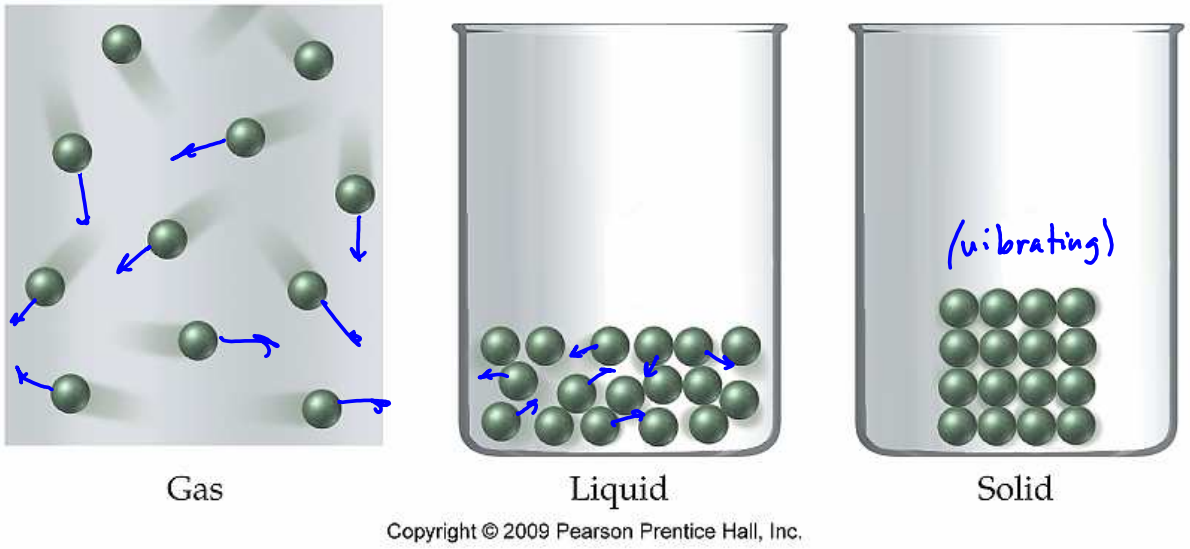
Phase	Density	Compressibility	Reason
(g)	low	yes	molecules far apart
(l)	high	no	close together
(s)	high	no	close together



definite or indefinite

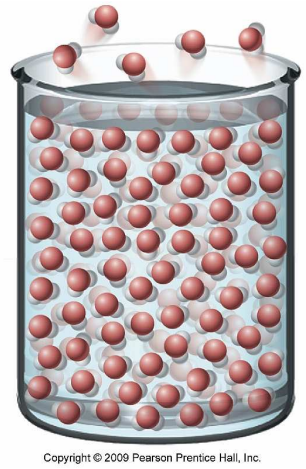
Phase	Shape	Fluid or rigid?	Reason
(g)	indef	fluid	fast molecular motion
(l)	indef	fluid	fast molecular motion
(s)	def	rigid	locked in place vibrating

Intermolecular forces: forces that attract one molecule to other molecules around it

If there were no intermolecular forces, what phase would all molecular substances be? gas

In order to convert liquid to gas, the intermolecular forces that hold the molecules close to each other in the liquid must be overcome.

In a sample of room-temperature water, the molecules with the highest energy will move the fastest.



When a faster molecule finds the surface, it launches into the gas phase - this process is called: evaporation

$H_2O(l) \rightarrow H_2O(g)$ feels cold, absorbs heat

Evaporation is **endothermic** - heat energy is absorbed into the liquid in order to overcome the intermolecular forces so a molecule can break away from the rest.

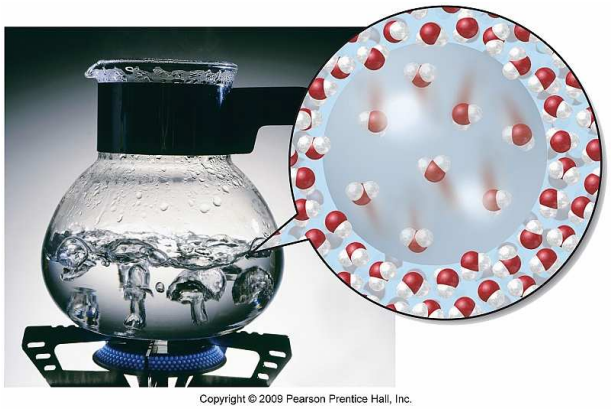
The opposite process, $H_2O(g) \rightarrow H_2O(l)$ is called: condensation

It gives off heat because the gas molecules slow down - this is an **exothermic** process. feel hot – give off heat

Boiling and the heating curve

Heating a liquid makes its molecules move: faster

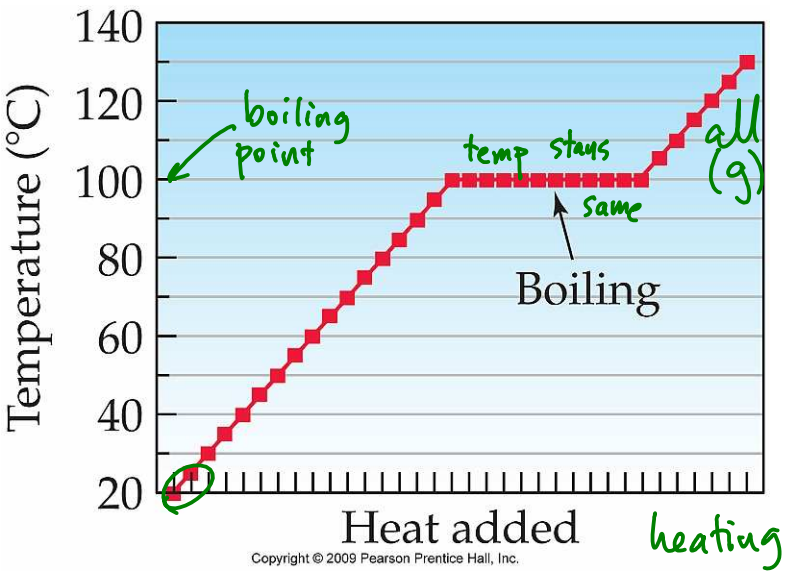
Eventually, they will all be moving fast enough to break free into the gas phase - even those in the interior of the liquid (not just at the surface like in evaporation).
This process is called: boiling (is endothermic)



Heat added to a liquid can do one of two things:

1. Raise the temperature
2. Perform a phase change

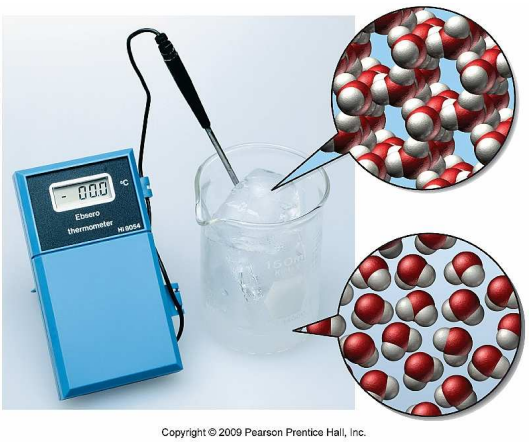
<u>...but only one at a time!!</u>

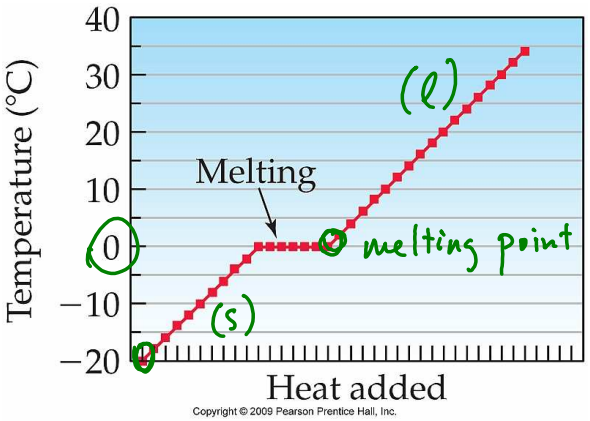


heating curve of water

Is boiling endothermic or exothermic?

Melting, freezing, sublimation

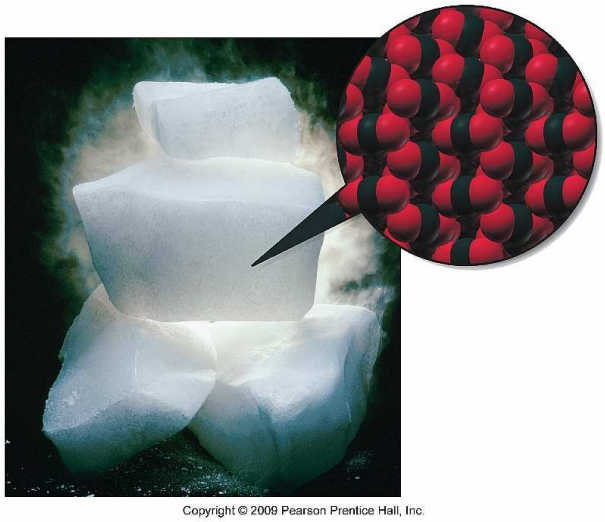




Melting: $H_2O(s) \rightarrow H_2O(\ell)$ endothermic *or* exothermic?

Freezing: $H_2O(\ell) \rightarrow H_2O(s)$ endothermic *or* exothermic?

Sublimation: $H_2O(s) \rightarrow H_2O(g)$ endothermic *or* exothermic?



O=C=O

etc

O=C=O

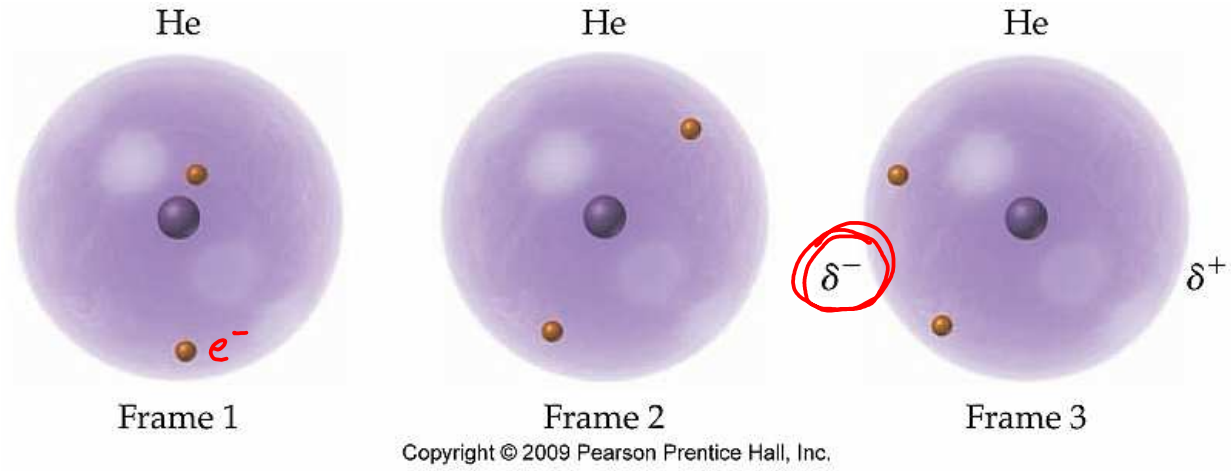
$CO_2(s) \rightarrow CO_2(g)$ sublimation

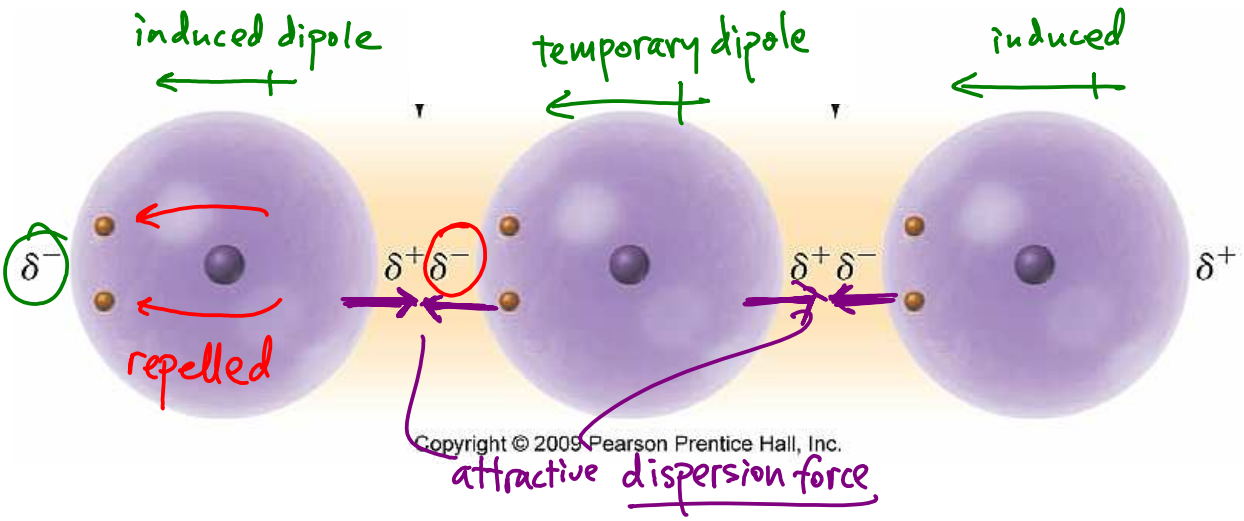
dry ice

There are 3 types of intermolecular forces:

1. Dispersion force
2. Dipole-dipole force
3. Hydrogen bonding

Dispersion force: (sometimes called London force) present between *all molecules*.





You can estimate the strength of a molecule's dispersion force by calculating its **molar mass**.

	MM	Strength of dispersion forces
I_2	~254	strongest
Br_2	~160	
Cl_2	~70	weakest

Boiling point: temp where (ℓ) becomes (g)

If a substance has relatively **strong** intermolecular forces, it will have a relatively high boiling point

Which has the highest boiling point, I_2, Br_2, or Cl_2?

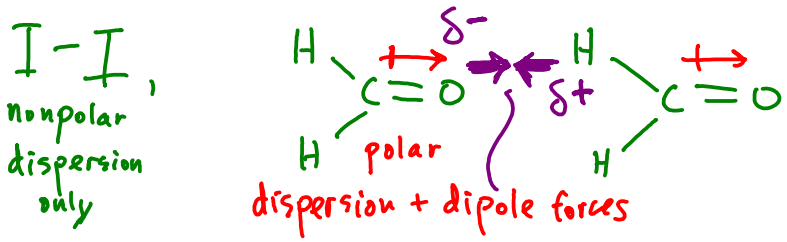
Strongest disp. forces (largest MM)

Which has the lowest boiling point, I_2, Br_2, or Cl_2?

Cl_2 - weakest disp forces

Dipole-dipole forces are attractions between opposite dipoles of **polar** molecules.

like magnets



Which has the higher boiling point, CH_2O or CH_3CH_3?

Disp. MM ~30 ~30 ~~similar~~ disp forces

Dipole-dipole polar nonpolar (like all hydrocarbons)

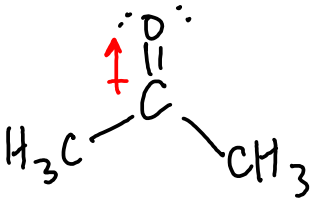
bp. higher lower

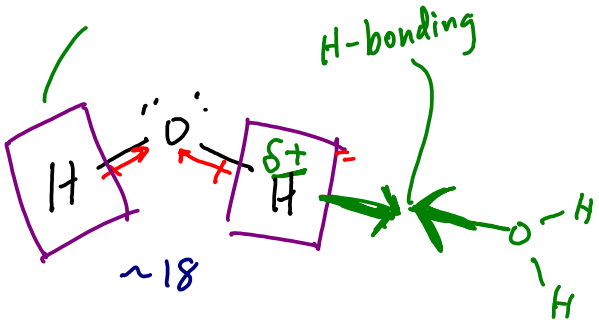
Polarity determines **miscibility** - whether or not two liquids will mix.

Only substances with similar polarities will mix.

(a) (b) (c)

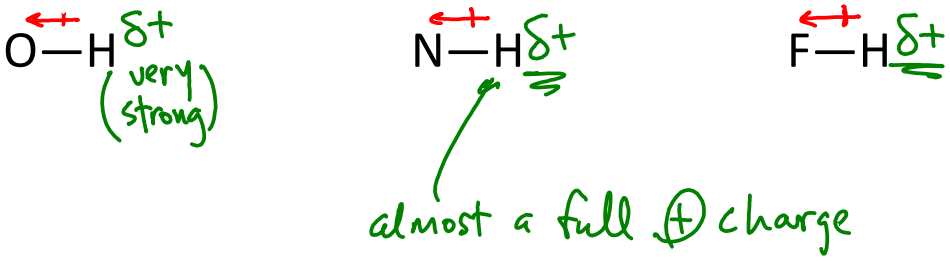
Consider acetone and water:



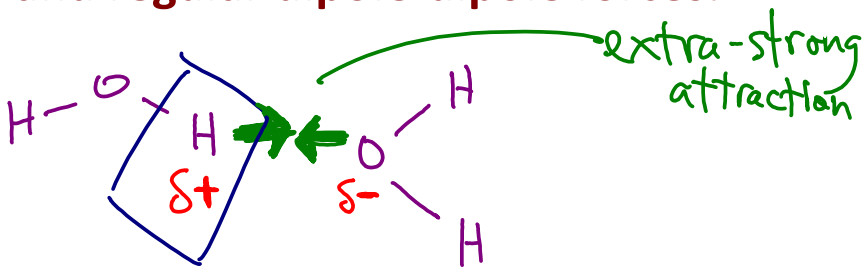


MM:	~58	~18
Dispersion:	stronger	weaker
Polar?	polar	polar
Dipole forces?	yes	yes
Experimental boiling point:	56 °C	100 °C
H-bonding	no	yes!

One of these molecules has **<u>hydrogen bonding</u>**, an extra-strong dipole force resulting from an **electropositive H:**



Hydrogen bonding is much stronger than dispersion forces and regular dipole-dipole forces.



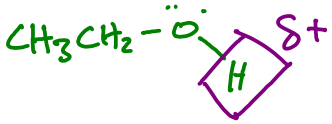
Boiling point practice

To rank compounds in order of boiling point:

1. Find compounds with **H-bonding** - they will have higher bp's than compounds without H-bonding
2. Use molar mass to determine **dispersion forces** (a difference of less than 10 is not significant)
3. Use polarity to determine **dipole-dipole forces**

The compound with the strongest intermolecular forces will have the highest boiling point!

Which has a higher boiling point, dimethyl ether (CH_3OCH_3) or ethanol (CH_3CH_2OH)?



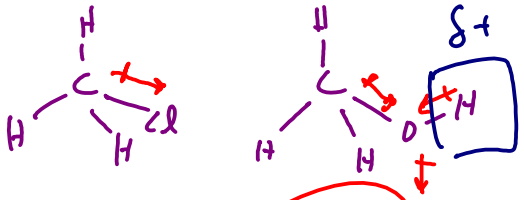
H-bonding? no yes

bp lower higher!

(actual ~10°C ~80°)

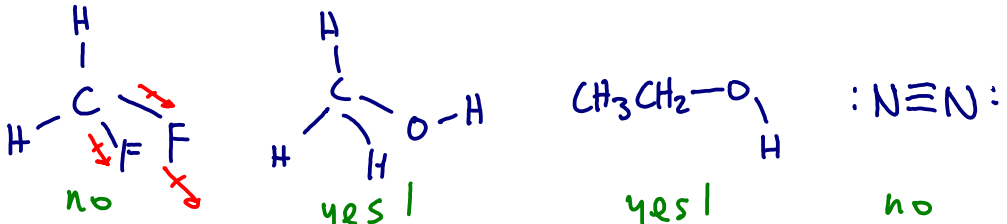
Boiling point practice

Rank these in order of increasing boiling point, with 1 as the lowest and 3 as the highest:
CH_3Cl, CH_3OH, CH_3CH_3



	CH_3Cl	CH_3OH	CH_3CH_3
H-bonding	no	yes!	no
Disp	~50 stronger	~32	~30
Dp-dp	yes (polar)	yes (polar)	no, nonpolar
B.P.	2	3	1

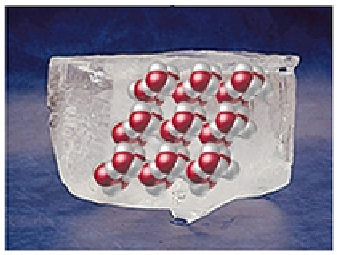
Rank these in order of increasing boiling point, with 1 as the lowest and 4 as the highest:
CH_2F_2, CH_3OH, CH_3CH_2OH, N_2.



	CH_2F_2	CH_3OH	CH_3CH_2OH	N_2
H-bonding	no	yes!	yes!	no
Disp	~52	~32	~46	~28
Dp-dp	yes	yes	yes	no
Bp.	2	3	4	1

Types of solids

	Molecular	Ionic	Metallic
Made of:	molecules 	ions / formula units Na^+, Cl^-	atoms
Elements:	nonmetals only	metal + nonmetal or poly. ions (NH_4Cl)	metals only
Held together by:	intermolecular forces (Disp., Dp-dp, H-bonding)	ionic bonds	"metallic" bonds
Charges?	partial charges $\delta+ \rightarrow \leftarrow \delta-$	full charges $Na^+ \rightarrow \leftarrow Cl^-$	
Melting point:	low < 200°C usu	very high >1000°C usu	variable mp.



Ice

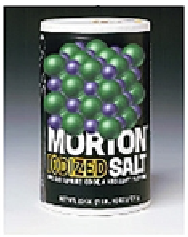
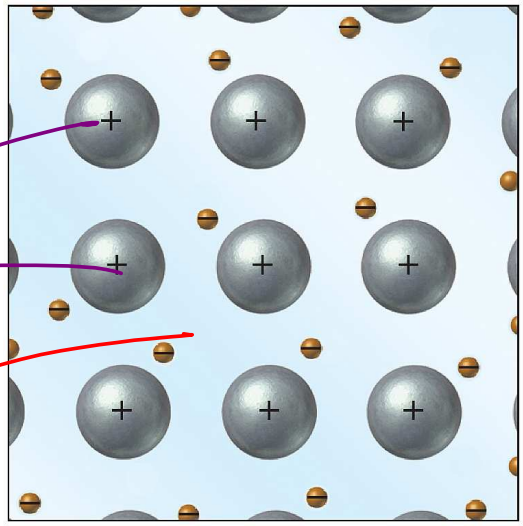


Table salt

Gold

metallic solid



metal atoms

Sea of shared electrons