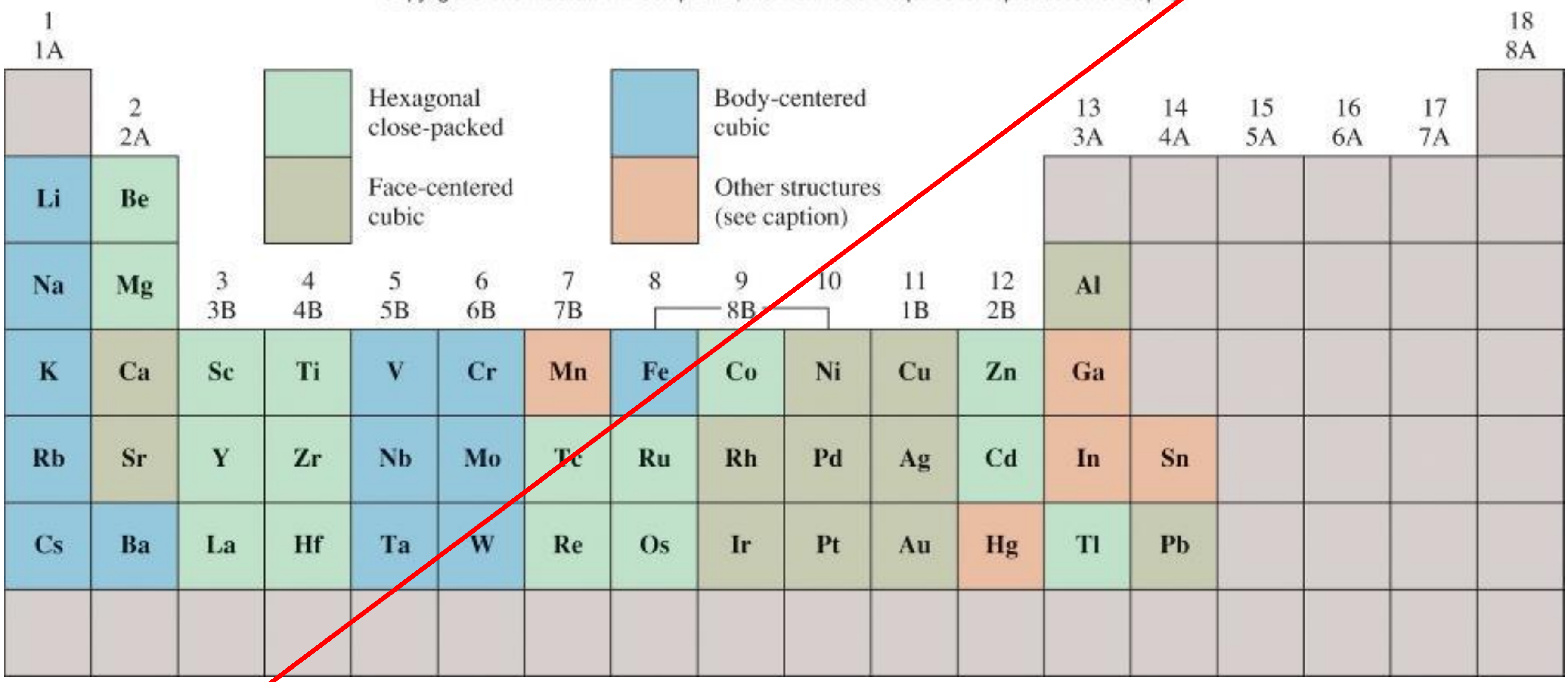
nucleus & inner shell e^-

mobile "sea" of e^-



CRYSTAL STRUCTURES OF METALS

openstax COLLEGE



CRYSTALS – A SUMMARY

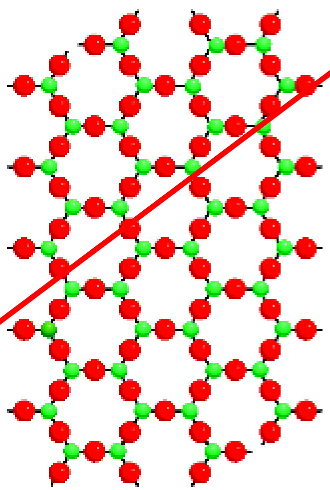
Table 11.4 Types of Crystals and General Properties

Type of Crystal	Force(s) Holding the Units Together	General Properties	Examples
Ionic	Electrostatic attraction	Hard, brittle, high melting point, poor conductor of heat and electricity	NaCl, LiF, MgO, $CaCO_3$
Covalent	Covalent bond	Hard, high melting point, poor conductor of heat and electricity	C (diamond),† SiO_2 (quartz)
Molecular*	Dispersion forces, dipole-dipole forces, hydrogen bonds	Soft, low melting point, poor conductor of heat and electricity	Ar, CO_2, I_2, H_2O, $C_{12}H_{22}O_{11}$ (sucrose)
Metallic	Metallic bond	Soft to hard, low to high melting point, good conductor of heat and electricity	All metallic elements; for example, Na, Mg, Fe, Cu

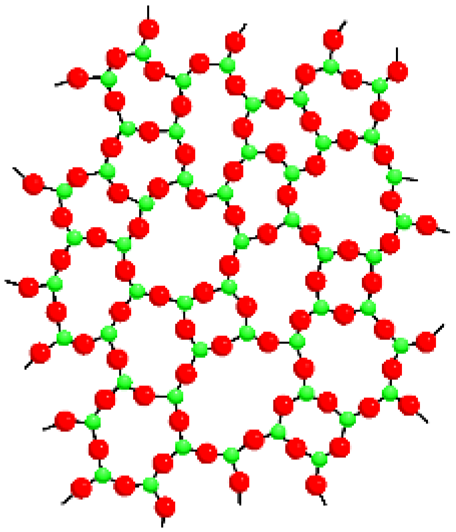
*Included in this category are crystals made up of individual atoms.
†Diamond is a good thermal conductor.

AMORPHOUS SOLIDS AND GLASSES

- An amorphous solid does not possess a well-defined arrangement and long-range molecular order.
- A glass is an optically transparent fusion product of inorganic materials that has cooled to a rigid state without crystallizing



Crystalline quartz (SiO_2)



Non-crystalline quartz glass

Chapter 10 LIQUIDS AND SOLIDS

HW problems:

2, 11, 13, 17, 21, 25, 31, 43, 51, 58, 63, 65, 69