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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 not 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

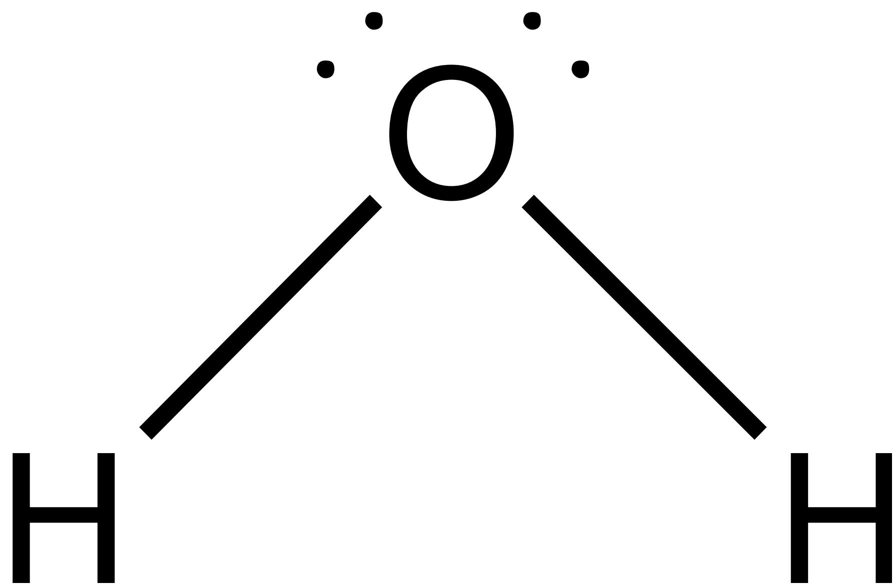
Chemistry is not about atoms, molecules, their structures and reactivities ....

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

Ability to distinguish between the model and the ‘reality’

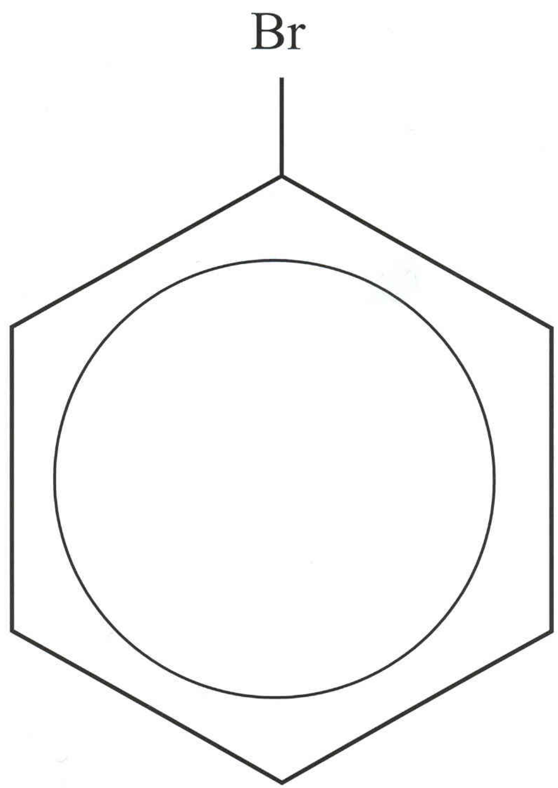
Are s, p, d, f orbitals reality? or models?

Are covalent bonds a reality?

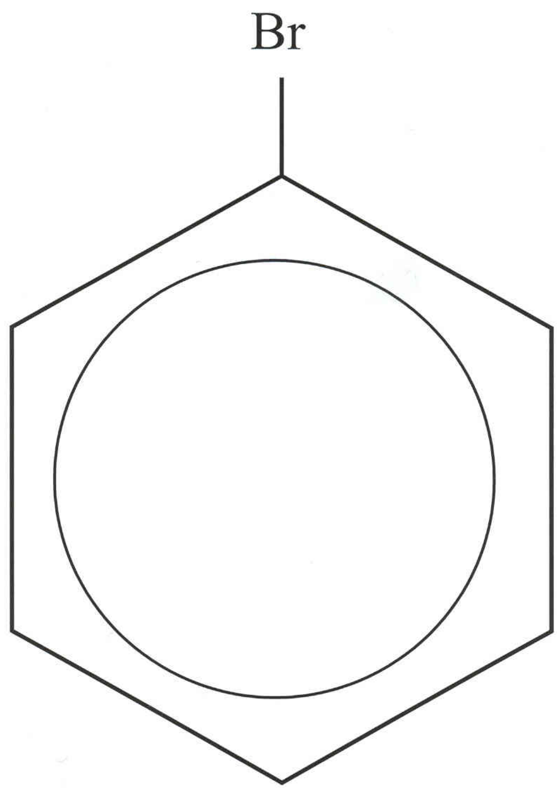


Is this really what a water molecule looks like?
Do we know what the reality is?

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



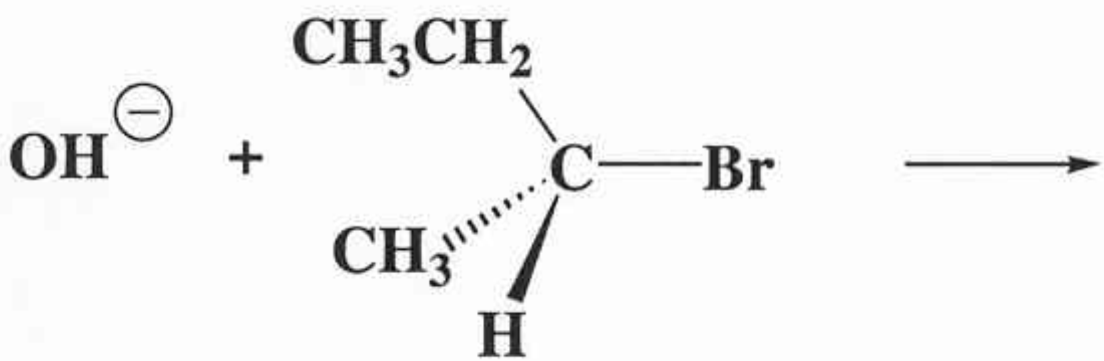
Kleinman et. al. (1987). Does bromobenzene have a plane of symmetry?

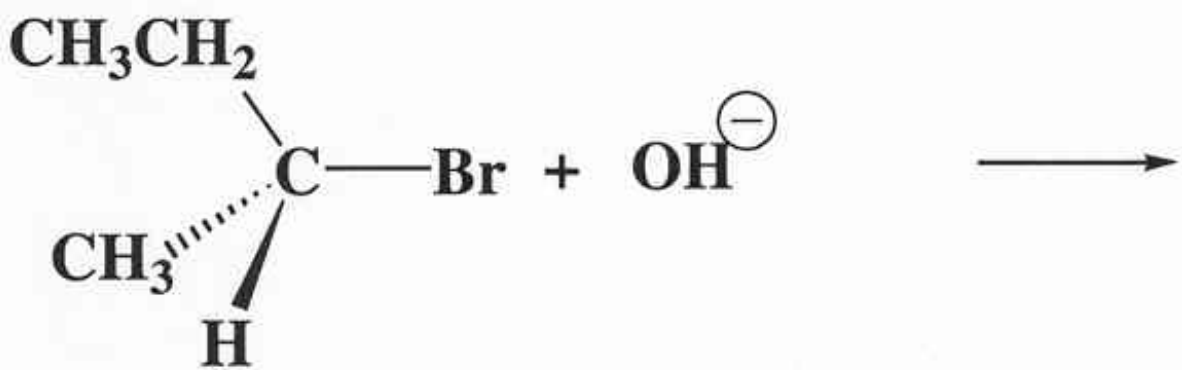


No because B $\neq$ r

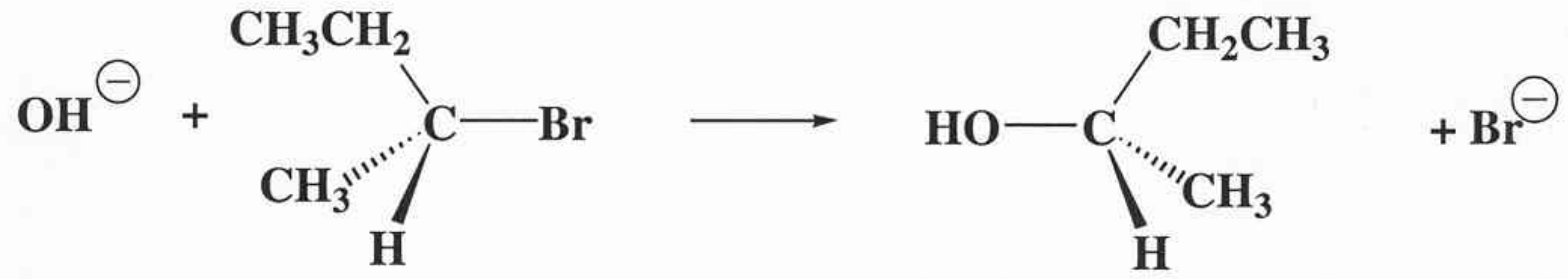
Ladhams Zieba (2004) - two tests to students …

What are the products?





The most common student responses



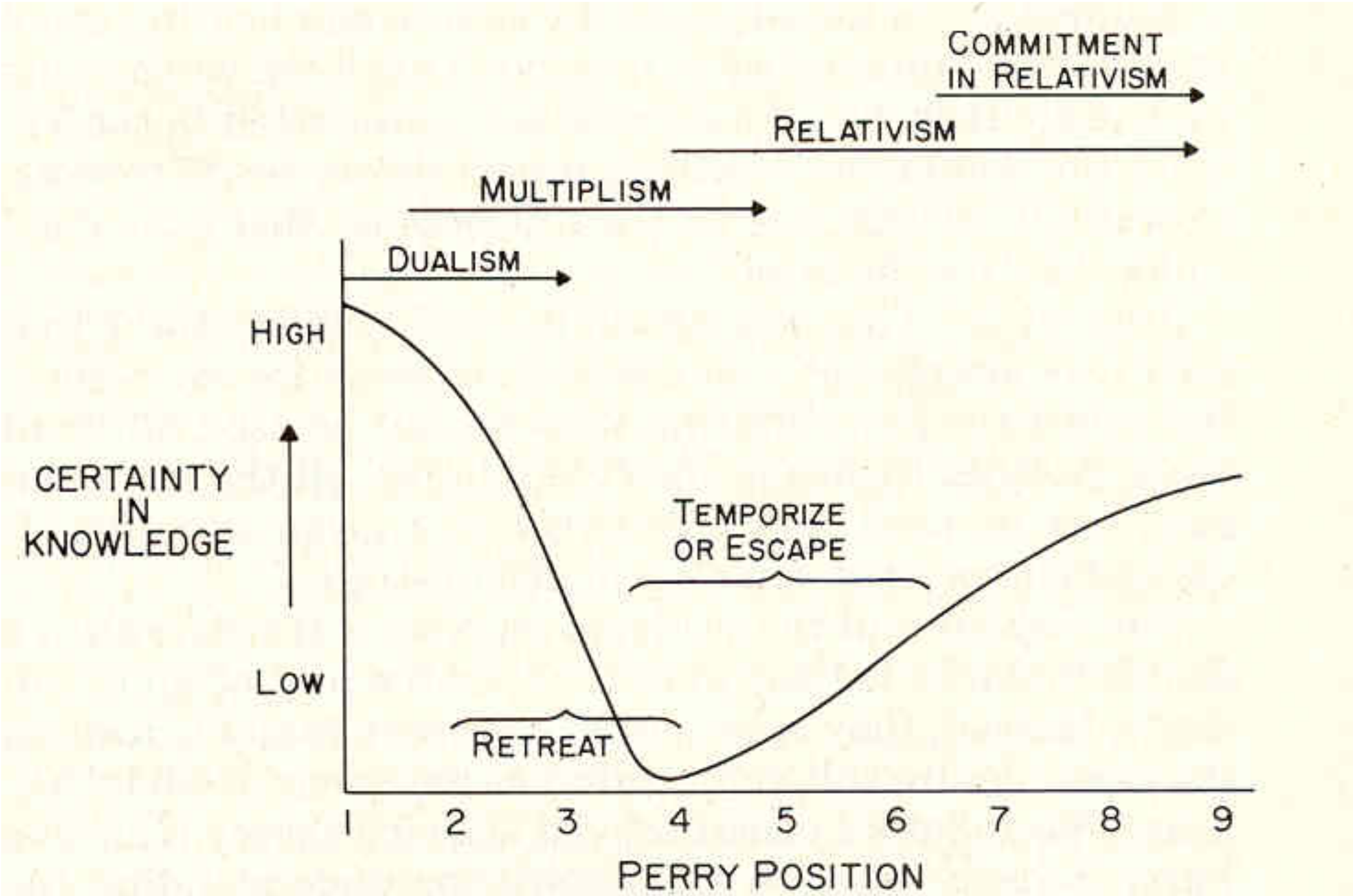
Is the outcome of a reaction determined by how we write the representation of our model of the system!?

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?

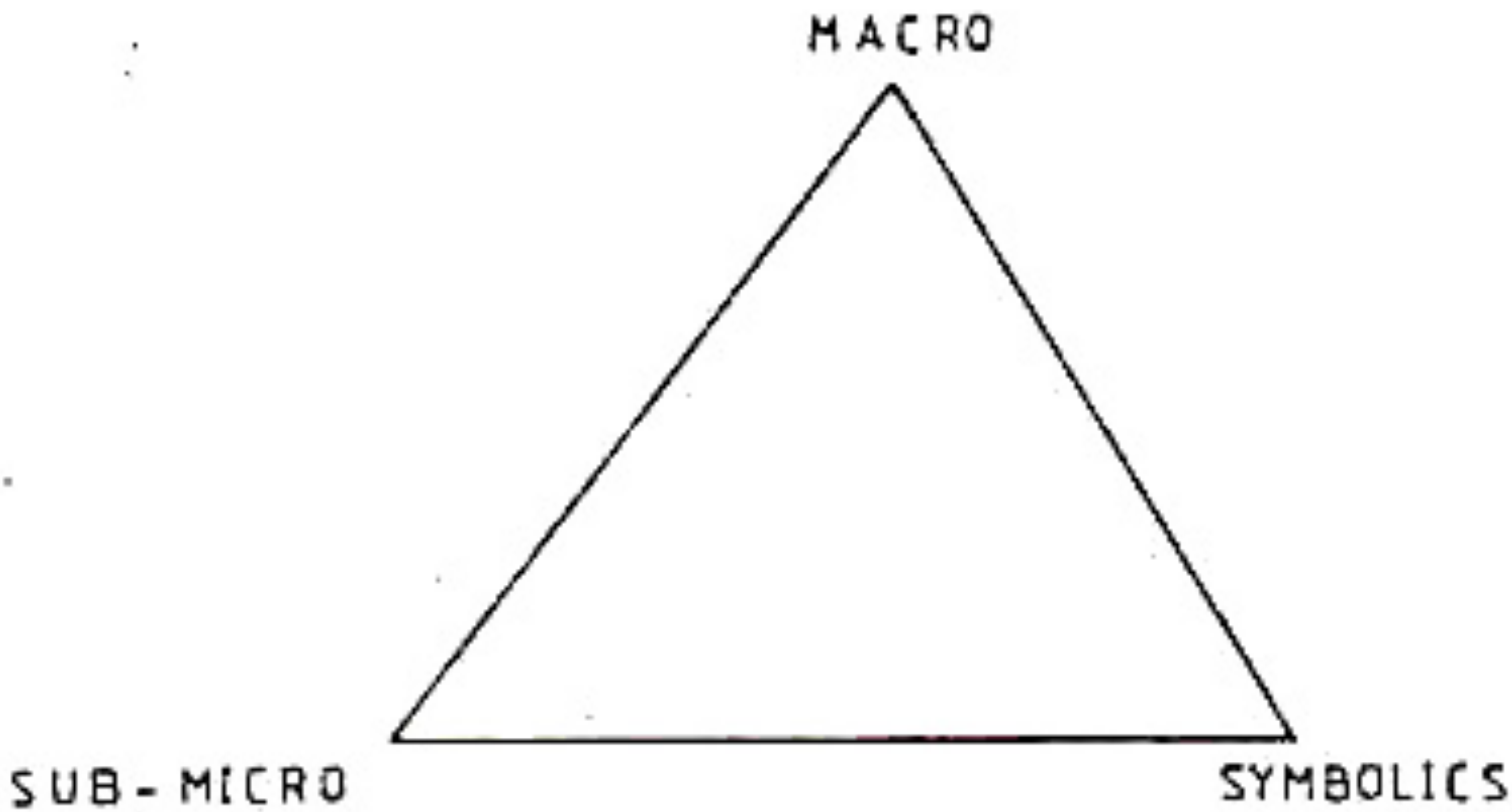
Recognition of the boundary conditions of applicability of models

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



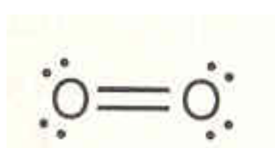
Levels of operation in chemistry – Johnstone (1991)

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

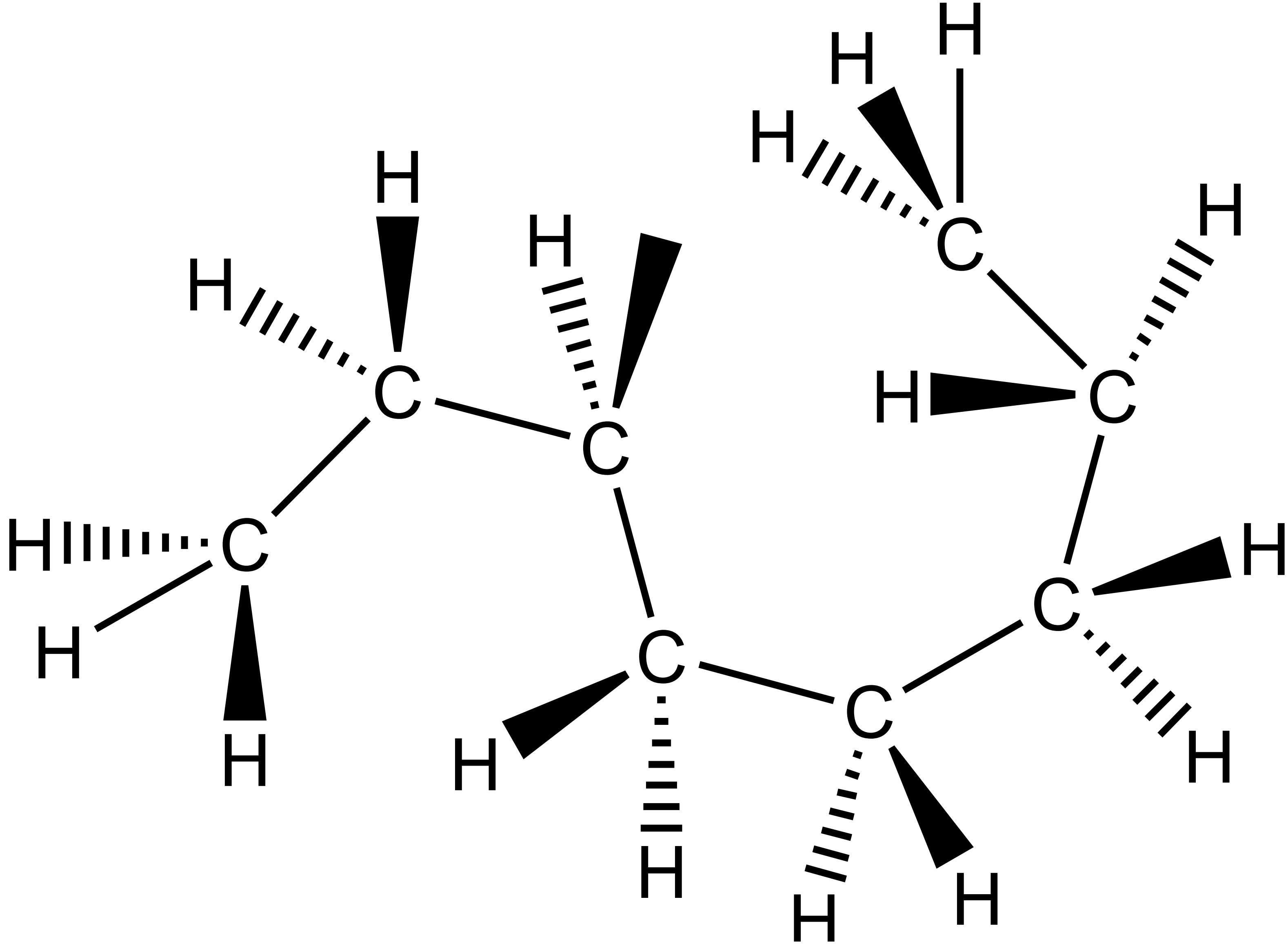
Jensen (1998)

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 

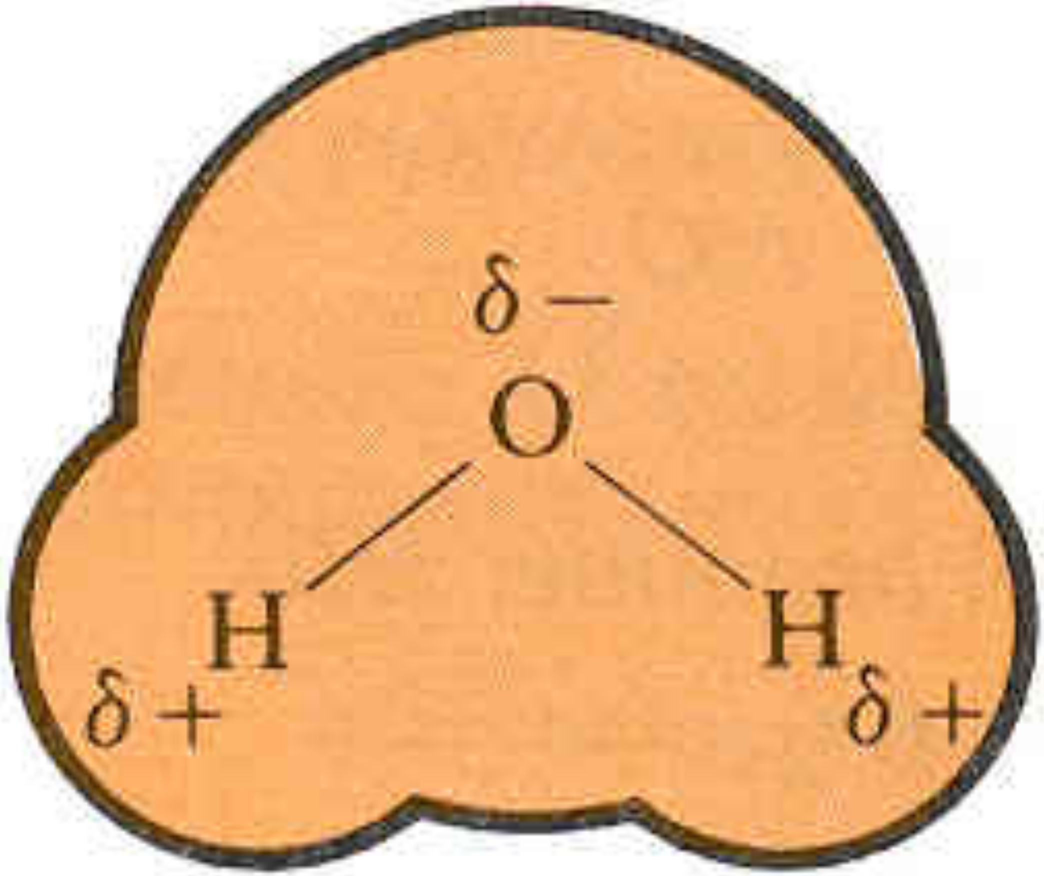
Molar Macroscopic	substances
Molecular Sub-microscopic	arrangements of atoms
Electrical	Distribution of electrons within atoms

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

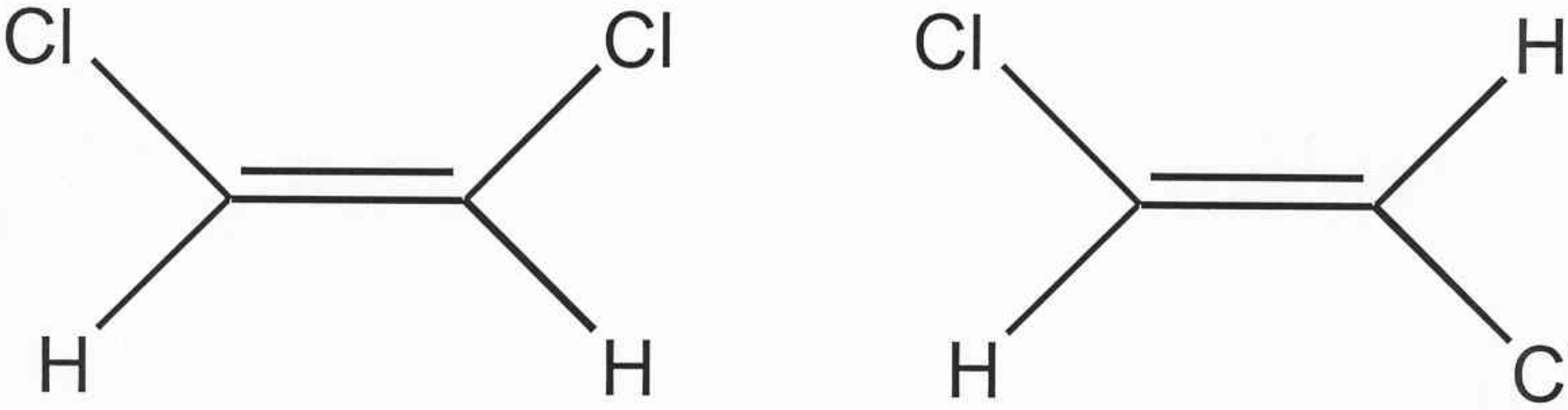
At the molecular level, sometimes we use a one-particle image



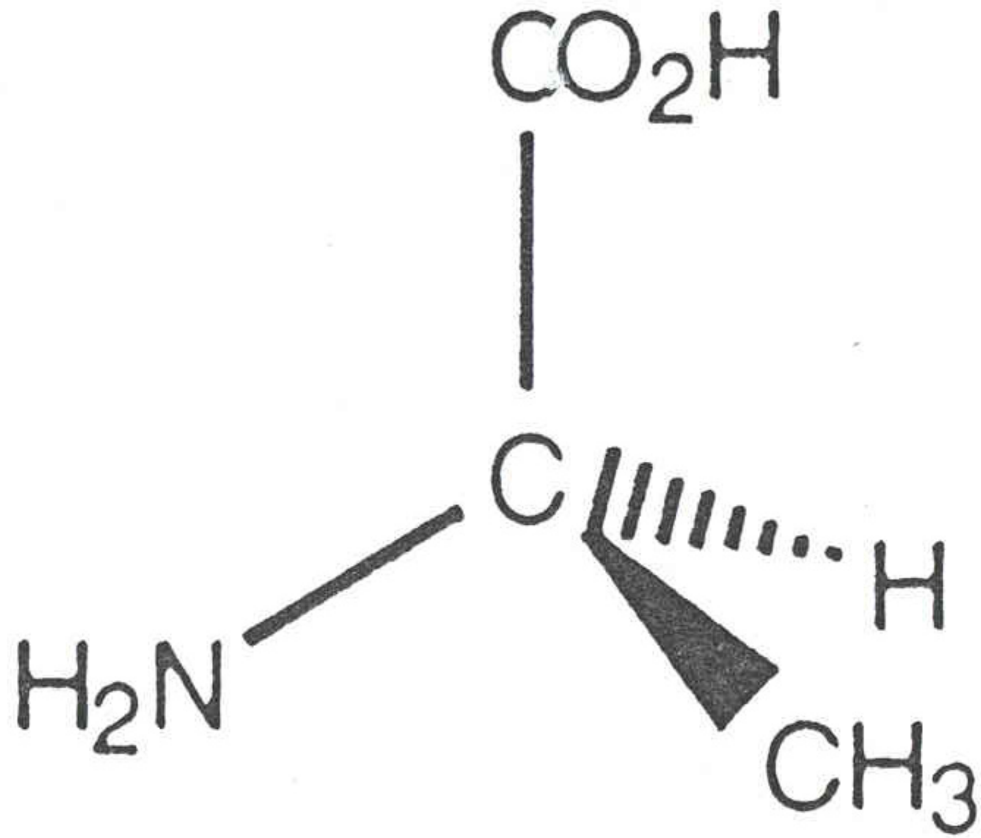
Connectivity and bond angles



polarity

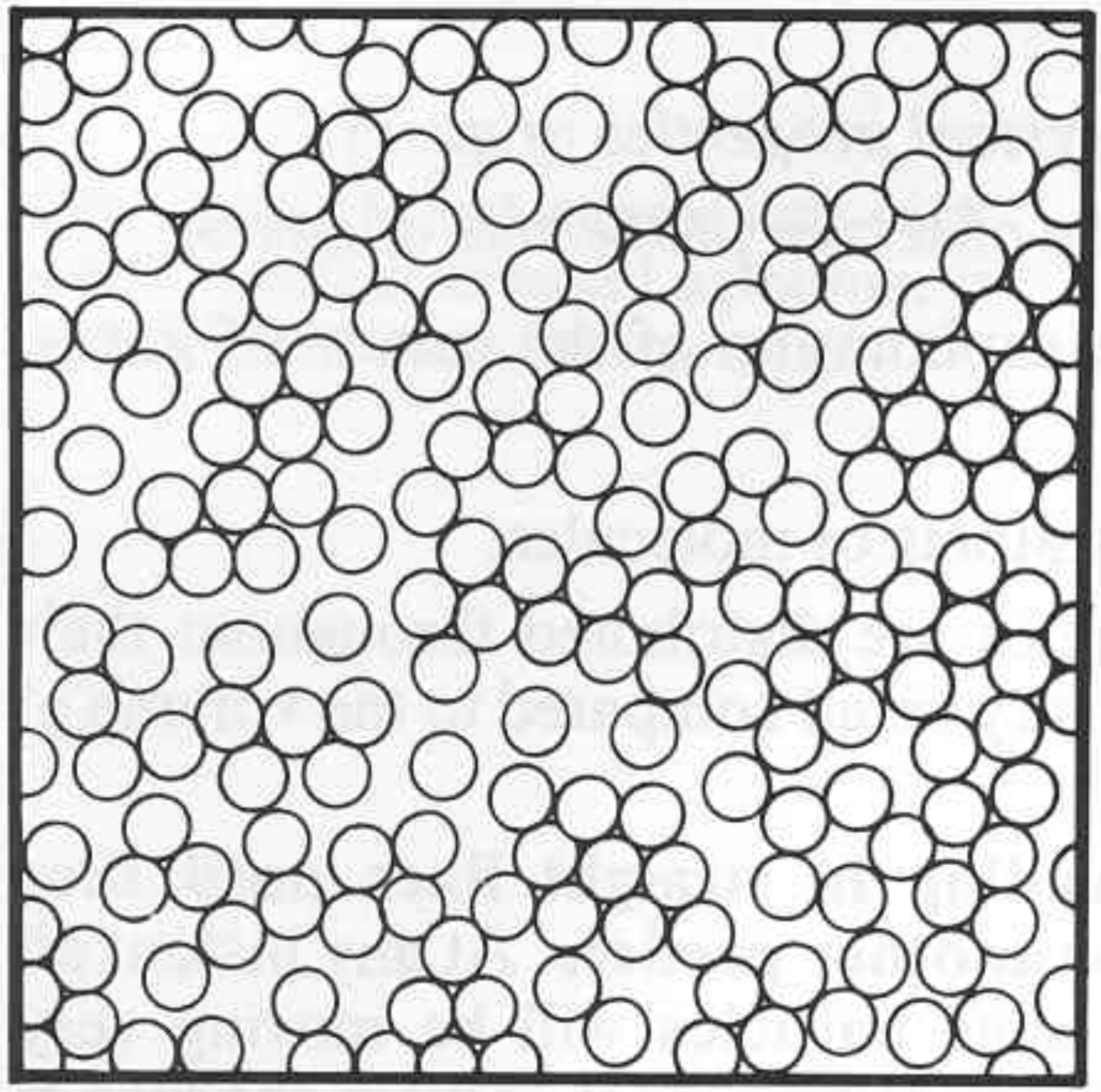


cis- trans- isomerism

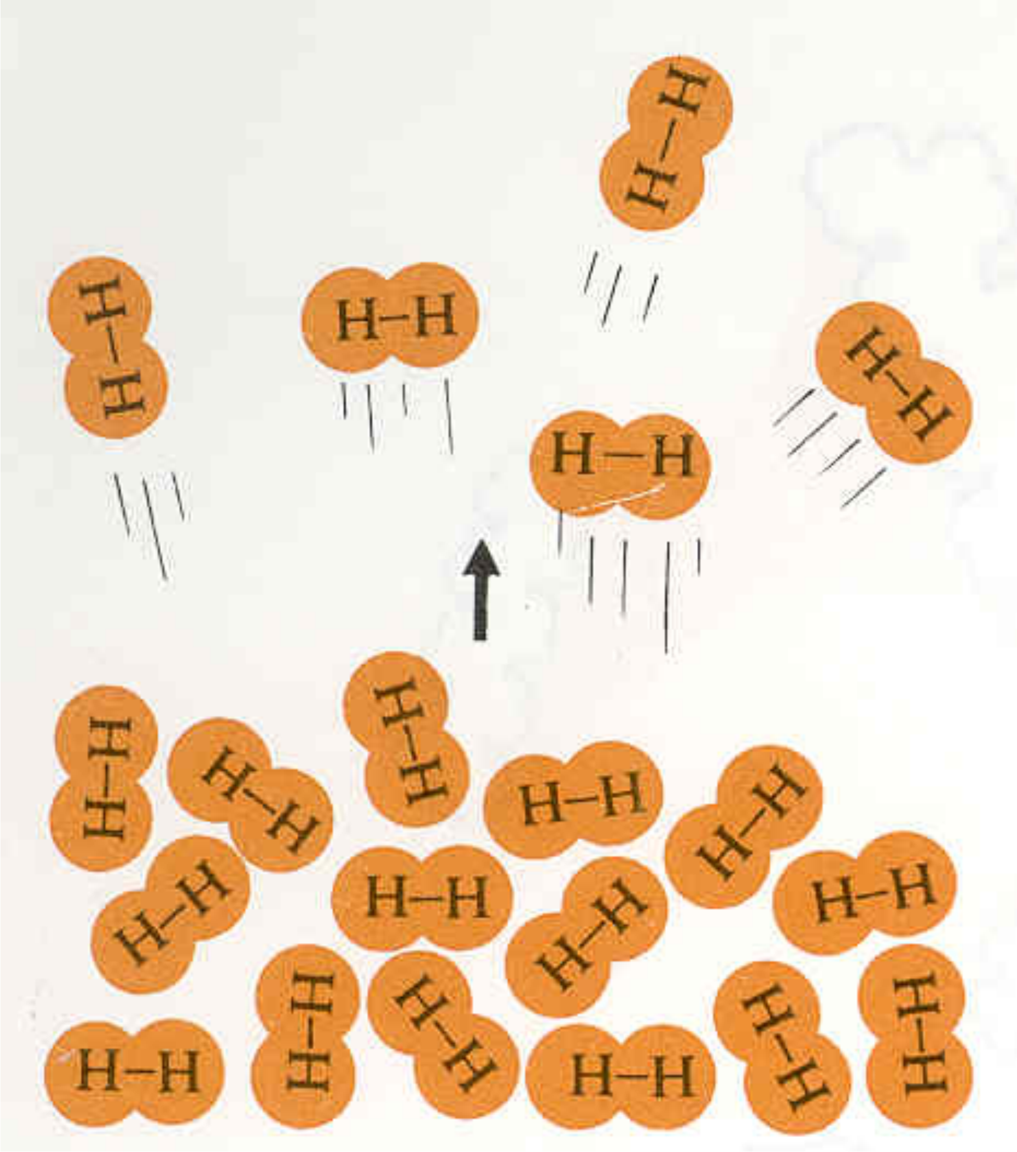


chirality

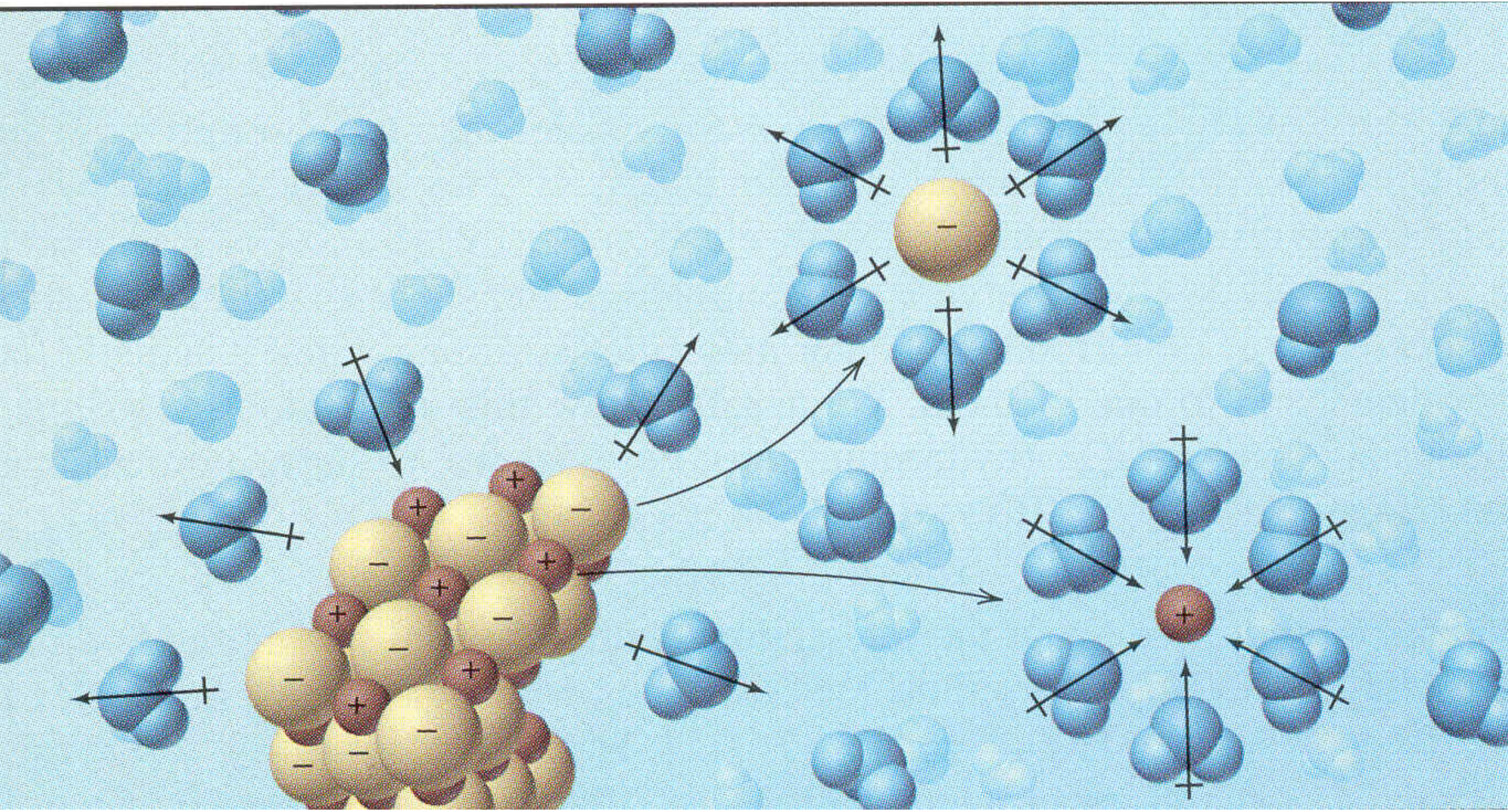
Sometimes we use a many-particle image:



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, Doni, 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* <u>*substances*</u> *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 $O_2(g)$?

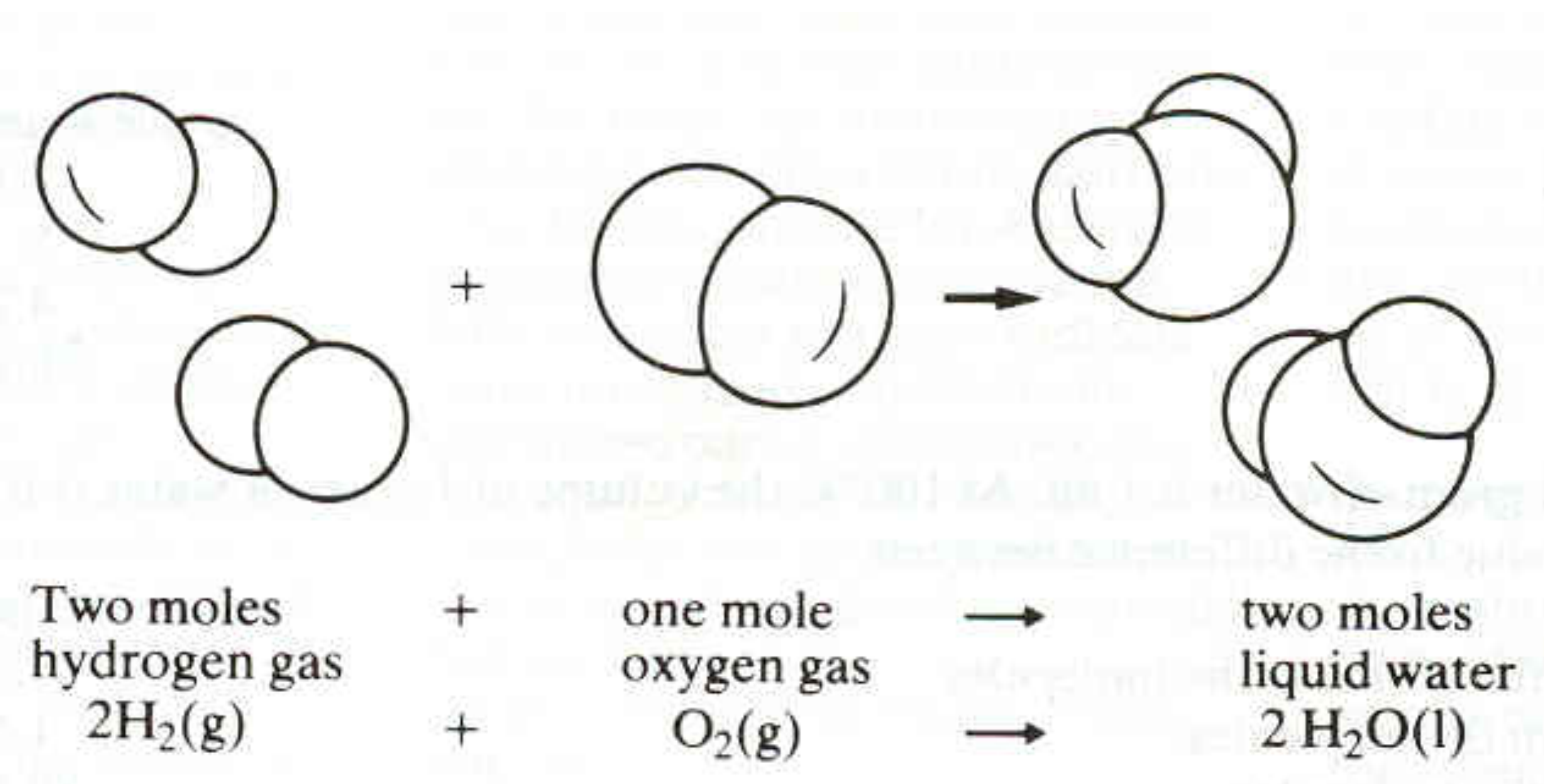
Does it matter?

Ben-Zvi *et. al* (1987)

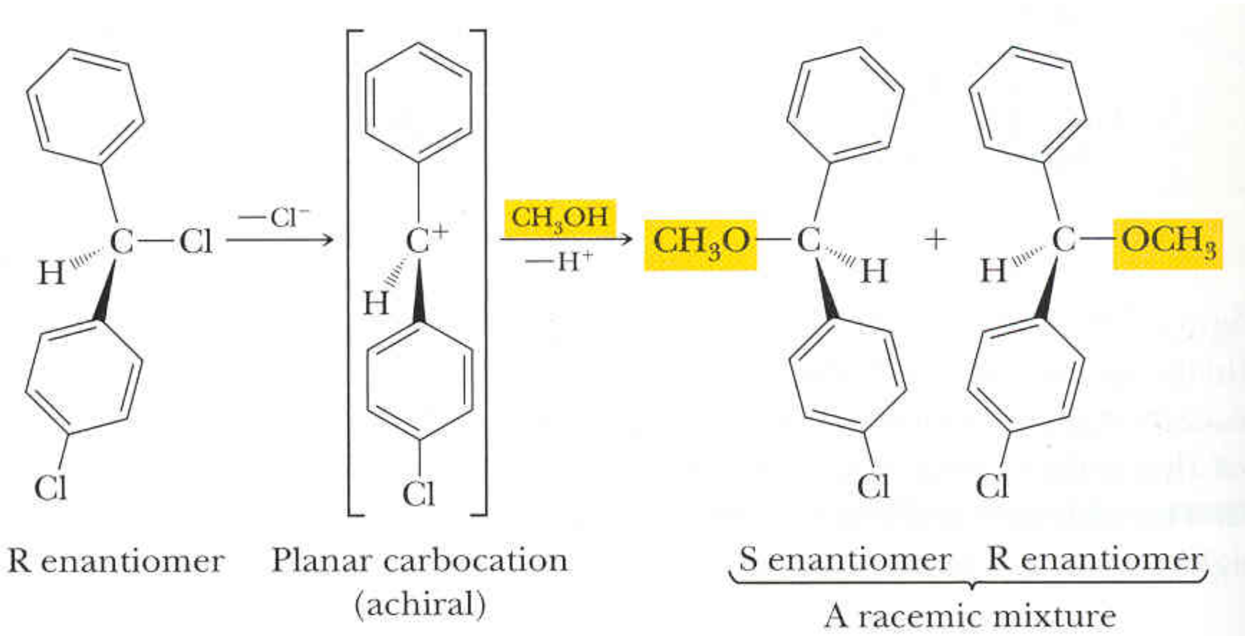
Is it possible for N_2O_5 to be formed by reaction between $N_2(g)$ and $O_2(g)$?

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

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

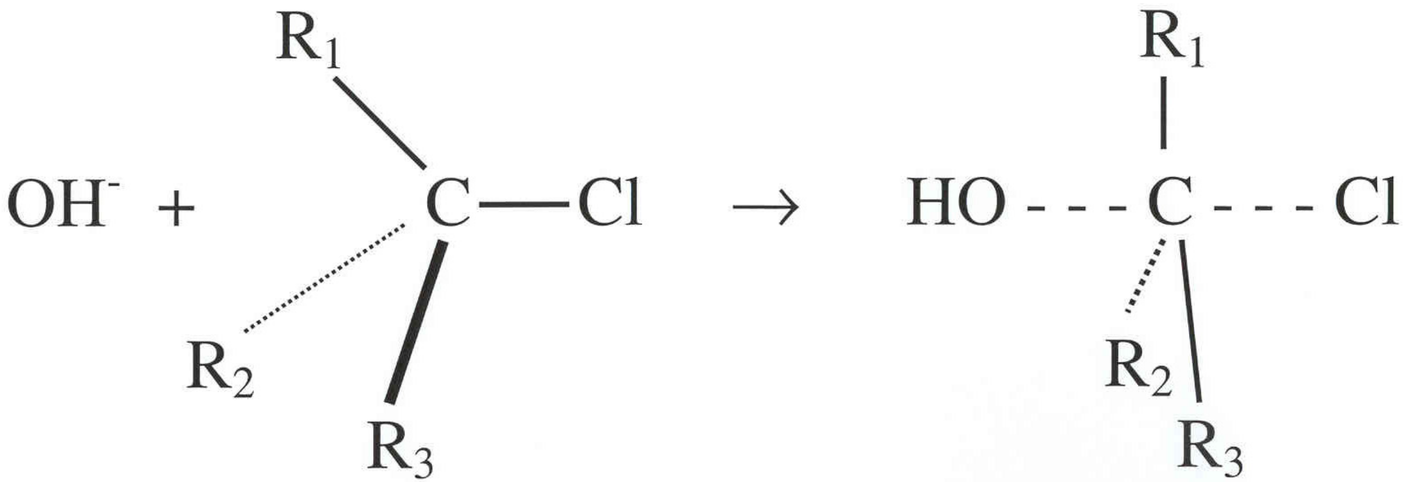


Ladhams Zieba (2002)



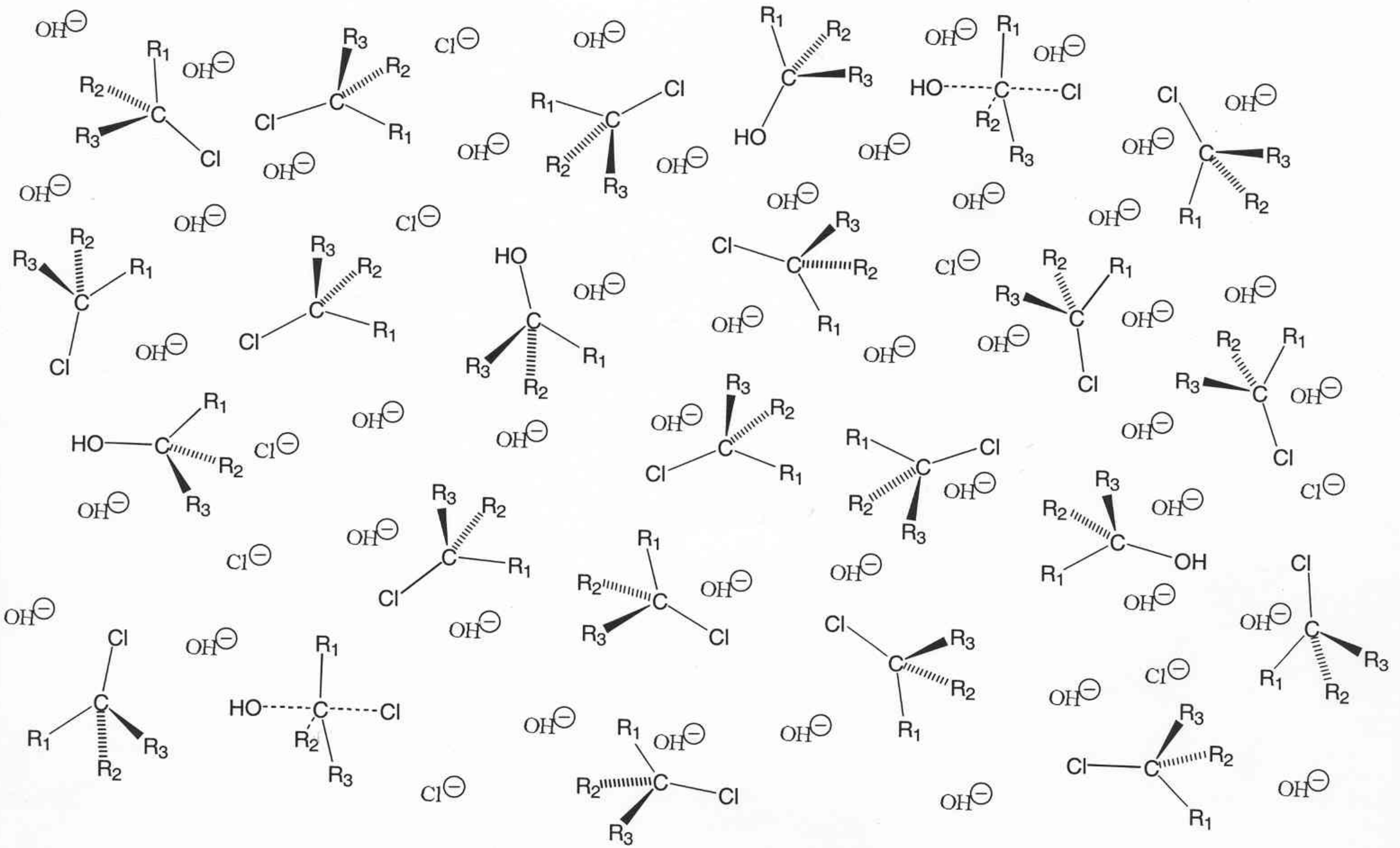
How can we get two product molecules from one starting molecule?

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