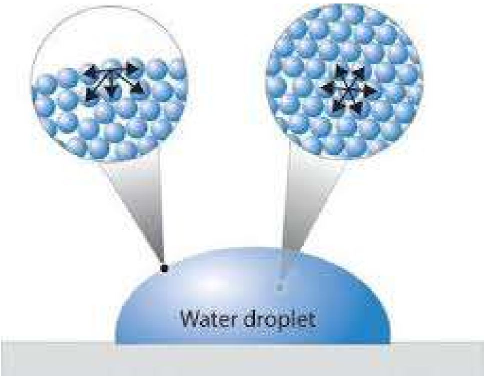
Module 7: Intermolecular Forces -Properties of Liquids – Lecture 2

Learning Objective	Openstax 2e Chapter
Hydrogen Bonding	10.1
Properties of Liquids	10.2

Suggested Practice Problems

Chapter 10 Exercises – Questions: 23, 27

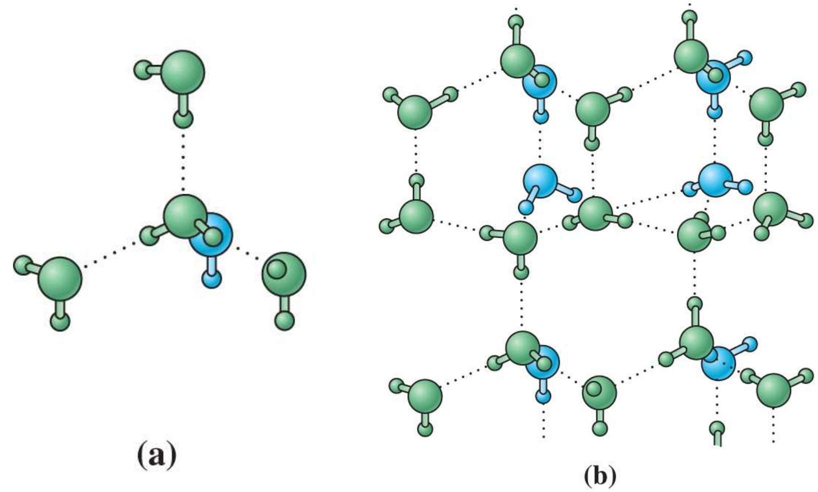
Answers can be found in the Chapter 10 Answer Key



Hydrogen Bonding in Water

(a) Each water molecule is linked to four others through hydrogen bonds. The arrangement is tetrahedral. Each H atom is situated along a line joining two O atoms, but closer to one O atom (100 pm) than to the other (180 pm).

(b) For the crystal structure of ice, H atoms lie between pairs of O atoms, closer to one O atom than to the other. (Molecules behind the plane of the page are light blue.) O atoms are arranged in bent hexagonal rings arranged in layers. This characteristic pattern is similar to the hexagonal shapes of most snowflakes.



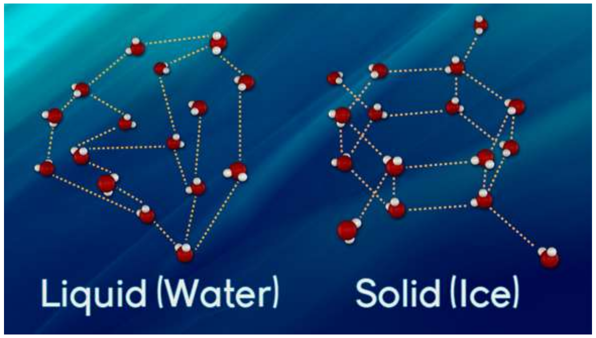
Snowflakes

[Short video discussing at least 17 forms of ice]

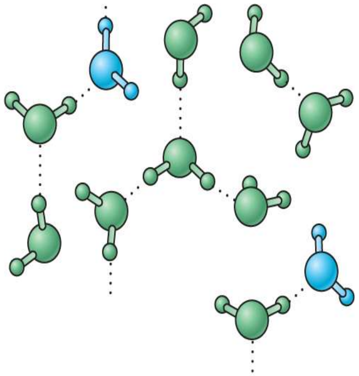
More on this later…

c) Water is less dense in its solid form than its liquid.

- weak hydrogen bonds between liquid water molecules constantly form and break, so the molecules are randomly distributed;
- when water freezes, the bonds form rigid lattices with each water molecule bonded to four others. These lattices contain relatively large gaps, which would be filled with atoms if the water were liquid.



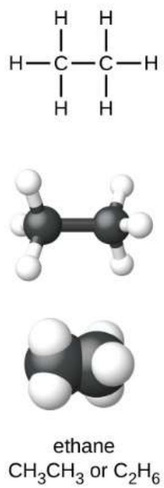
d) In liquid phase, water molecules have hydrogen bonds only to some of their neighbors. Water molecules pack ~ 10% more densely in the liquid than in the solid.



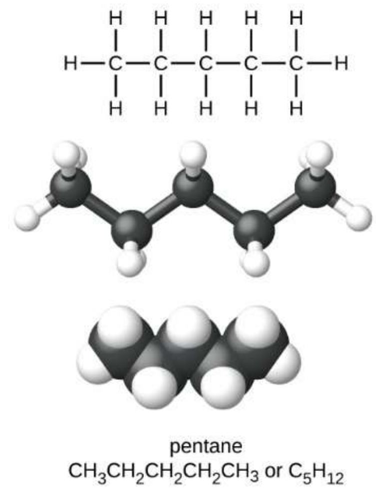
(c)

Boiling Point Trends - assessment

B.P. −162 °C



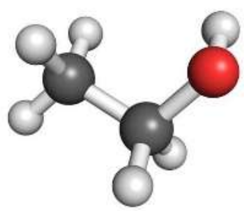
B.P. −89 °C



B.P. 36 °C

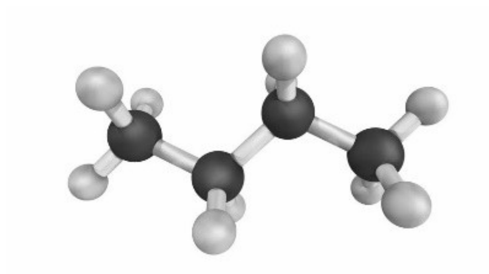
B.P. and M.P. of some alkanes

Name of alkane	Melting point (°C)	Boiling point (°C)
methane	−182	−162
ethane	−183	−89
propane	−187	−42
butane	−138	0.5
pentane	−130	36
hexane	−94	69
heptane	−90	98
octane	−57	125
nonane	−54	150
decane	−30	174



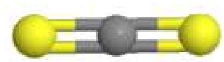
ethanol

B.P. 78 °C



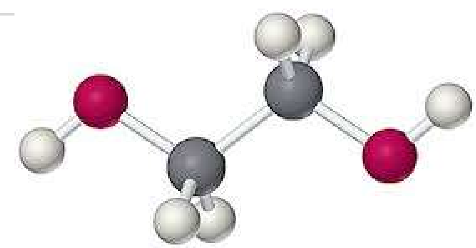
butane

B.P. −1 °C



CS_2

B.P. 46 °C

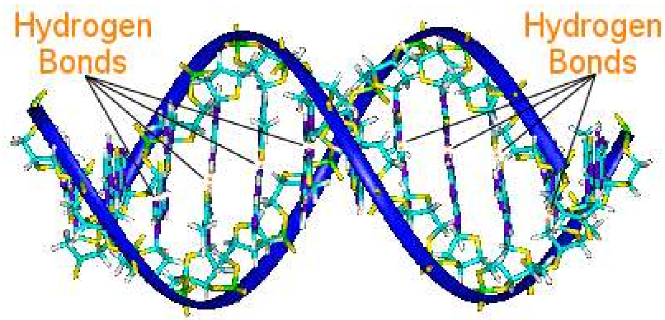


ethylene glycol

B.P. 197 °C

H-Bonding: important for so many molecules… life

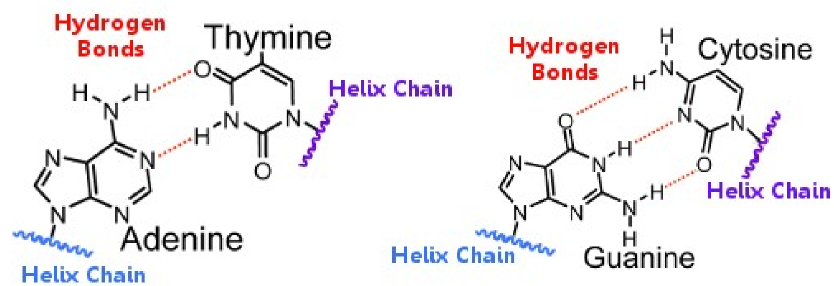
- Hydrogen bonds hold complementary strands of DNA together



DNA

Nucleotides pair precisely based on the position of an available hydrogen bond.

- Thymine has one donor and one acceptor site that pairs perfectly with the nucleotide adenine's complementary acceptor and donor site.
- Cytosine pairs perfectly with guanine through three hydrogen bonds.



A:T **G:C**

https://www.chemicool.com/examples/hydrogen-bonding.html

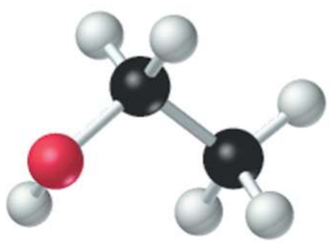
Other properties affected by H-Bonding

Viscosity

- The viscosity of a liquid can also be related to the intermolecular forces and to molar mass
- Higher molar mass means more viscous - higher "centipoise" (cP)
- Stronger intermolecular forces mean more viscous liquids since the molecules are "less free"
- Glycerol $C_3H_8O_3$ has three OH groups and therefore lots of hydrogen bonding

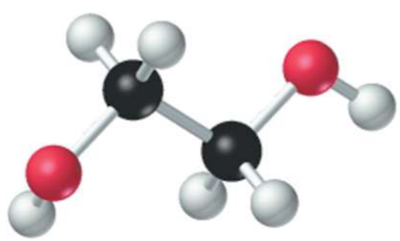
1 P = 0.1 Pa.s
= 0.1 $N.s.m^{-2}$
1 cP = 1 mPa.s

Substance	Viscosity (mPa·s)	Temp. (°C)
Water	1.00	20
Whole milk	2.12	20
Blood	2 - 9	37
Olive oil	56.2	26
Canola oil	46.2	30
Sunflower oil	48.8	26
Honey	≈2000-10,000	20



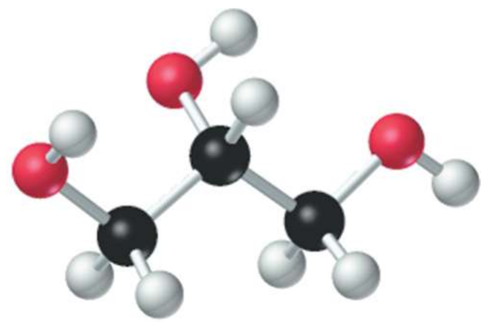
Ethyl alcohol
(ethanol)
at 20 °C: $\eta = 1.20$ cP

One hydroxyl



Ethylene glycol
(1,2-ethanediol)
at 20 °C: $\eta = 19.9$ cP

Two hydroxyls

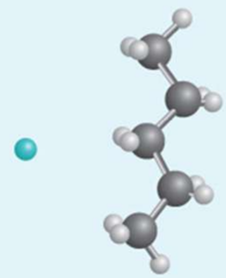
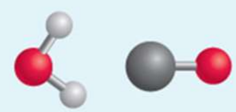
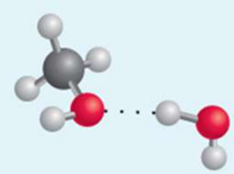


Glycerol
(1,2,3-propanetriol)
at 20 °C: $\eta = 1490$ cP

Three hydroxyls

Summary of Non-Covalent Interactions

TABLE 12.3 Summary of Noncovalent Interactions

Force	Energy,[a] kJ/mol	Example	Model
Intermolecular			
London dispersion	0.05–40	$CH_4 \cdots CH_4$	
Dipole–induced dipole	2–10	$CH_3(CO)CH_3 \cdots C_5H_{12}$	
Ion–induced dipole	3–15	$Li^+ \cdots C_5H_{12}$	
Dipole–dipole	5–25	$H_2O \cdots CO$	
Hydrogen bond	10–40	$CH_3OH \cdots H_2O$	

[a]These are gas phase values.

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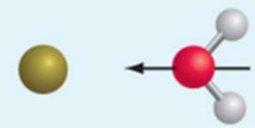
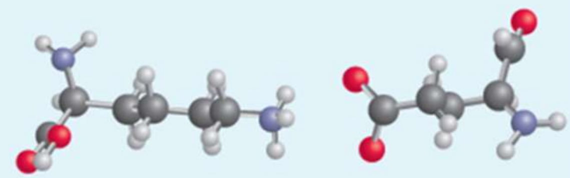
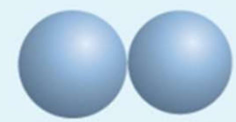
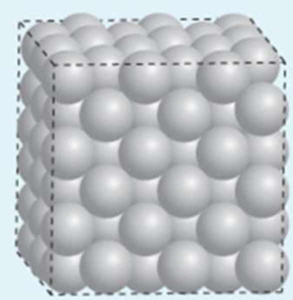
Summary of Non-Covalent Interactions cont.:

TABLE 12.3 Summary of Noncovalent Interactions

Force	Energy,[a] kJ/mol	Example	Model
Ion–dipole	40–600	$K^+ \cdots H_2O$	
Ion–ion	400–4000	$Lys^+ \cdots Glu^-$	
Interatomic			
London dispersion	0.05–40	$Ar \cdots Ar$	
Ion–ion	400–4000	$Na^+ \cdots Cl^-$	
Metallic	100–1000	$Ag \cdots Ag$	

[a]These are gas phase values.

Properties of Liquids

Cohesive Forces

Intermolecular forces between like molecules.

Adhesive Forces

Intermolecular forces between unlike molecules.

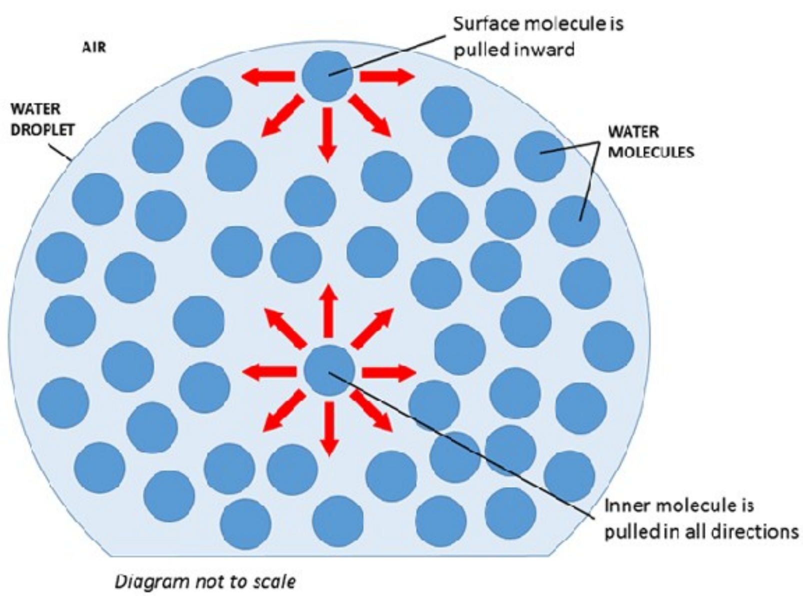
Surface Tension

Energy or work required to increase the surface area of a liquid.

Surface tension illustrated

Properties of Liquids- Surface Tension

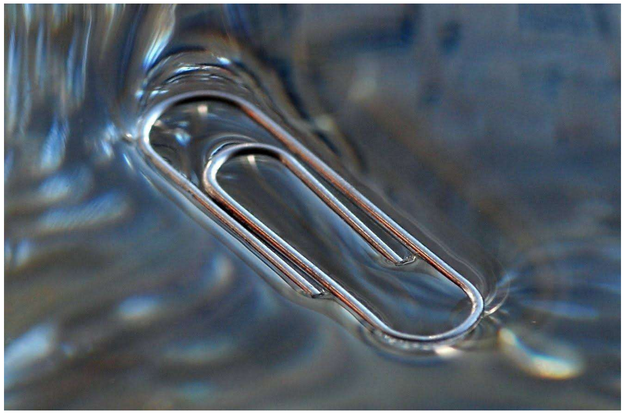
- Surface tension is caused by molecular attractions
- Interior molecules have more neighbors and experience more attractive intermolecular interactions than surface molecules
- Liquids tend to exhibit minimum surface area (i.e., a spherical shape)
- The surface behaves as if it were tightened into an elastic film



Strong intermolecular forces can lead to high surface tension

Surface tension is the energy needed to increase the surface area of a liquid. Units of J m^{-2}.

Consequences of Surface Tension



Steel is much denser than water, however, the paper clip can be supported by water surface tension

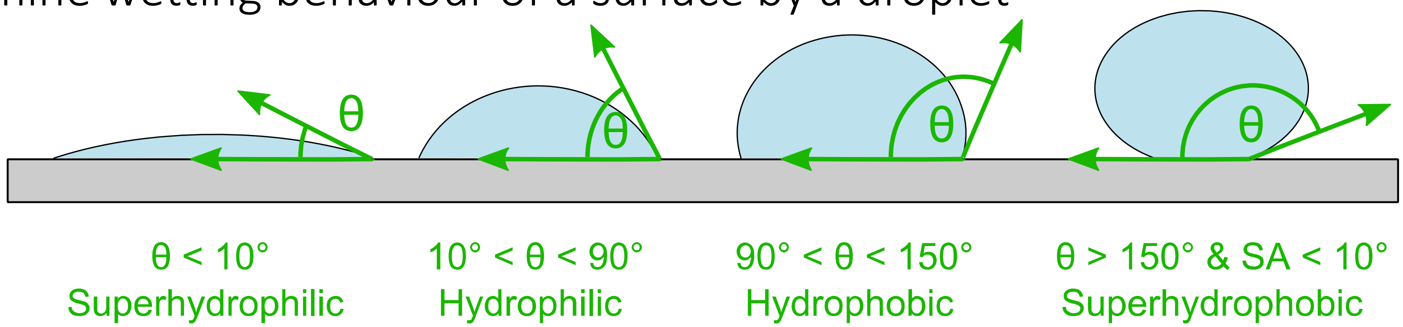
The potential energy of the 'water strider' as it sinks (from its mass) is balanced by the energy increase of increasing the water surface area where the feet 'dent' the surface

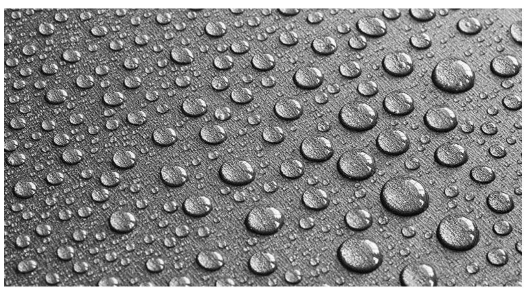
A man sits on a vat of mercury. The surface tension of water is 7.28 $\times 10^{-2}$ J m^{-2} while that of mercury is more than six times larger at 47.2 $\times 10^{-2}$ J m^{-2}

Why do you think mercury has such a high surface tension?

Consequences of Surface Tension

Surface Wetting-high energy and low energy surfaces
-examine wetting behaviour of a surface by a droplet





Droplets on wax, 100° contact angle

20 μL droplet of water on superhydrophobic surface, <1° sliding angle (SA)

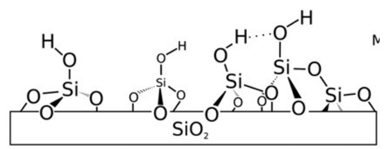
Superhydrophobic Colocasia "elephant ear" Plant

Why would plants evolve this type of surface?

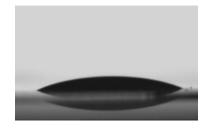
Surface Wetting with Water

Hydrophobic or Hydrophilic?

Glass

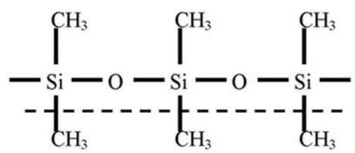


Hydrophilic

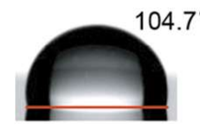


http://web.mit.edu/nnf/education/wettability/wetting.html

Polydimethylsiloxane

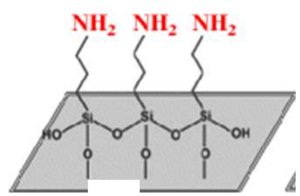


Hydrophobic



Lab Chip, 2014, **14**, 1564-1571

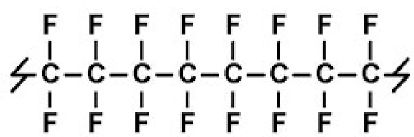
Amine Modified Surface



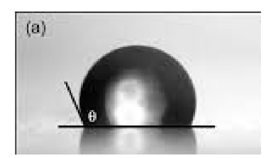
Hydrophilic

Applied Surface Science 300:22–28, 2014

Polytetrafluoroethylene
(Teflon)



Hydrophobic



What kinds of intramolecular forces are involved?