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2019

Schedule: tentative

Meeting	Date	Content
9		21st century chemistry learning
10		Creativity and Innovation
11		Critical thinking and problem solving
12		Communications
13		Skill of argumentation
14		Participatory action research
15		Collaboration – project
16		UAS

Pedagogical content knowledge

Knowing about the teaching of particular content

In the context of the chemistry curriculum …..

Knowledge of chemistry content is different from knowledge about teaching that content

What does it mean to ‘know’ chemistry?

The complexity of learning chemistry

– a non-linear process

Dimensions along which chemistry understanding can progress.

An example of PCK

to illustrate the difference between

knowing about chemistry

and

knowing about the teaching of chemistry

To teach a subject well, we should know something about what it means to ‘know’ that subject

What is involved in ‘knowing’ chemistry?

1. Knowing more “facts”.
2. Understanding the role of models and theories in chemistry
3. Ability to alternate between the macro world and related sub-microscopic models
4. Quality of images at the sub-micro level
5. Understanding the language of chemistry
6. Ability to operate at multiple levels of explanation, rationalisation and prediction
7. Memory bank of episodes
8. Ability to distinguish between demonstrable knowledge and arbitrary knowledge
9. Appreciation of the sources of our knowledge

10. Recognition of the place and role of chemistry in society.
11. Understanding what chemists do
12. Knowing what we do not know
13. Interlinking learning

The ‘facts’ of chemistry may be either

- ***propositional*** knowledge (knowing that ....)
- ***procedural*** knowledge (knowing how to ......)

Highly capable experts have a deep store of propositional and procedural knowledge (as well as other sorts of understandings).

Some propositional knowledge generalises:

- The reaction of any metal with dilute HCl solution produces hydrogen gas
- Electronegativity increases as we go along the second row from left to right
- The elements of Group 15 increase in metallic character from element to element down the group
- The substances at the top of the table of reduction potentials are the most powerful oxidisers

Some propositional knowledge is specific:

- When zinc reacts with dilute HCl solution, hydrogen gas is formed
- The electronegativity of phosphorus on the Pauling scale is 2.1
- The elements of the second row are Li, Be, B, C, N, O, F, Ne
- The Zn^{2+} ion is higher up the table of standard reduction potentials than the Ag^{+} ion

The importance of knowing ‘facts’, whether propositional knowledge of procedural knowledge, should not be underestimated. Any highly capable plumber, lawyer, builder, butcher or chemist demonstrates an impressive store of this sort of knowledge to call upon to explain, to predict, and to decide on a course of action. But …..

They also need knowledge in other dimensions. Our curricula will not represent well the subject of chemistry if it is dominated by facts

Claim:

Generalised propositional knowledge without specific propositional knowledge may be nearly useless.

This is “rote learning.”

Procedural knowledge:

- Knowing how to purify a substance by recrystallisation
- Knowing how to calculate a standard cell emf from standard reduction potentials
- Knowing how to estimate boiling point at a specified pressure, from a phase diagram
- Knowing how to estimate pH of a solution with a pH meter

The richer and deeper is our knowing along this dimension, the better is our understanding in chemistry

Dimension 2

Understanding the role of models and theories in Chemistry

At the heart of chemistry is our use of models/ theories at the level of atoms and molecules to make sense of observable phenomena.

Understanding that concepts and ideas are human constructions

Understanding that chemistry (science) is a human endeavour

Chemistry is not about atoms and molecules ...

It is about **people** studying atoms and molecules

Why does a piece of copper expand on heating?

A. The pressure on the copper sample is reduced
B. The copper atoms/ions expand
C. The forces of attraction between the atoms are reduced
D. More vigorous vibrations of the atoms push each other outwards
E. None of the above

Generally, students who answer other than (D) are marked wrong

$r(Cu) = \frac{1}{2}$(average distance between nuclei)

Estimates of $r(Cu)$:

At 20 °C	$r(Cu) = 128.0$ pm
At 220 °C	$r(Cu) = 128.4$ pm

The size of the copper atoms has increased!

Compare the attitudes to chemistry displayed in the following test items:

1. Why does the pressure of a sample of gas increase if we raise the temperature, keeping volume constant?
2. If we use the kinetic molecular model of matter, how can we explain that the pressure of a sample of gas increases if we raise the temperature, keeping volume constant?

In textbooks and examinations, seldom is the nature of substances in their various states developed as a model (rather than as a set of ‘facts’).

Knowing about the kinetic molecular model of matter is <u>not</u> the same category of knowledge as knowing about the reaction of zinc with dilute HCl solution

Chemistry – a human endeavour

If a radiation bomb eliminated all of human life, would there still be

- s, p, d, f orbitals?
- sp^3 hybridisation?
- resonance?
- Gibbs energy?

Perhaps we are so familiar with both our ‘reality’ and our models that both are regarded as everyday phenomena?

but then ....

Substances that consist of separate molecules, called covalent molecular compounds, are generally soft and low melting because of the weak forces between the molecules. Unlike ionic compounds, most covalent substances are poor electrical conductors, even when melted or dissolved in water. In covalent substances, the electrons are localised as either shared or unshared pairs, so no ions are present.

Some covalent substances do not consist of separate molecules. Rather, they are held together by covalent bonds that extend in three dimensions throughout the sample. These are called covalent network solids. An example is diamond, which consists of covalent bonds connecting each carbon atom to four others throughout the sample. Because of this, it is the hardest substance known and has a very high melting point.

Where is mention of people?

The models are presented as facts

The models are presented as determinants of behaviour (rather than as explanatory tools).

Does it matter?

It does if we want to present chemistry as a science

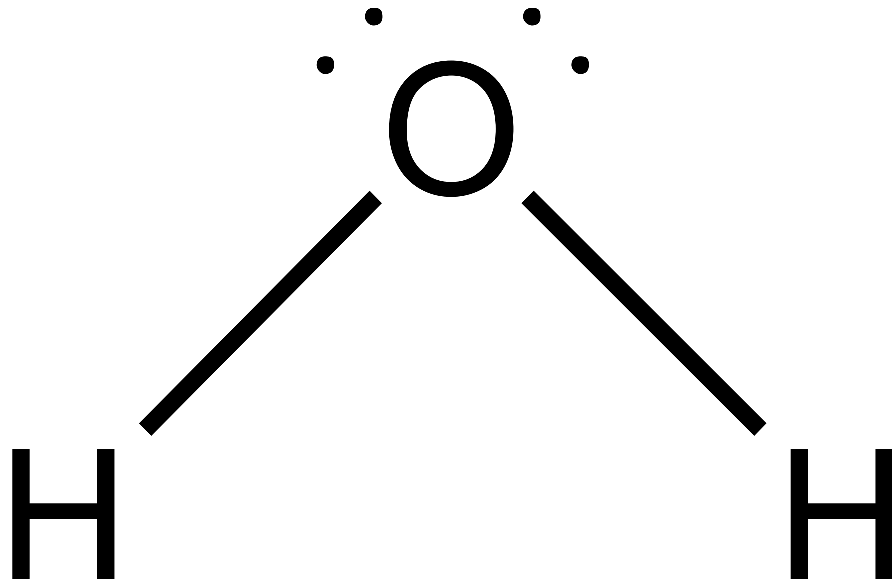
Chemistry is not about atoms, molecules, their structures and reactivities ....

Chemistry is ***people*** investigating and thinking about atoms, molecules, their structures and reactivities ....

Ability to distinguish between the model and the ‘reality’

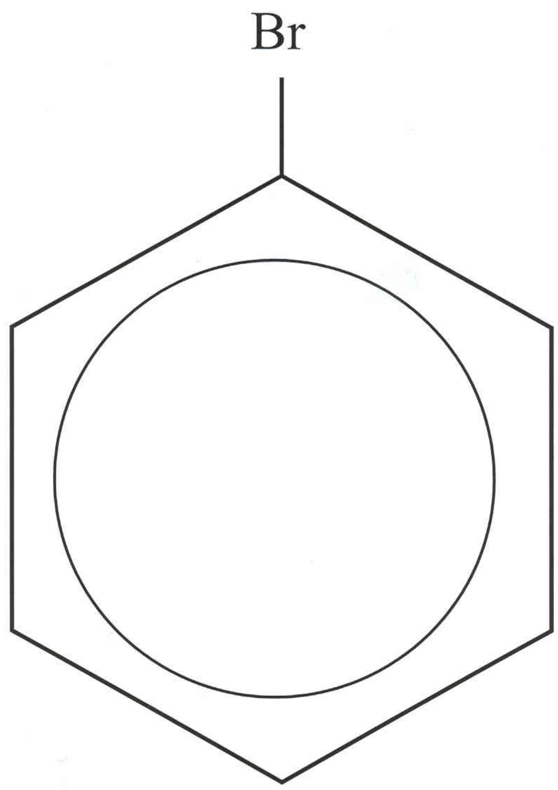
Are s, p, d, f orbitals reality? or models?

Are covalent bonds a reality?

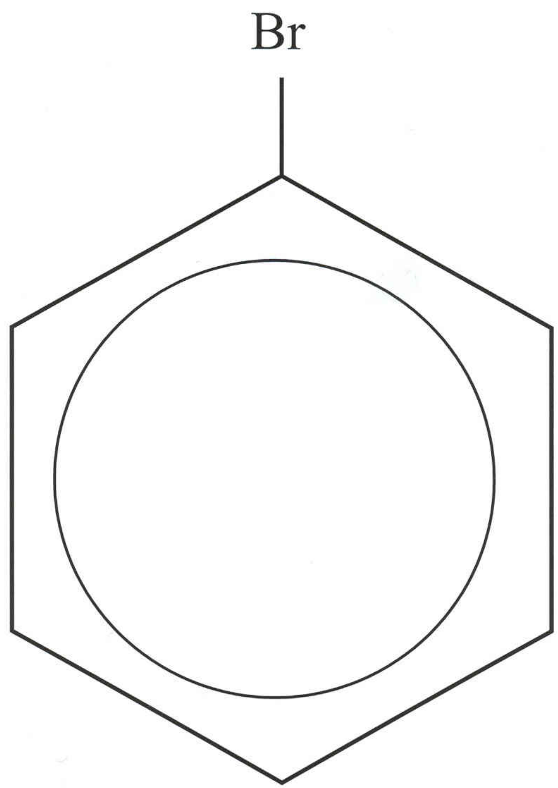


Is this really what a water molecule looks like?
Do we know what the reality is?

Kleinman et. al. (1987). Does bromobenzene have a plane of symmetry?



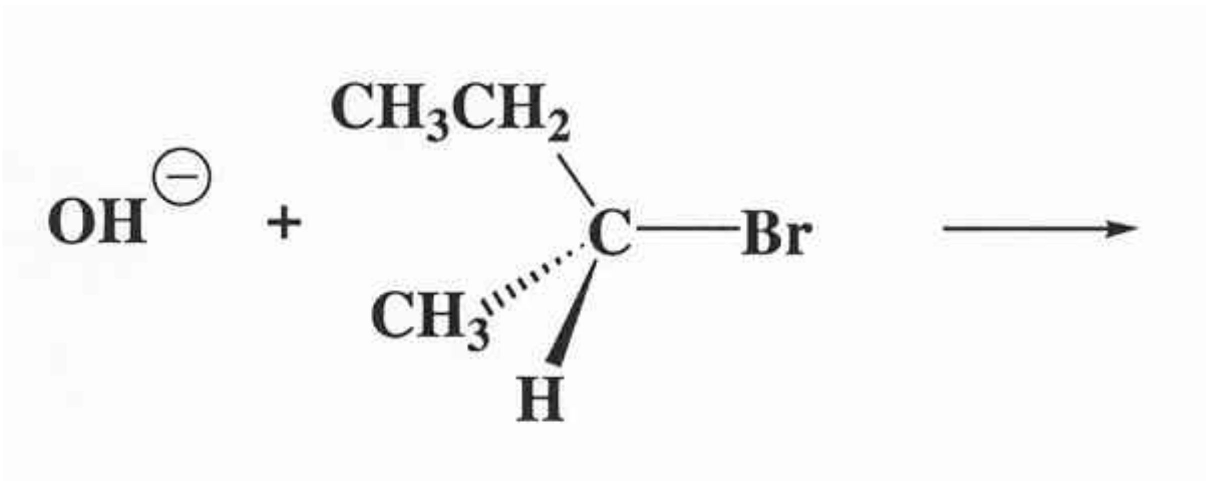
Kleinman et. al. (1987). Does bromobenzene have a plane of symmetry?

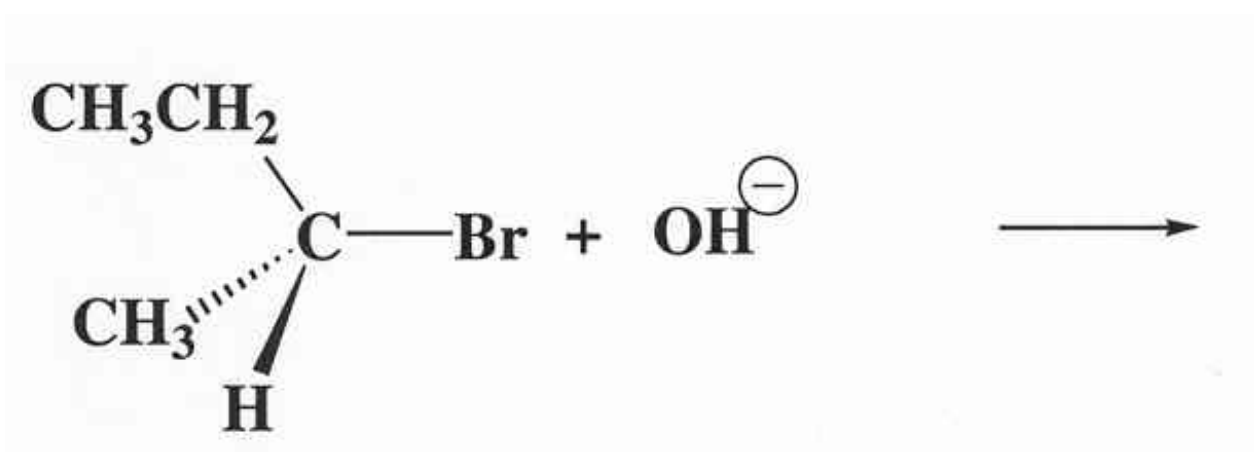


No because B $\neq$ r

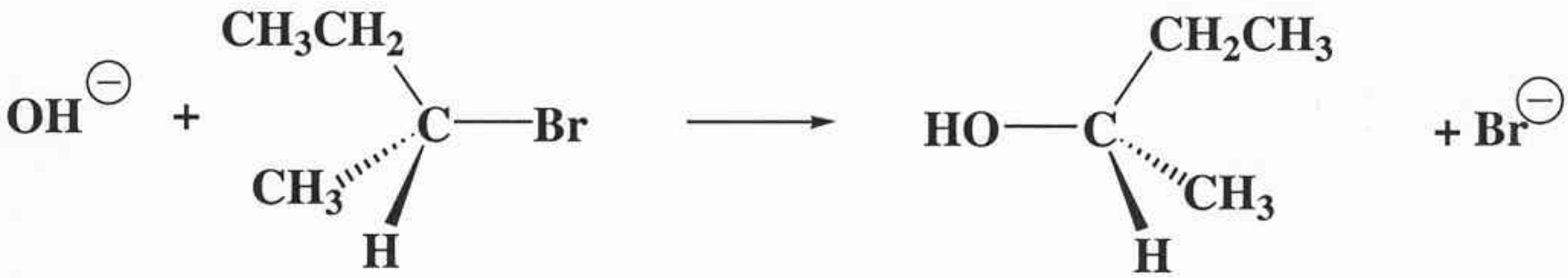
Ladhams Zieba (2004) - two tests to students …

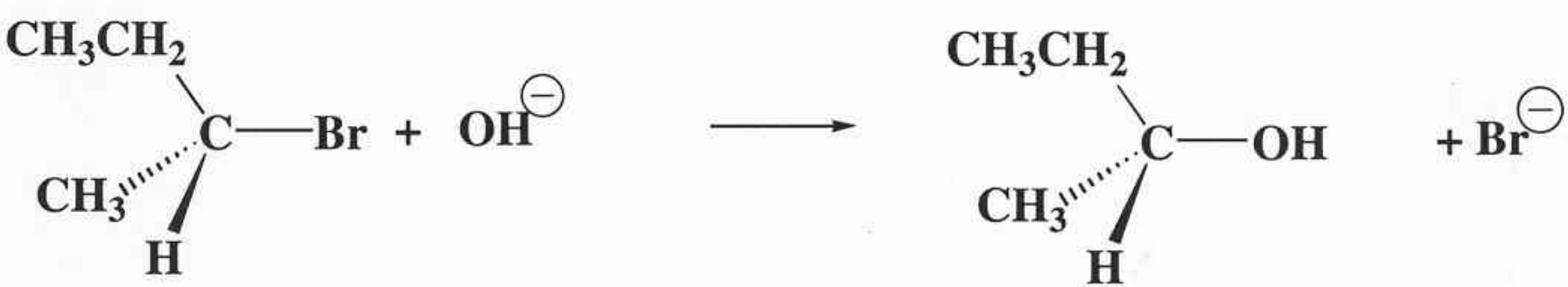
What are the products?





The most common student responses





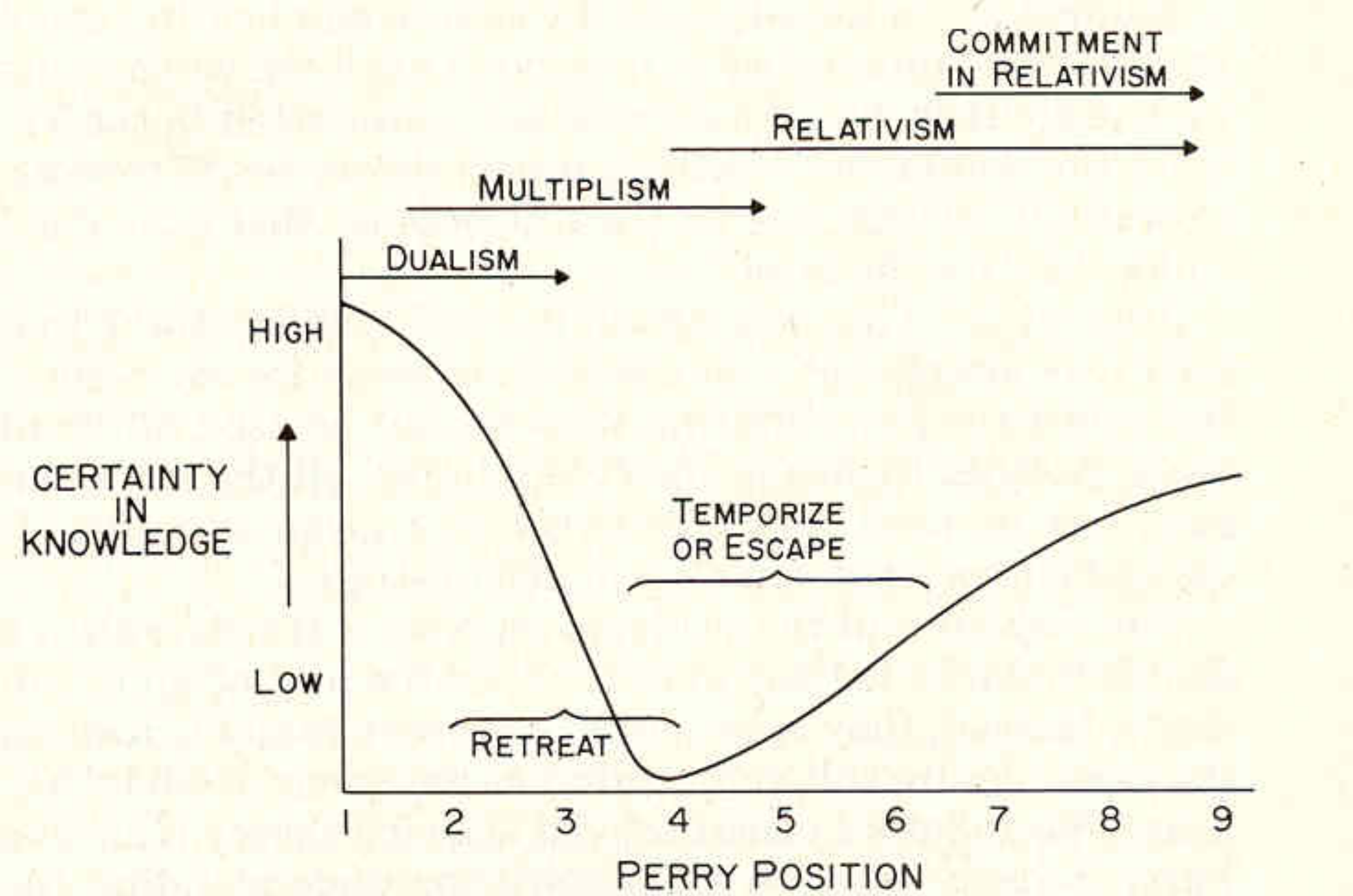
Is the outcome of a reaction determined by how we write the representation of our model of the system!?

Did the student try to imagine the reality, or did they operate on the drawings on the page?

Various models can be used for the same phenomenon

To make sense of acid-base observations

- Arrhenius model
- Bronsted-Lowry model
- Lewis model



Perry (1979) in Finster (1989)

Dualistic student: *I am puzzled! The teacher didn't explain which was right – the Arrhenius theory or the Bronsted-Lowry model.*

Multiplistic student: *I can't tell which to use either. Although both theories seem to work, she seemed to favour the Arrhenius approach. I think that's the one we should use in the exam.*

Relativistic student: *Great class! Now I see how different theories can be used in different ways. No theory is absolutely 'right', but each can be useful for a particular purpose.*

Understanding chemists' 'ideal' models *vs*. real behaviour

Propositional knowledge:
Gases do not obey exactly the Ideal Gas Law

Students' responses ….. Which is better

They should!

or

This attempt to model behaviour is quite good, but not exact. Are there more sophisticated models?

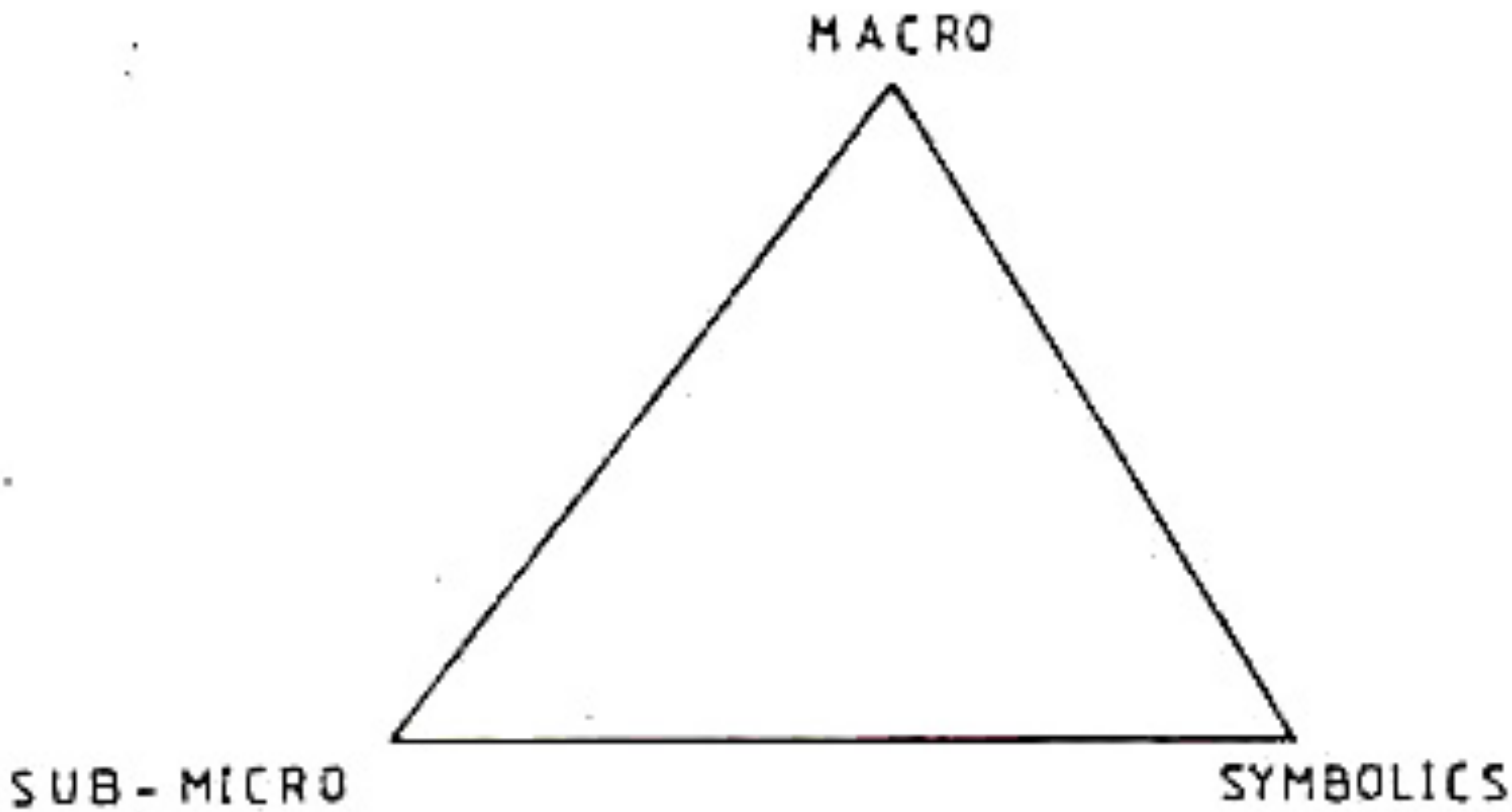
Recognition of the boundary conditions of applicability of models

Under what conditions of P, T does $PV = nRT$ satisfy my criterion of accuracy of prediction?

The richer and deeper is our knowing along this dimension, the better is our understanding in chemistry

Dimension 3

Ability to alternate between the macro world and sub-microscopic models



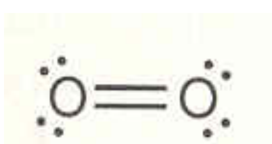
Levels of operation in chemistry – Johnstone (1991)

Macroscopic behaviour	Sub-microscopic explanation
Pressure of a gas	Collisions of rapidly moving particles on vessel walls
Melting	Temperature is high enough that the particles have enough energy to overcome intermolecular forces
Sodium chloride dissolves in water	Ion-dipole forces of attraction between water molecules and ions are sufficient to overcome the forces between oppositely charged ions in the solid lattice.
Reactions proceed more quickly at higher temperature	A higher fraction of collisions have total energy of colliding particles greater than the activation energy required for reaction.

Johnstone (1982)

macroscopic level	bulk properties observable continuously varying
sub-microscopic level	non-observable imagined world discontinuous matter

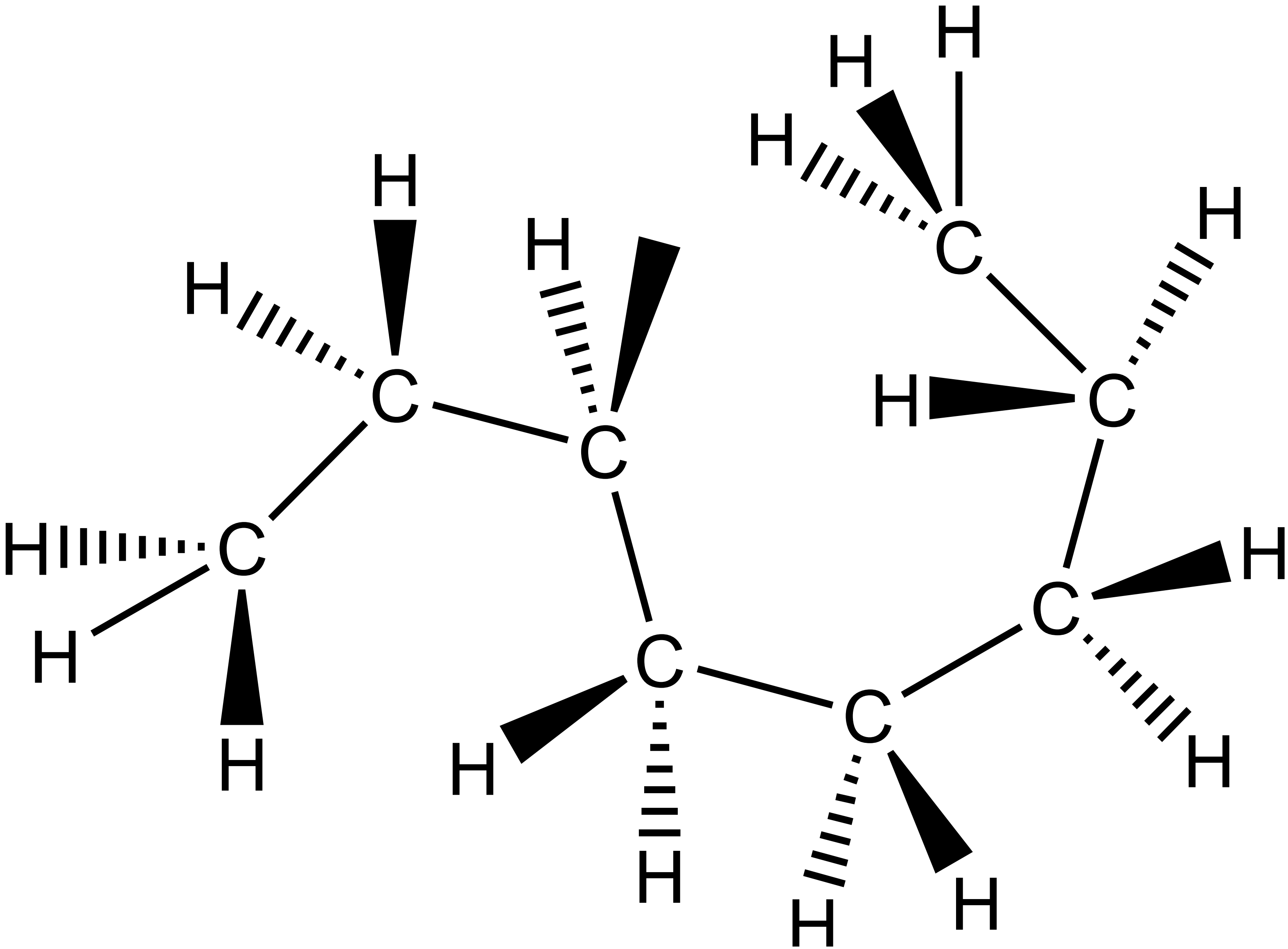
Jensen (1998)

molar	Colourless, odourless, paramagnetic, highly reactive gas, essential for most life, composing 21% of atmosphere by volume, mp = 54.8 K, bp = 90.2 K
molecular	Diatomic O_2 molecule, non-polar, O-O bond length = 121 pm
electrical	$(\sigma_{2s})^2(\sigma^*_{2s})^2(\pi_{2px})^2(\pi_{2py})^2(\sigma_{2p})^2(\pi^*_{2px})(\pi^*_{2py})$ or 

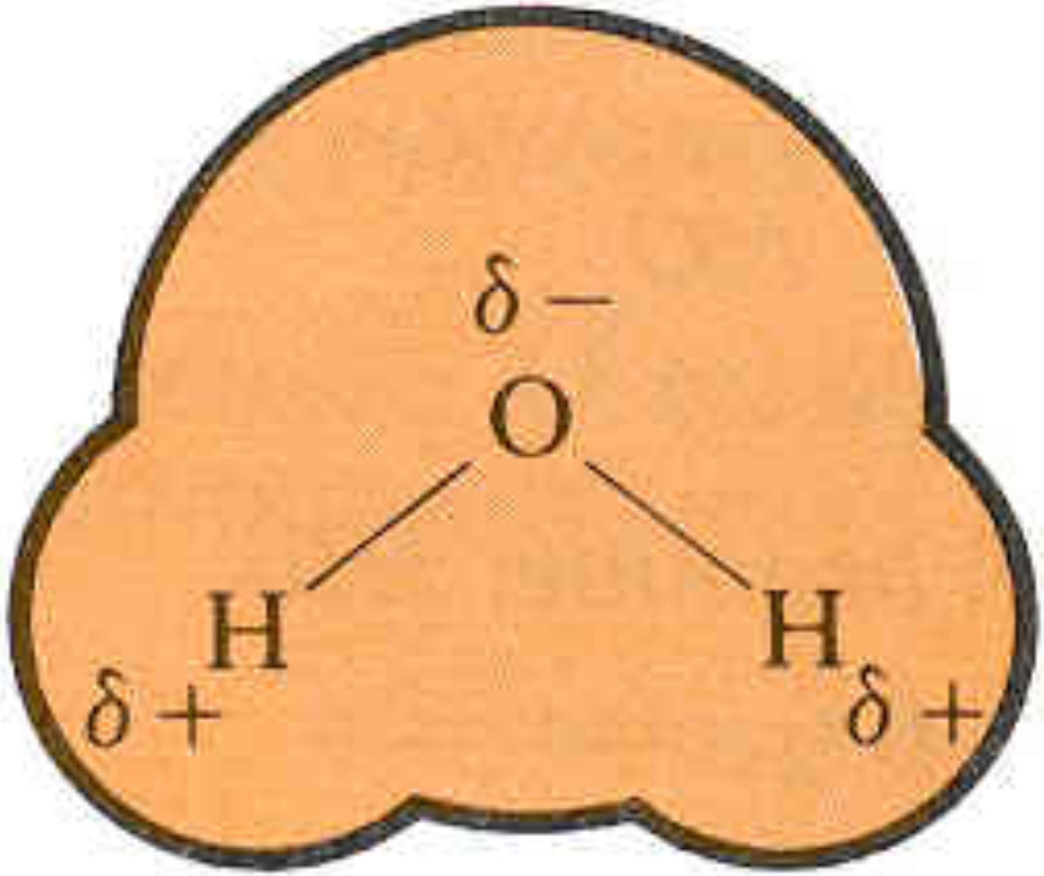
Molar Macroscopic	substances
Molecular Sub-microscopic	arrangements of atoms
Electrical	Distribution of electrons within atoms

Johnstone levels (1982)	**Jensen levels (1998)**	**This paper**
macroscopic	molar	macroscopic
submicroscopic	molecular	molecular – single particle
		molecular – many particles
	electrical	intermolecular

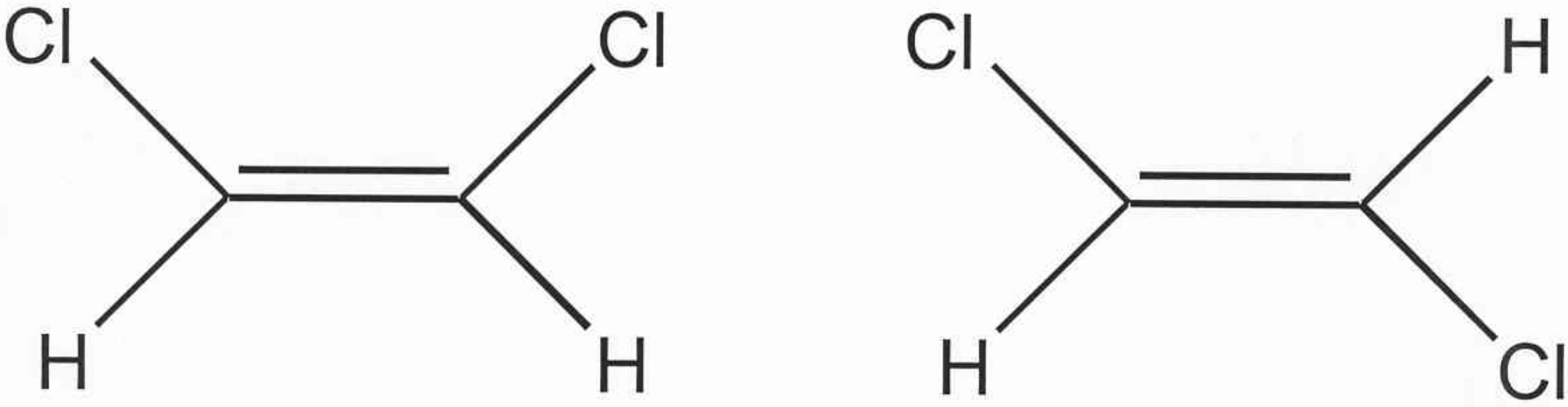
At the molecular level, sometimes we use a one-particle image



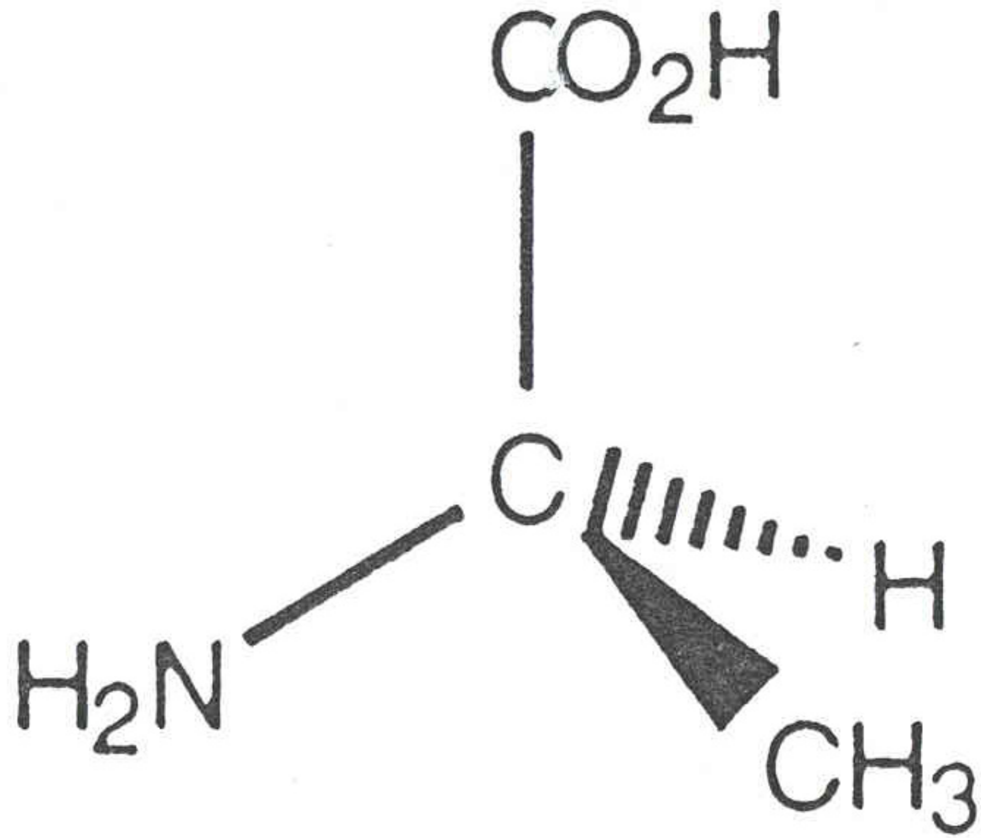
Connectivity and bond angles



polarity

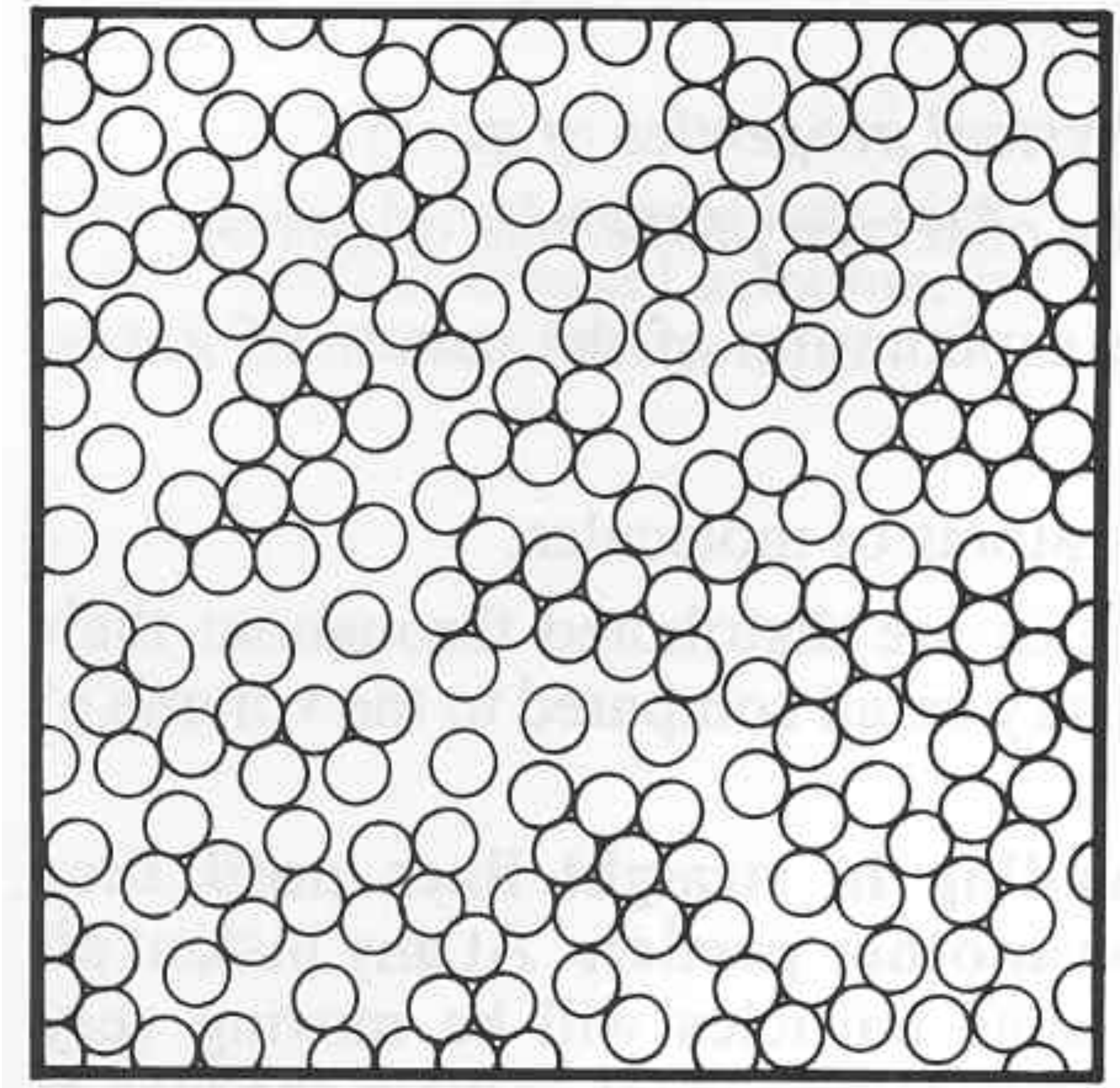


cis- trans- isomerism

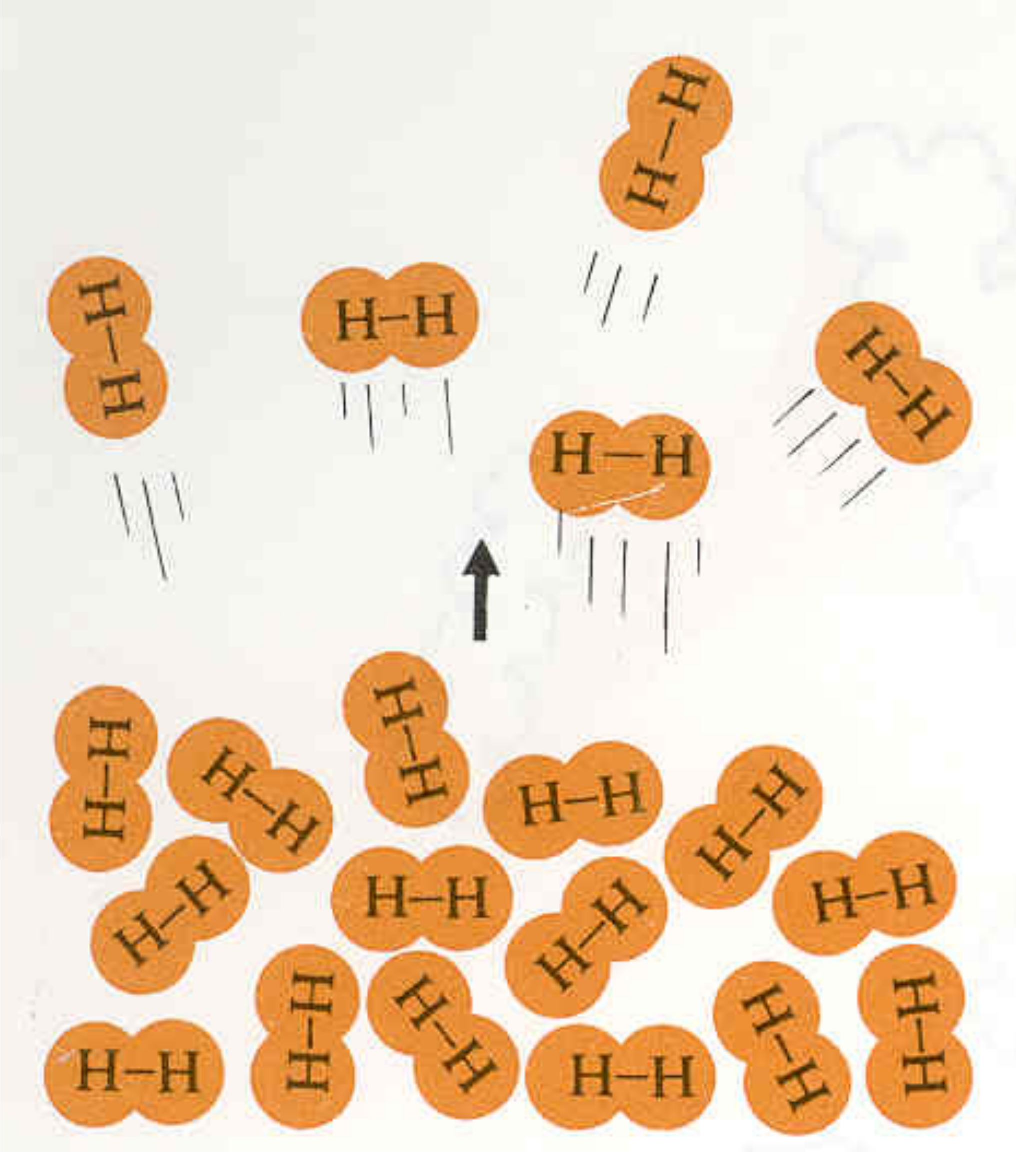


chirality

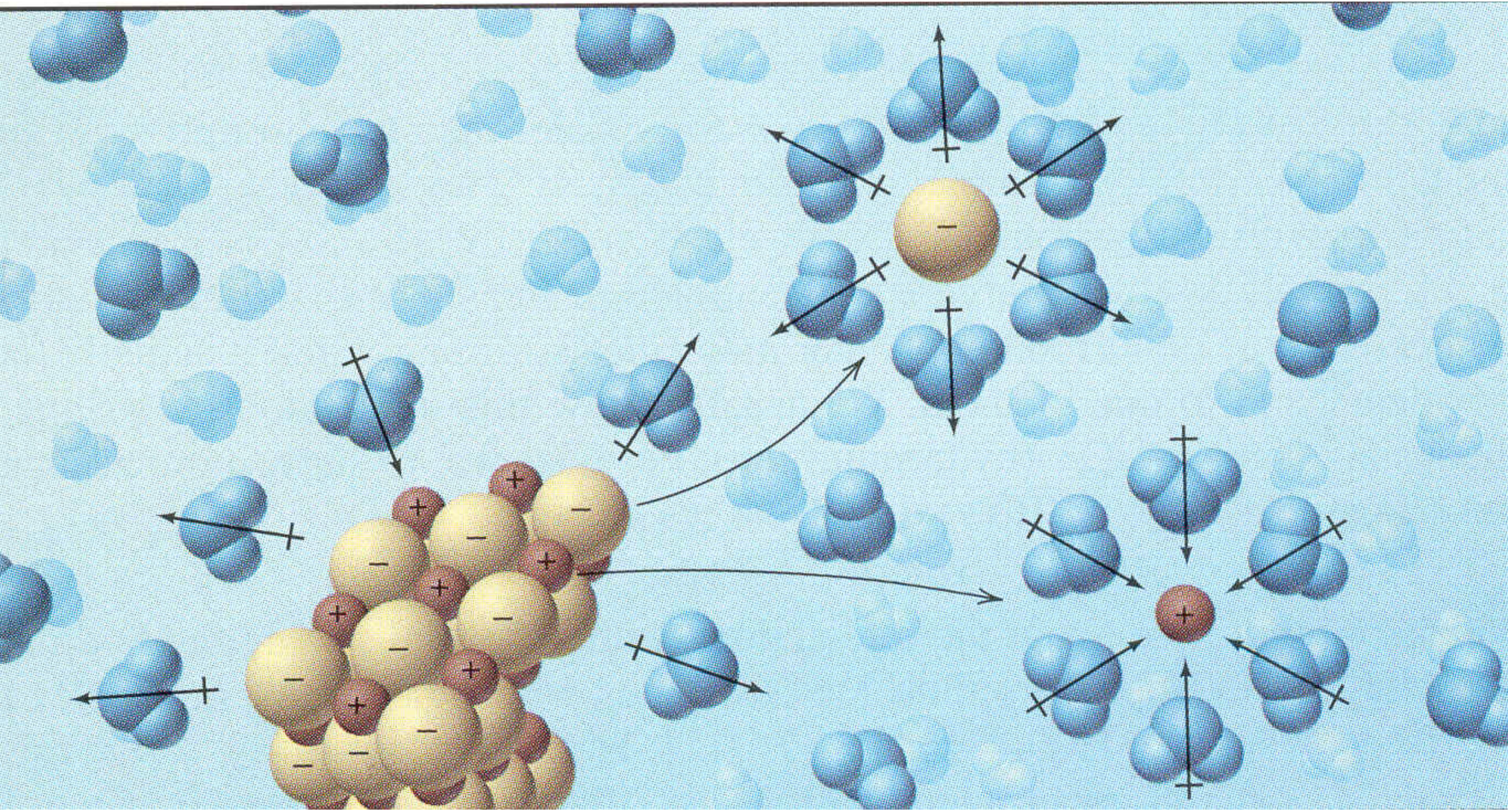
Sometimes we use a many-particle image:



The liquid state



Evaporation



Dissolving as a competitive process

Also ....

- diffusion of gases
- optical activity
- brittleness of an ionic solid

So what?

Does it matter?

Prof to me:

Which of these molecules would you expect to have the highest surface tension?

(a) $CH_3CH_2CH_2CH_2CH_2CH_2CH_2OH$

(b) $CH_3CH_2CH_2CH_2CH_2CH_2CH_3$

(c) $HOCH_2CH_2CH_2CH_2CH_2CH_2CH_2OH$

What do you think?

My answer to the prof ….

None of them has a surface tension.

The prof gave me a mark 0/10

Prof: *I'm surprised at you, Bucat, for not knowing the answer to that question*!

Me: *But Professor, I can't see how a molecule can have a surface tension. Only substances can.*

Prof: *Well of course I meant which of the substances has the highest surface tension*.

Me (to myself): *Well YOU knew what YOU meant. How am I supposed to see inside your mind? You didn't even try to see what was in my mind!*

The properties of substances are NOT the properties of its molecules or atoms.

•Are gold atoms gold-coloured?

•Are chlorine molecules green?

•Are glycerol molecules viscous?

•Does a water molecule melt at 0 °C?

•Are copper atoms malleable?

•Does an ethanol molecule have hydrogen bonds?

Does it matter?

Ben-Zvi *et. al* (1987)

Is it possible for N_2O_5 to be formed by reaction between $N_2(g)$ and $O_2(g)$?

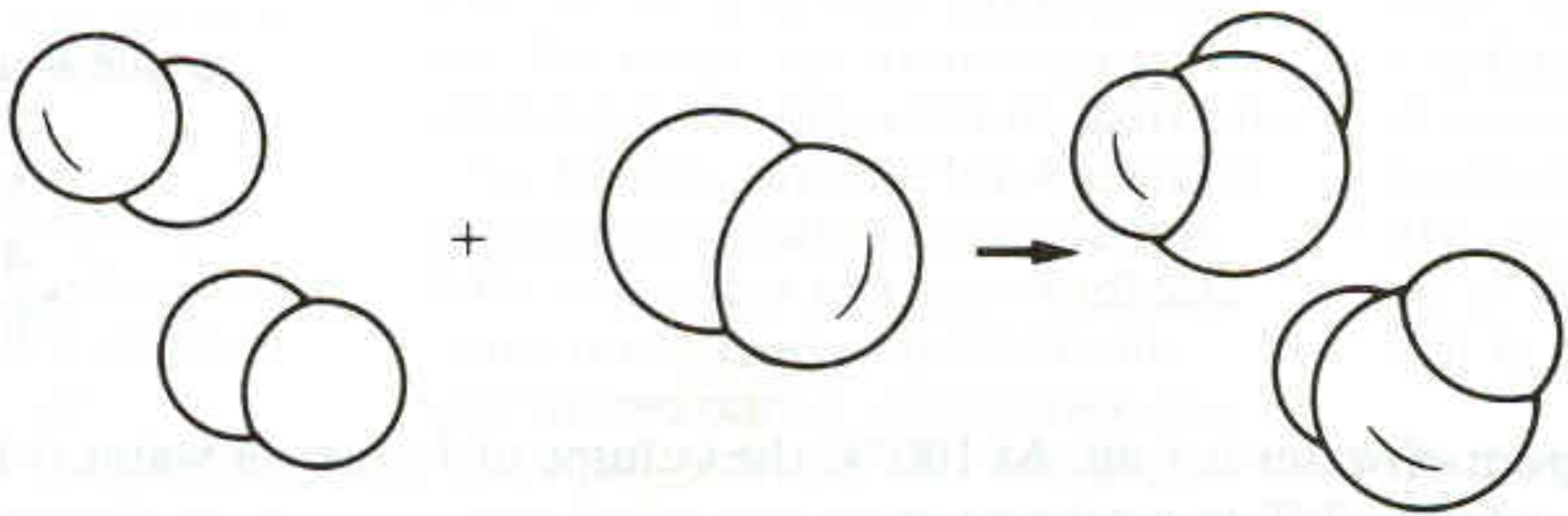
Does it matter?

Ben-Zvi *et. al* (1987)

Is it possible for N_2O_5 *to be formed by reaction between* $N_2(g)$ *and* $O_2(g)$?

No. Where from did we get three additional oxygen atoms?

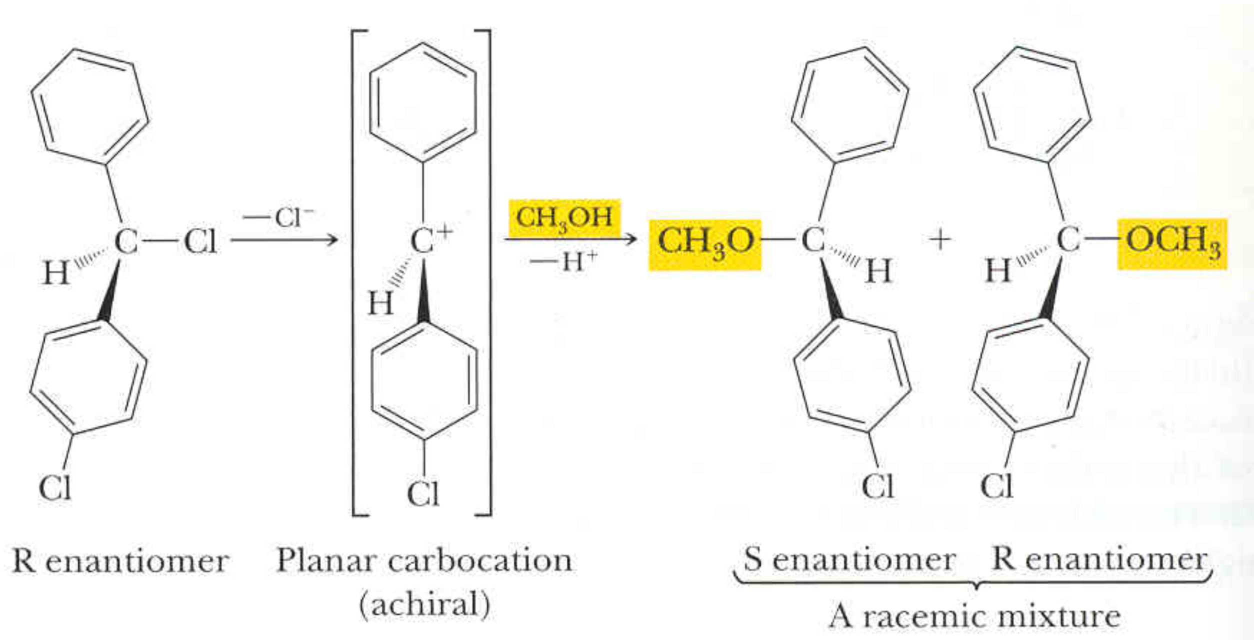
Sometimes we use single-particle pictures for a many-particle event



Two moles hydrogen gas + one mole oxygen gas → two moles liquid water

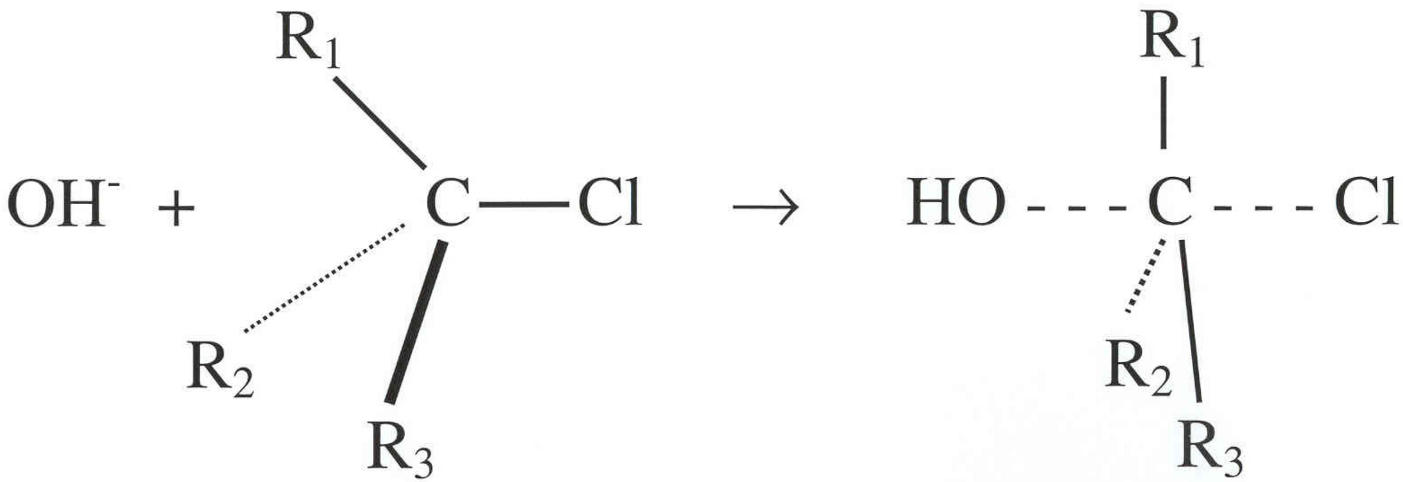
$2H_2(g) + O_2(g) \rightarrow 2\,H_2O(l)$

Ladhams Zieba (2002)



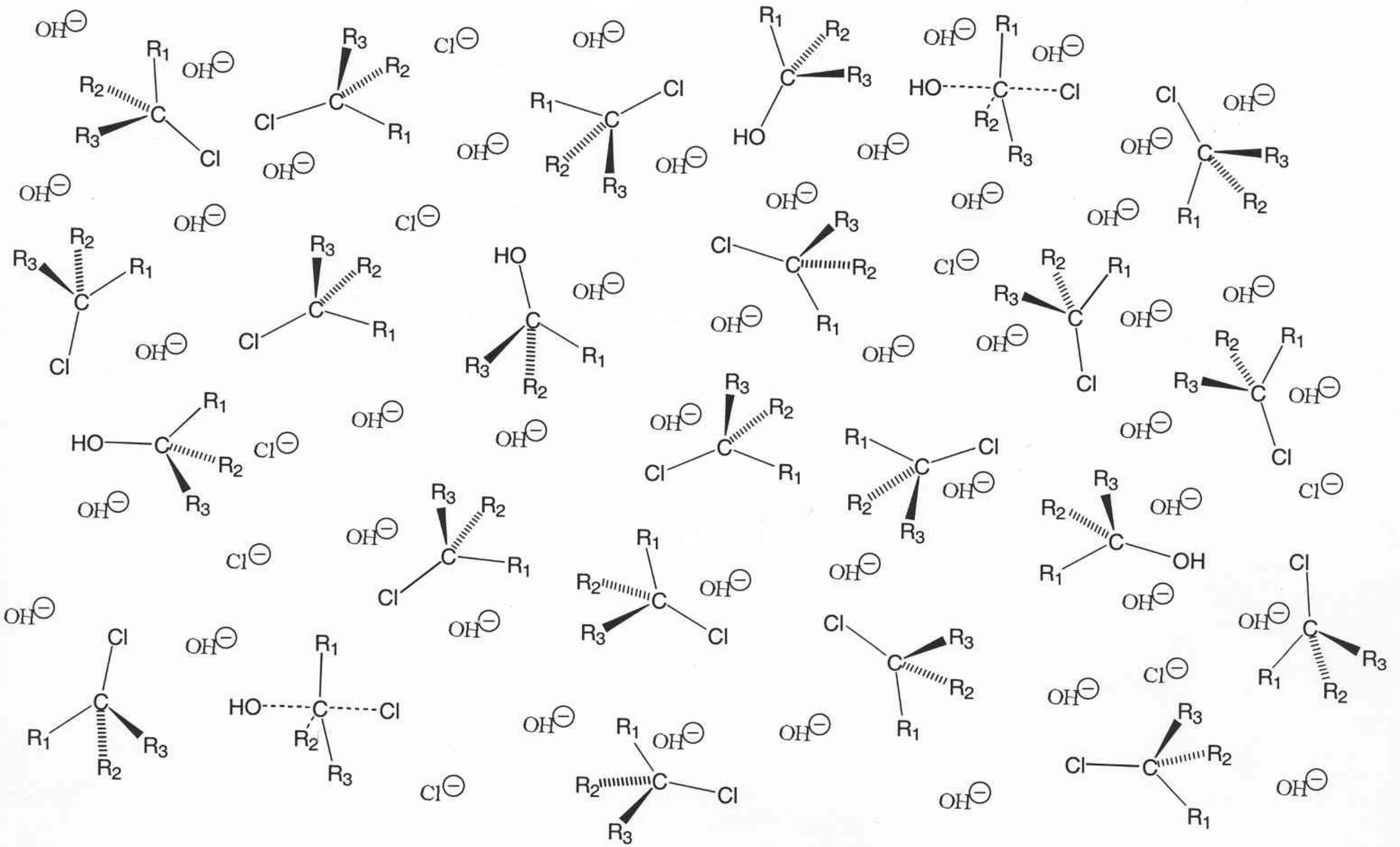
How can we get two product molecules from one starting molecule?

The rate of some substitution reactions (S_N2) depends on the concentrations of both reactants.



How is *rate of reaction* interpreted in this single-particle representation?

Rate does **not** mean how fast this event occurs!

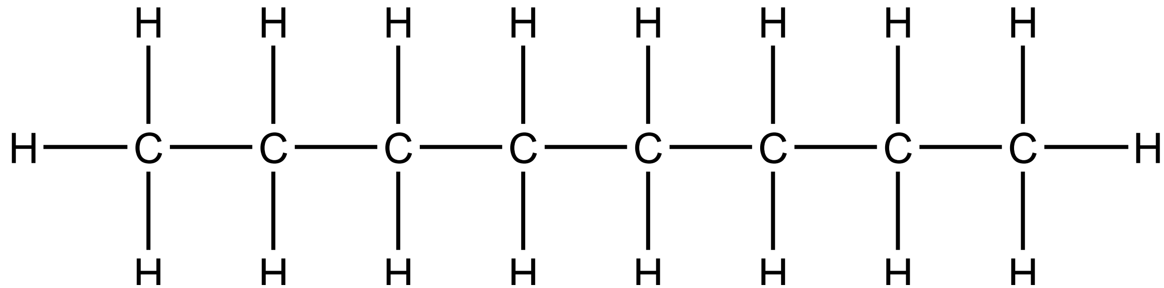


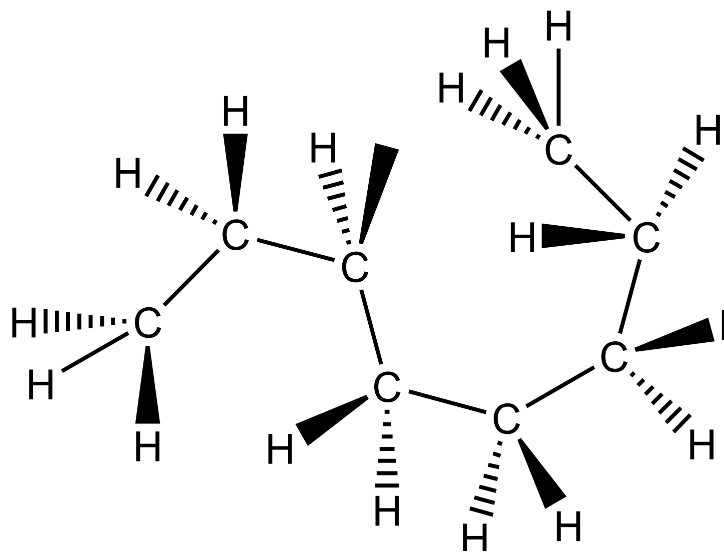
A useful image?

The richer and deeper is our knowing along this dimension, the better is our understanding in chemistry

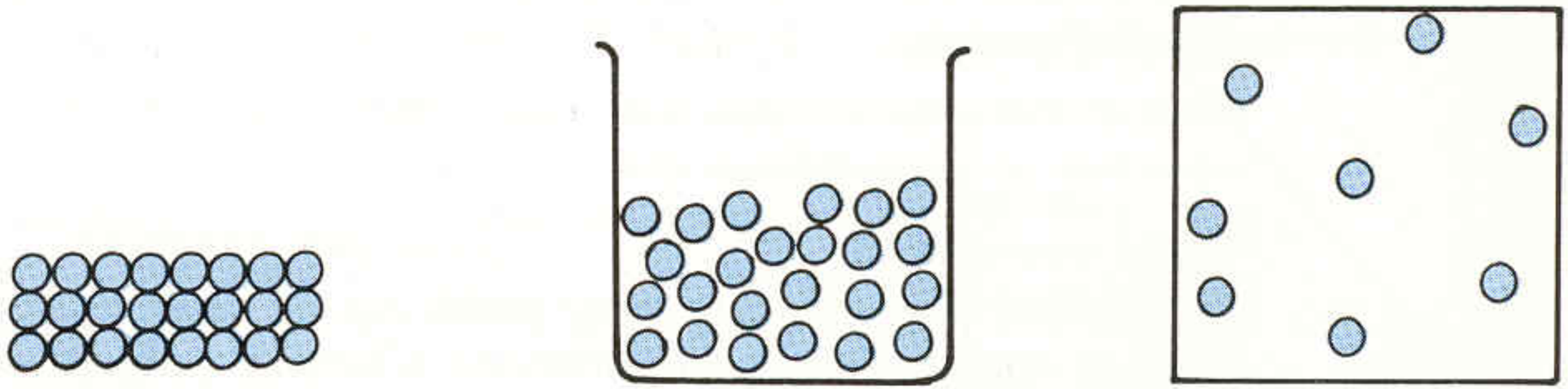
Dimension 4

The quality of images at the sub-microscopic level





Which image of octane is preferable?



Solid
Particles closely packed and held in position in a rigid structure

Liquid
Particles close to one another but free to move

Gas
Particles far apart and move independently of one another

Are these enriching images to build on?

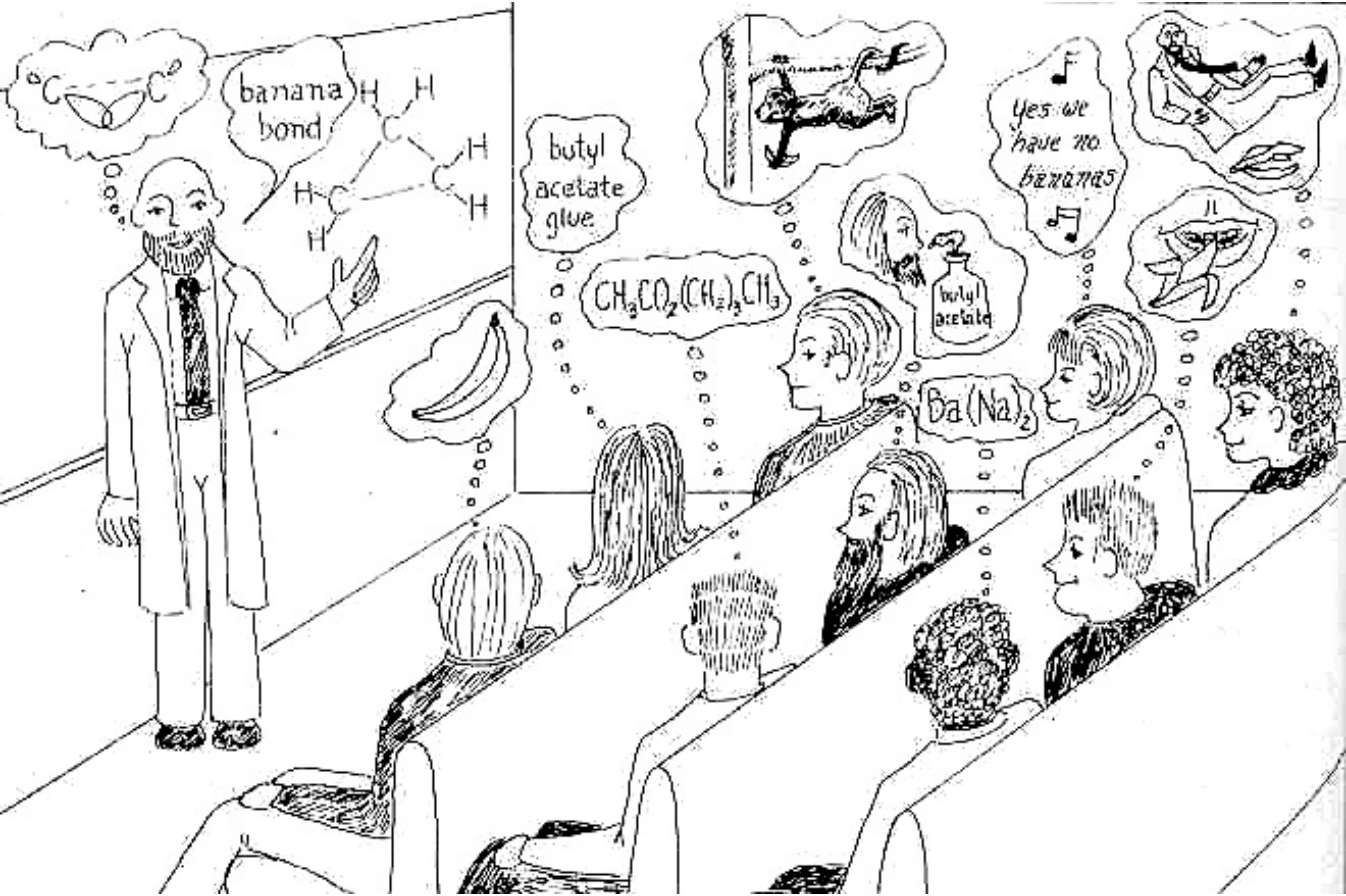
Quality of knowledge depends on quality of image:

- a process at equilibrium in aqueous solution
- diffusion of a gas through air
- a cubic close-packed arrangement of anions with cations occupying half the tetrahedral holes
- changing relative concentrations of hydroxy species as the pH is increased

The richer and deeper is our knowing along this dimension, the better is our understanding in chemistry

Dimension 5

Understanding the language of chemistry



banana bond
butyl acetate glue
$CH_3CO_2(CH_2)_3CH_3$
butyl acetate
yes we have no bananas
Ba(Na)$_2$

H.A. Bent, *J.Chem.Educ*, 61**, 1984, 774**

Zinc reduces copper(II) ion

Copper(II) ion oxidises zinc

Zinc displaces copper from solution

Copper won’t displace zinc from solution

Zinc is a better reducing agent than copper

Cu^{2+} ion is a better oxidising agent than Zn^{2+} ion

and ……

Zinc is a better electron donor than copper

Cu^{2+} ion is a better electron acceptor than Zn^{2+} ion

Copper is more easily displaced than zinc

Copper is more noble than zinc

Symbols

O vs. O_2 vs. O^{2-} vs. O_2^{2-}

Formulas

$BaCl_2$ vs. $BaCO_3$

$Cu(NH_3)_4^{2+}$

Chemical equations

$$Mg(s) + 2H^+(aq) = Mg^{2+}(aq) + H_2(g)$$

Technical jargon

- *electronegativity*
- *weak acid*
- *standard reduction potential*
- *enthalpy*
- *cation*
- *molecular orbital*
- *leaving group*
- *carboxylic acid*

From the IUPAC 'Gold Book':

Base: A *chemical species* or *molecular entity* having an available pair of electrons capable of forming a *covalent bond* with a *hydron* (proton) (see *Brønsted base*) or with the vacant orbital of some other species (see *Lewis base*).

And ….

Polarity: When applied to solvents, this rather ill-defined term covers their overall solvation capability for solutes, which in turn depends on the action of all possible, nonspecific and specific, intermolecular interactions between solute ions or molecules and solvent molecules, excluding such interactions leading to definite chemical alterations of the ions or molecules of the solute.

Everyday terms with special meaning

preparation
concentration
hard
volatile
attractive
migration
fusion
reduction
weak
saturated
dispersion
complex
basic
spontaneous

Diagrammatic symbols

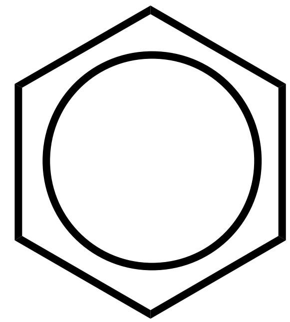
$\longrightarrow$

$\curvearrowright$

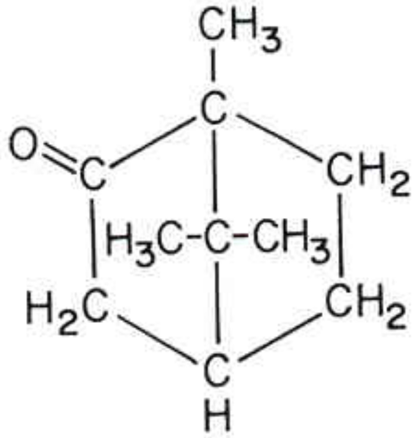
$\rightleftharpoons$

$\longleftrightarrow$

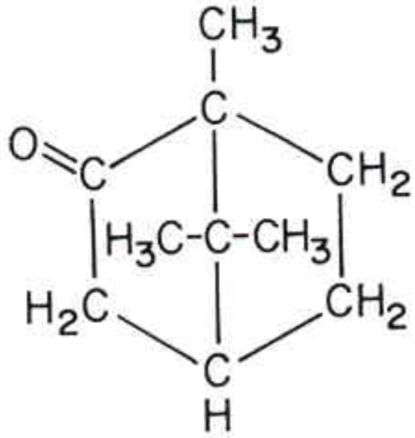
$C{=}C$

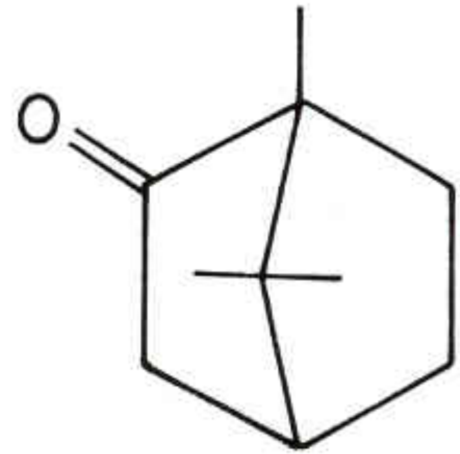


E°

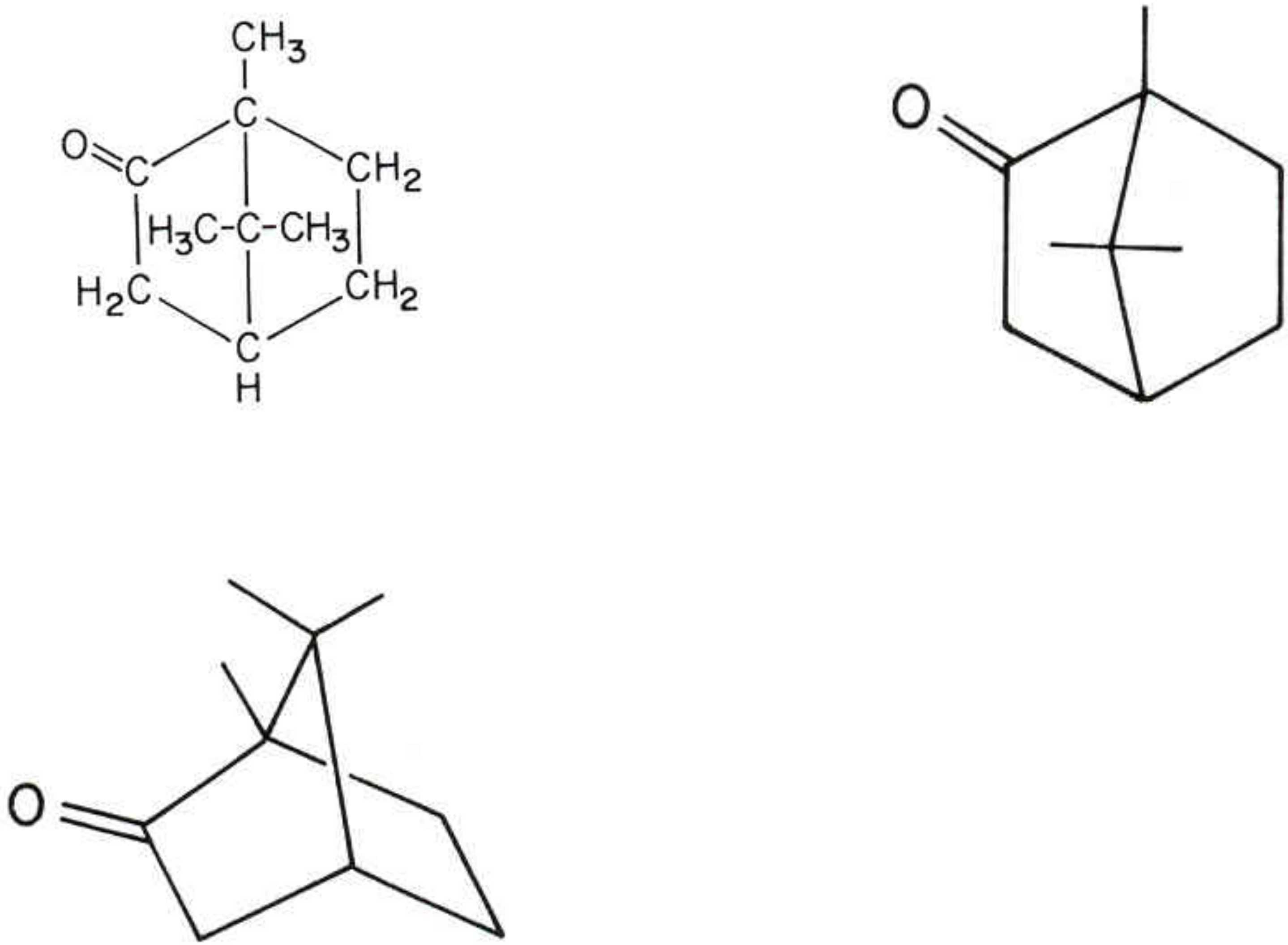


camphor





camphor



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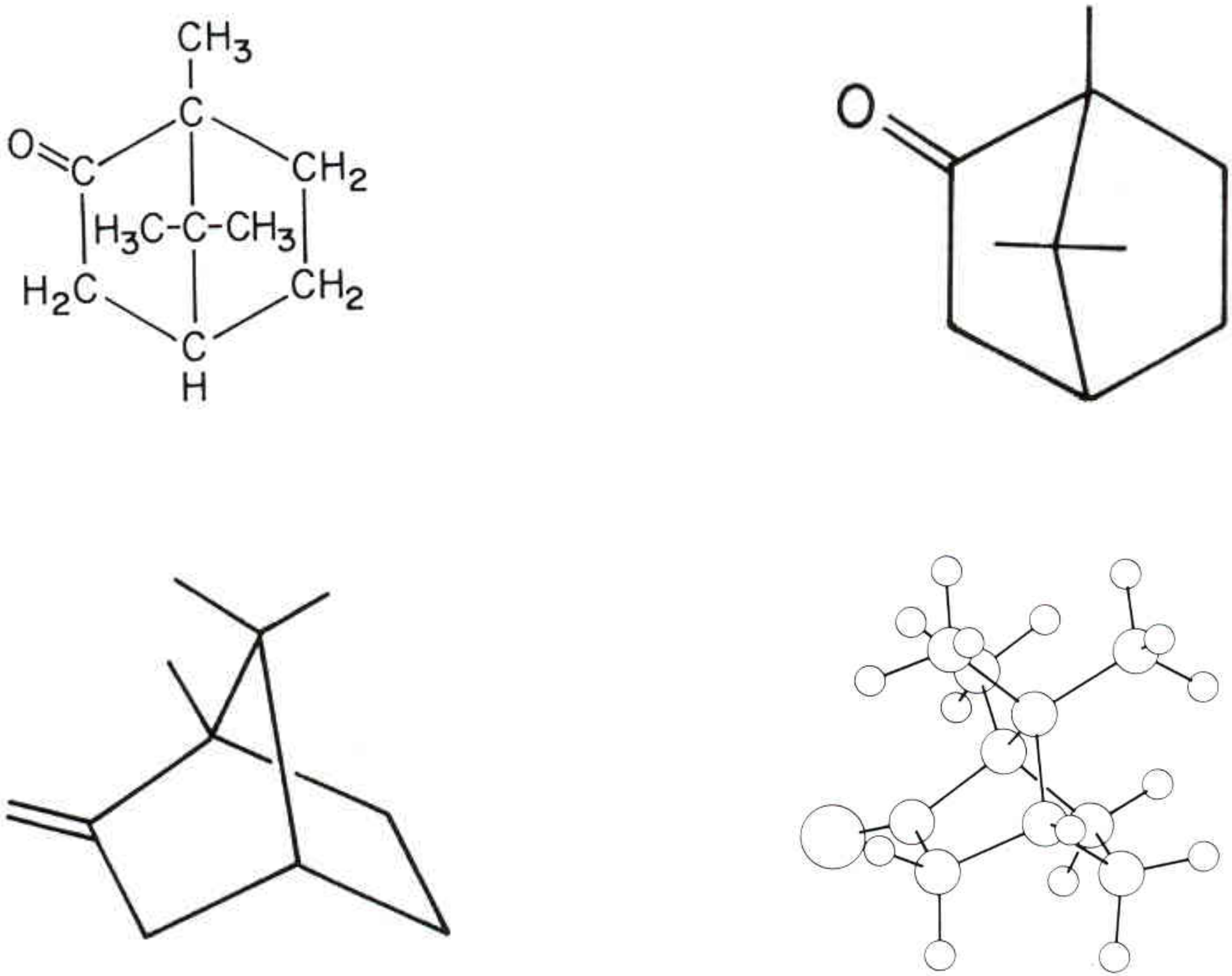

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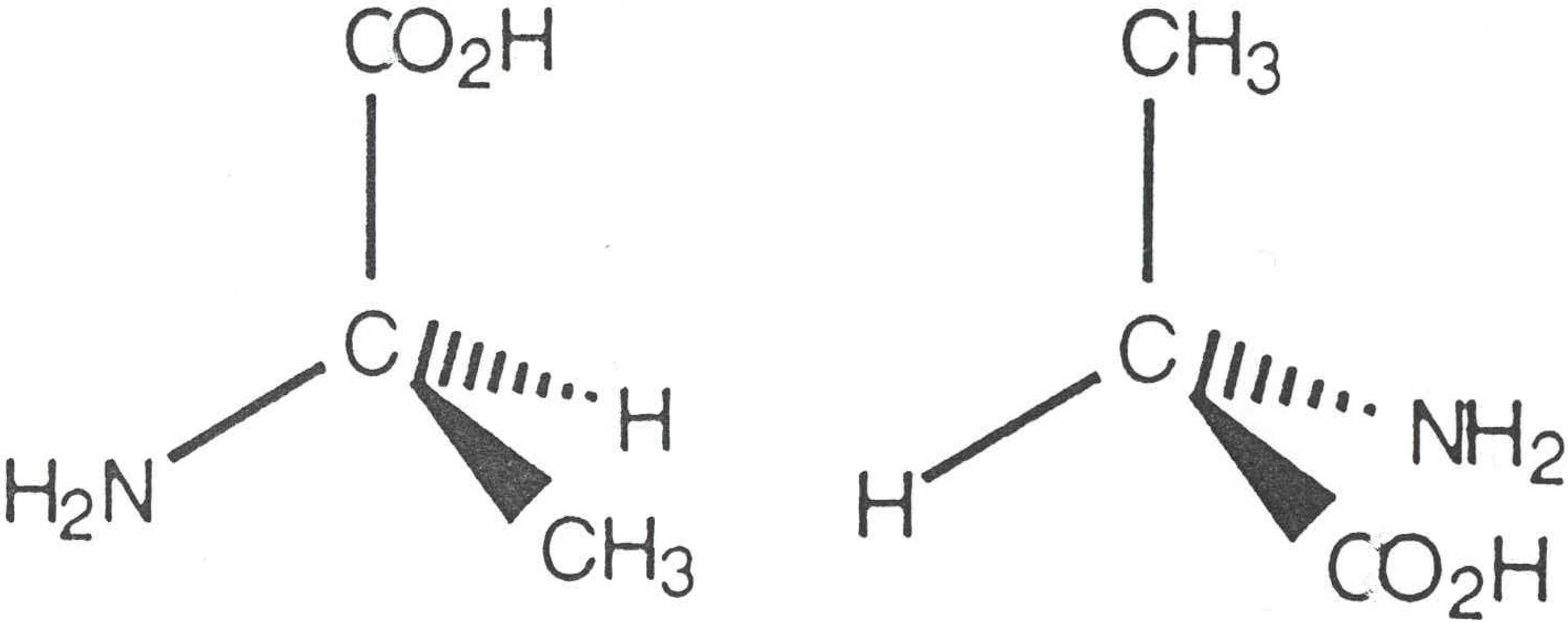
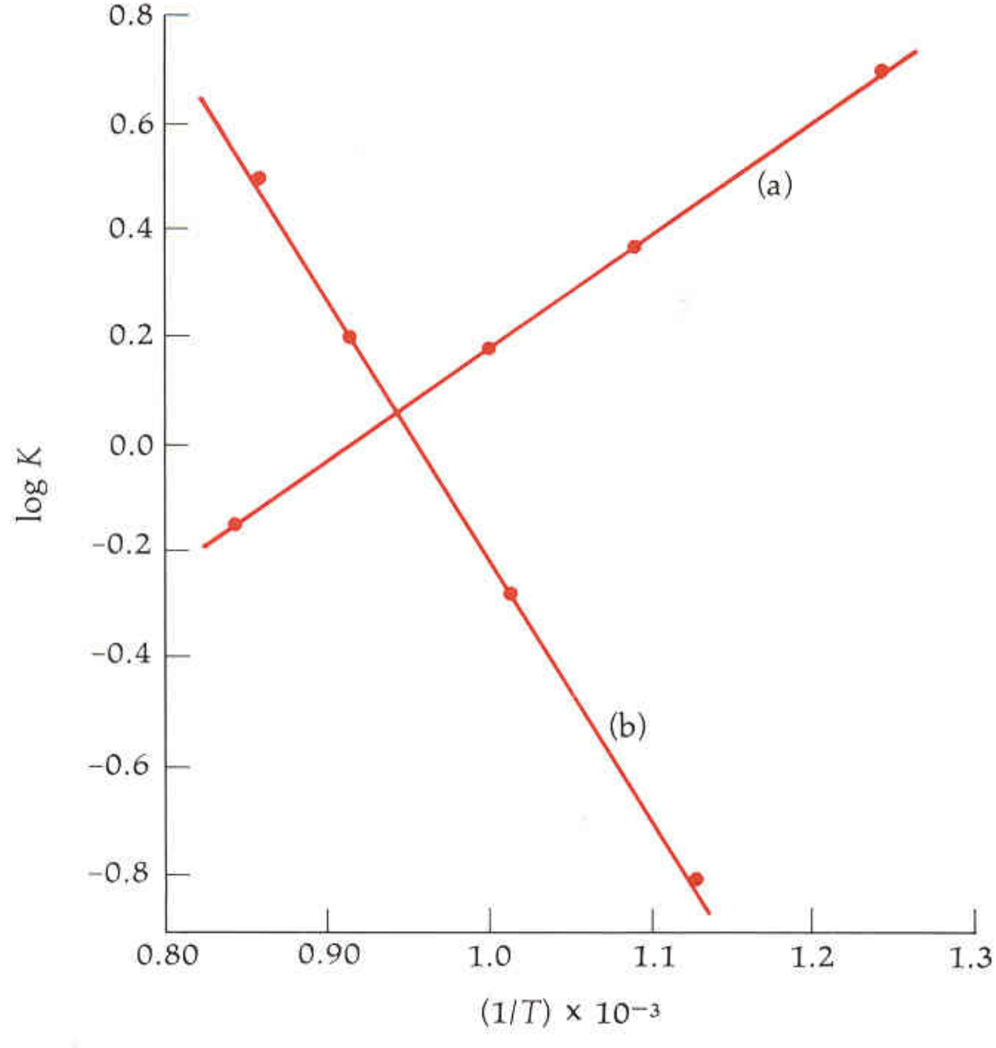


Alanine: identical or enantiomers?

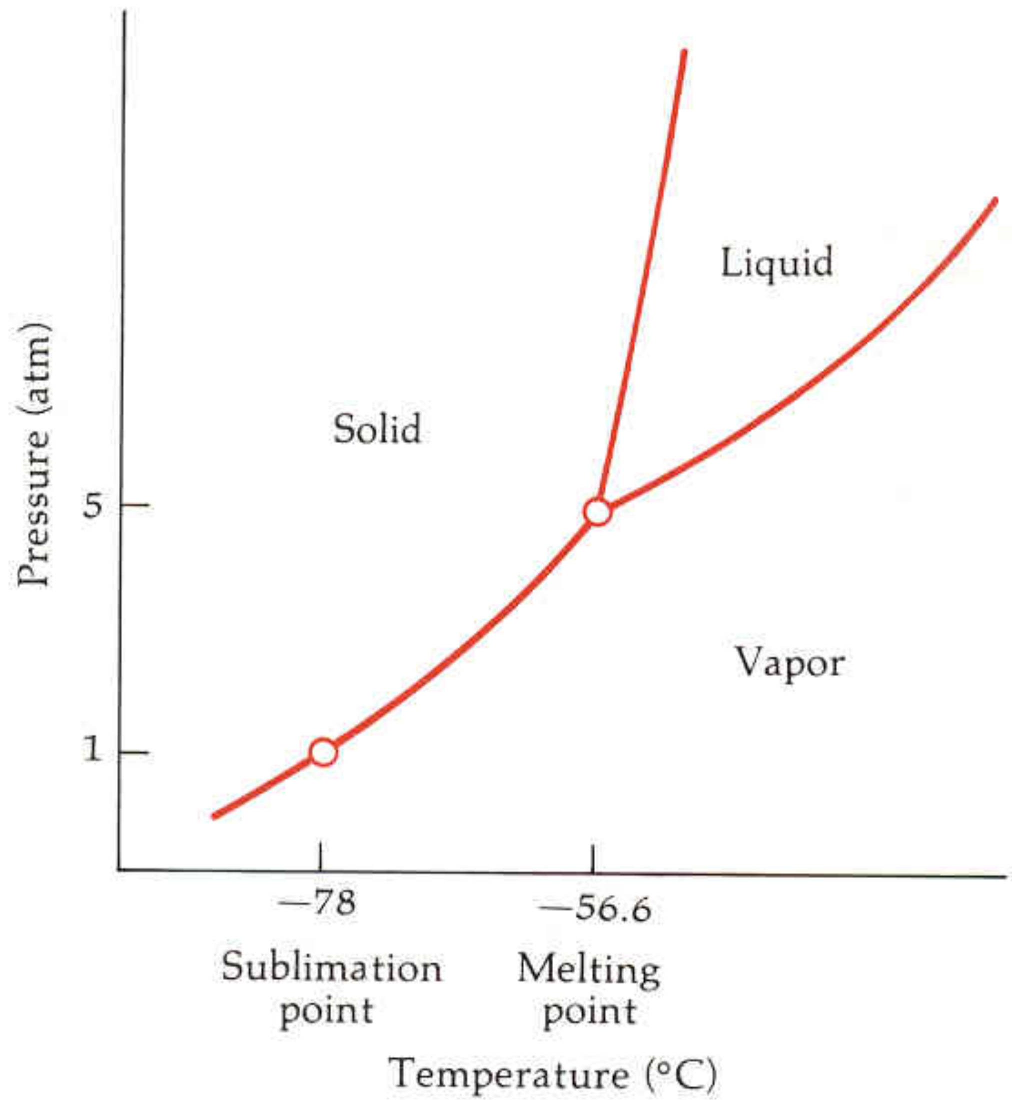
$$\Delta H^\circ(T_2) = \Delta H^\circ(T_1) + \int_{T_1}^{T_2} \Delta C_\mathrm{p}^\circ \, dT$$

$$\Delta S^\circ(T_2) = \Delta S^\circ(T_1) + \int_{T_1}^{T_2} \frac{\Delta C_\mathrm{p}^\circ}{T} \, dT$$

Language – mathematical expressions



Mathematics portrayed graphically



Experimental data portrayed graphically

The richer and deeper is our knowing along this dimension, the better is our understanding in chemistry

Dimension 6

Memory bank of episodes

Episodes are images of real experiences and events

Enriching episodes

- Demonstration of critical point in sealed tube
- Measurement of optical rotation
- Combustion of a balloon containing hydrogen compared with one with both hydrogen and oxygen
- NMR spectrum of particular significance
- Fractional distillation with wrongly positioned thermometer

The richer and deeper is our knowing along this dimension, the better is our understanding in chemistry

Dimension 7

Ability to distinguish between demonstrable knowledge and arbitrary knowledge

White (1994)

Demonstrable knowledge:

- Action of dilute acids on metals

Arbitrary knowledge

- Electric current flows from the positive terminal of a cell

- Bismuth is a metal, selenium is a non-metal

Dimension 8

Appreciation of the sources of our knowledge

or

Knowing why we believe what we believe

- Why do we believe that all matter consists of atoms?
- Why do we believe methanol consists of molecules?
- Why do we believe a methanol molecule has three H atoms joined to a C atom, which is also joined to an O atom, which is in turn joined to an H atom?
- Why do we believe all the bonds in a methanol molecule are single bonds?
- Why do we believe the C-O-H bond angle is 109°?
- Why do we believe the C-O bond can rotate?

The richer and deeper is our knowing along this dimension, the better is our understanding in chemistry

Dimension 10

Recognition of the place and role of chemistry in society

Appreciation of the societal context of chemistry – at the local, national and global levels.

Dimension 11

Understanding what chemists do

as well as when and why

Dimension 12

Knowing what we do not know

Including

- What I do not know
- what the chemistry community does not know

Dimension 13

Degree of interlinking knowledge

What is the pH of a solution which is 0.1 M in acetic acid and 0.1 M in sodium acetate?

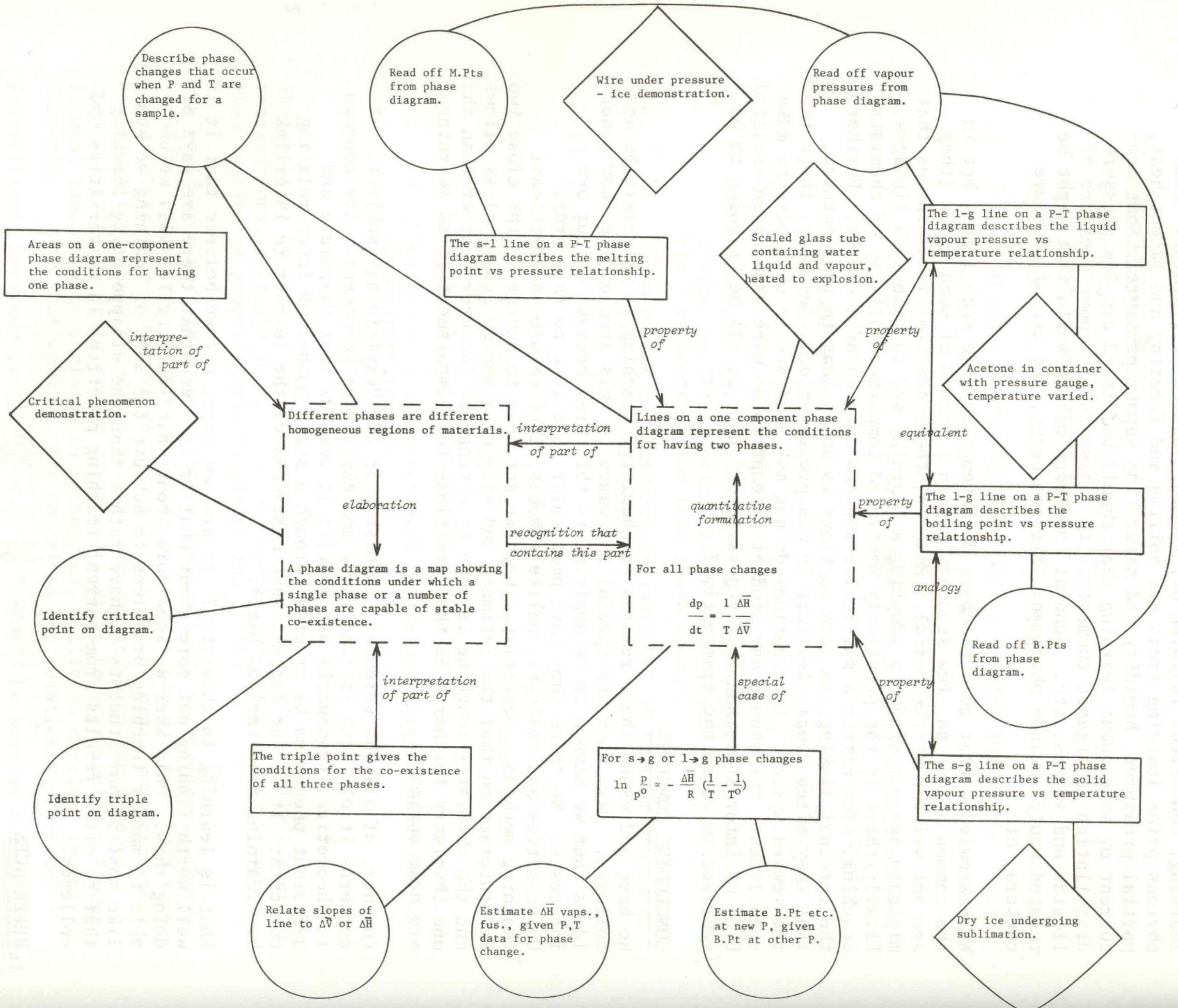
What is the pH of a buffer solution which is 0.1 M in acetic acid and 0.1 M in sodium acetate?

Links:

- between knowledge bits in the same area
- to knowledge in other areas of chemistry
- to knowledge in other disciplines (physics, biochemistry, or even art and history)
- to real-world applications

Links within the same topic:

- Proposition to proposition
- Proposition to procedure
- Episode to procedure
- Episode to image of sub-micro level
- Symbol to image of sub-micro level
- Jargon to episode

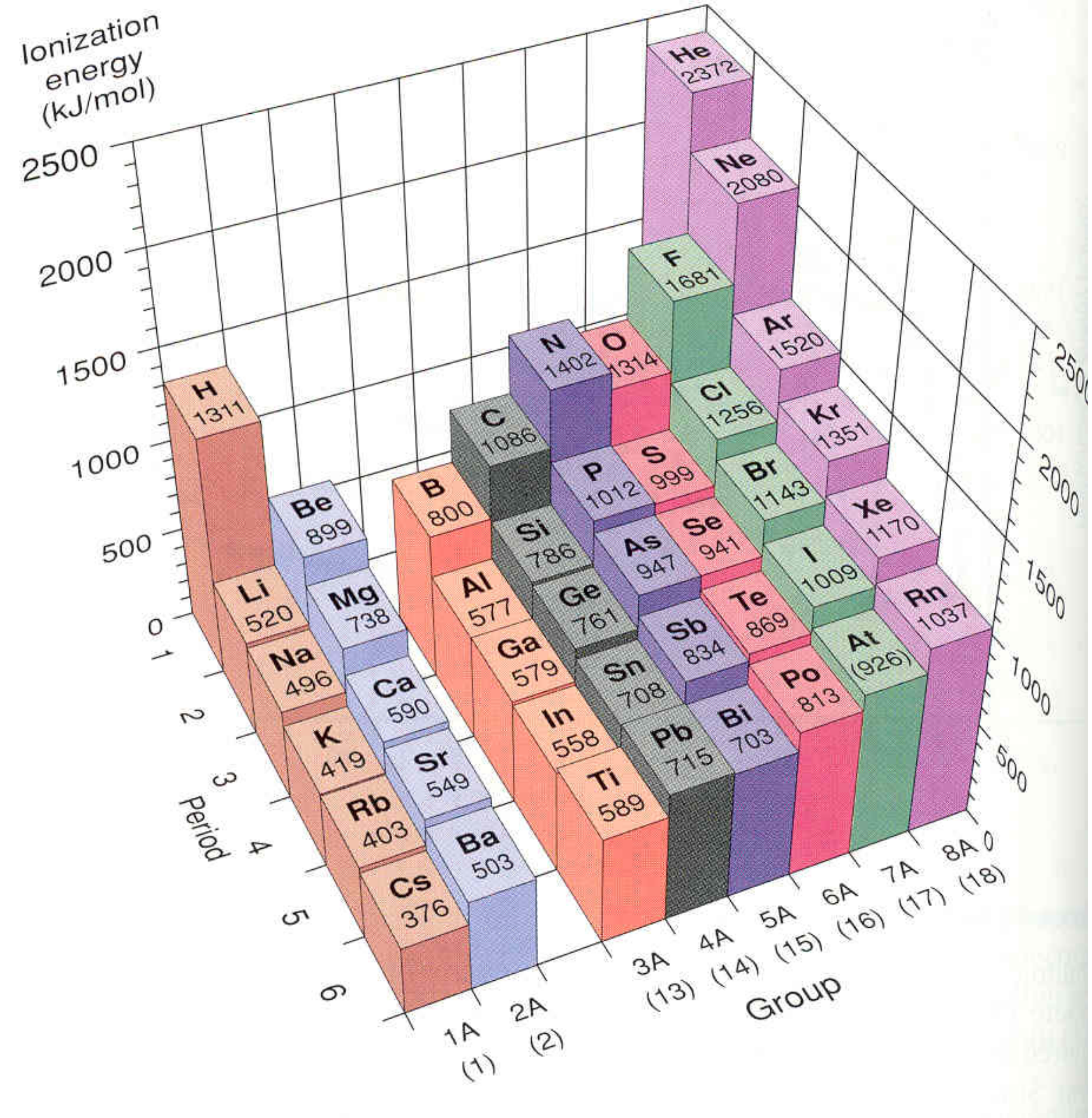


Describe phase changes that occur when P and T are changed for a sample.
Read off M.Pts from phase diagram.
Wire under pressure - ice demonstration.
Read off vapour pressures from phase diagram.
Areas on a one-component phase diagram represent the conditions for having one phase.
The s-l line on a P-T phase diagram describes the melting point vs pressure relationship.
Scaled glass tube containing water liquid and vapour, heated to explosion.
The l-g line on a P-T phase diagram describes the liquid vapour pressure vs temperature relationship.
interpretation of part of
property of
property of
Acetone in container with pressure gauge, temperature varied.
Critical phenomenon demonstration.
Different phases are different homogeneous regions of materials.
interpretation of part of
Lines on a one component phase diagram represent the conditions for having two phases.
equivalent
elaboration
quantitative formulation
property of
The l-g line on a P-T phase diagram describes the boiling point vs pressure relationship.
recognition that contains this part
A phase diagram is a map showing the conditions under which a single phase or a number of phases are capable of stable co-existence.
For all phase changes
$\frac{dp}{dt} = \frac{1}{T}\frac{\Delta\bar{H}}{\Delta\bar{V}}$
analogy
Identify critical point on diagram.
Read off B.Pts from phase diagram.
interpretation of part of
special case of
property of
The triple point gives the conditions for the co-existence of all three phases.
For s→g or l→g phase changes
$\ln\frac{p}{p^o} \simeq -\frac{\Delta\bar{H}}{R}\left(\frac{1}{T}-\frac{1}{T^o}\right)$
The s-g line on a P-T phase diagram describes the solid vapour pressure vs temperature relationship.
Identify triple point on diagram.
Relate slopes of line to $\Delta\bar{V}$ or $\Delta\bar{H}$
Estimate $\Delta\bar{H}$ vaps., fus., given P,T data for phase change.
Estimate B.Pt etc. at new P, given B.Pt at other P.
Dry ice undergoing sublimation.

The richer and deeper is our knowing along this dimension, the better is our understanding in chemistry

Thesis 1

Learning in chemistry occurs along a number of dimensions, each different in character from the others



Knowledge growing along different dimensions of chemistry

Thesis 2

Increased knowledge along any one dimension in chemistry may depend upon knowledge along one or more other dimensions

A model of learning chemistry

One's knowledge of chemistry along any dimension is partial, and differs in degree from dimension to dimension

Understanding grows by incremental progress in the partial knowing along one or more dimensions.

Each increment of growth along one dimension may render possible progress in the partial knowing along other dimensions

Some implications

Awareness of these dimensions of knowing chemistry might help us to re-think the emphases of our curricula and examinations

Knowing (and learning) chemistry is unique because it has characteristic demands along the various dimensions of knowing, so teaching chemistry has unique demands.

Knowing thermochemistry, for example, is unique because it has characteristic demands along particular dimensions.

While in some sense there are generic teaching skills, many of the pedagogical skills of the outstanding teacher are content-specific.

Beginning teachers need to learn not just 'how to teach', but rather 'how to teach chemical equilibrium', or 'how to teach oxidation-reduction', or 'how to teach stereochemistry'. Good teachers need to able to transform chemistry knowledge into a form learnable by the students.

Geddis (1993)

Professional amnesia

In other professions, successive standard-bearers "stand on the shoulders of giants who came before them"

The teaching profession is engaged in many-fold "re-inventions of the wheel": the PCK of each of teacher grows with experience, and then disappears - often with hardly a contribution to the collective wisdom.

We need ‘applied research’ into the strategies of successful teachers

..... to illuminate the teaching of particular topics, rather than to illuminate teaching in some generic sense.

In teacher education

(pre-service and in-service)

should we pay more attention to

pedagogical content knowledge

?

Content knowledge

Understanding the subject matter

Pedagogical knowledge

Understanding teaching and learning, independent of subject matter

Pedagogical content knowledge

Knowledge about the teaching and learning of particular subject matter, based on the particular learning demands inherent in the subject matter.

Mary knows how to whistle

Mary knows a lot about pedagogy

Does Mary know all that is necessary
to teach people to whistle?

Mary must know about whistling from a learning point of view. What is involved in the act of whistling? What are the problems for students to learn this?

There must be a focus on the subject matter from learner's perspective. Understanding the problems of the student helps us to decide how to teach.

Is understanding pedagogical chemistry knowledge an area for future research?

Pedagogical *particle model of matter* knowledge

Pedagogical *chemical equilibrium* knowledge

Pedagogical *stoichiometry* knowledge

Pedagogical *hydrogen bond* knowledge

Pedagogical *distillation* knowledge

To know about chemical equilibrium is not the same as to know about communicating concepts of chemical equilibrium to others

To know about chemical equilibrium is a necessary but insufficient criterion of knowing how to teach about chemical equilibrium.

I urge the encouragement of research into teaching and learning that investigates content-related issues (ie, pedagogical content knowledge research)

I urge the acceptance of this sort of research, recognition of its value, and recognition of it as valid scholarship

I urge that it be performed in collaboration with those in chemistry departments.

Where to?

We have been intensively engaged in *pure* chemical education research – advancing fundamental pedagogical knowledge.

Perhaps it is time to engage in a form of *applied* research which is of more direct use to the chemistry teacher.

Recommendation 1

For each topic, teachers, chemists and chemistry education researchers should work together to systematically identify and document a pool of PCK relevant to the teaching and learning of the topic.

Recommendation 2

Chemistry teaching could benefit from research which provides detailed case studies of master teachers teaching about chemical equilibrium, for example.

This ‘applied research’ would not only describe the teacher’s actions, but also probe his/her thought processes at critical points, and track the changing understandings and perceptions of the students.

We need studies which observe, characterise, interpret and evaluate the PCK used by particular teachers in instruction of a particular topic, ***to illuminate the teaching of that topic***, rather than to illuminate teaching in some generic sense.

And finally …

Development of pedagogical content knowledge about topic X constitutes the creation of new knowledge different from, but equally as worthy as, research knowledge about topic X itself.

Recognition of this might enhance the status of good chemistry teachers and good chemistry education researchers

Listen to …..
TedTalk (Malcolm Gladwell)

Choice, happiness and spaghetti sauce

https://www.google.com.au/search?q=malcolm+gladwell+ted+talk+choice+happiness+and+spaghetti+sauce&rlz=1C1CHZL_enAU748AU748&oq=Malcolm+Gladwell+Ted+Talk+Chocie&aqs=chrome.1.69i57j0.18419j0j8&sourceid=chrome&ie=UTF-8