ALTERNATE SOLVENTS- GREEN SOLVENTS

SOLVENT USAGE :-

- Solvents are substances that are liquid during application and will dissolve other substances, which can be recovered unchanged on removal of the solvent.
- Research in green chemistry is making dramatic achievements in the design of chemicals, chemical syntheses, and chemical processes that are environmentally benign and economically feasible.
- The goal of green chemistry is to reduce the hazards associated with products and processes

- Widely used throughout the chemical industry
  - Synthetic Chemistry
    - Reaction medium on laboratory and industrial scale
    - Extensively used in work-up and purification (usually more than for reaction medium)
  - Analytical Chemistry
    - Sample extraction and preparation (Spectroscopy)
    - Chromatography mobile phase (HPLC, TLC etc.)
  - Crystallisation
    - Recrystallisation to purify compounds and prepare crystals suitable for analysis

- Used much more widely than just synthetic chemistry
- Coatings:
  - Paints, adhesives
    - Solvent usually removed by evaporation after application leaving coating behind
    - Coating removal
- Cleaning
  - E.g. Dry cleaning – extensive use of perchloroethylene, a known cancer suspect agent, which also contaminates groundwater supplies
- Extraction
  - E.g. Coffee decaffeination (benzene, CH_2Cl_2)

- Is the substance really needed?
- Could alternate, less toxic substitutes be used?
- What are the risks versus benefits for continued use of the agent?
- What is the environmental impact of the substance?
- Does the procurement of the agent deplete an environmental resource?
- Does existing technology permit the “final” disposal of the substance?
- If used, do we have the technology to ensure the “safe” use of the substance?

- <u>Solvents as a Green Chemistry Tool :-</u>

  Through a combination of knowledge of the nature of a chemical's hazardous properties with the ability to manipulate the chemical's structure, chemists possess the ability and skill to mitigate the hazard.

- <u>Selection of Solvents and Reaction Conditions:-</u>

  Selection of a solvent should be based not only on any hazards that the chemical may possess, but also on existing environmental problems that its use may exacerbate.

SOLVENT EFFECTS & GREEN CHEMISTRY

In order to study the solvent effect we need an help of conceptual basis such as:-

- Theories of molecular structures.
- Concept of polarity.
- Bulk properties

a) Dielectric constant

b) Density

PHYSICAL PROPERTIES OF SOLVENT’S:-

- The physical properties of solvents greatly influence the choice of solvent for a particular application.
- The solvent should be liquid under the temperature and pressure conditions at which it is employed.
- thermodynamic properties:- density & vapor pressure, temperature & pressure coefficients, as well as the heat capacity surface tension.
- transport properties:- such as viscosity, diffusion coefficient, & thermal conductivity, also need to be considered

- Electrical, optical, and magnetic properties, such as the dipole moment, dielectric constant, refractive index, magnetic susceptibility, and electrical conductance are relevant, too.
- Molecular characteristics, such as the size, surface area, and volume, as well as orientational relaxational times, have appreciable bearing on the applicability of a solvent or on the interpretation of solvent effects.

CHEMICAL PROPERTIES OF SOLVENT'S:-

- The chemical properties of solvents have obviously a strong bearing on their applicability for various purposes.

- Structuredness of Solvents:-The volatility, viscosity, diffusion coefficient and relaxation rates of solvents are described quantitatively by their structuredness.

- Stiffness:-expressed by the cohesive energy density

- Openness:-the difference between its molar and intrinsic volumes

- Ordering:- This is the deficit of entropy of the liquid solvent relative to the solvent vapor or the dipole orientation correlation.

- Polarity in Molecules:-*Dispersion Forces-* Molecules that have no permanent dipole still have their electrons in movement.
- *Polarization and Polarizability*:-If the molecules have a dipole but there is no applied electric field, the dipoles are randomly orientated.
- Dipole–dipole interactions between rotating dipolar molecules are small.

Only for molecules with large dipoles, and where hydrogen bonding is absent, such as DMSO (dimethyl sulfoxide) and acetonitrile, do dipole–dipole attractions contribute significantly to molecular association.

- **Dipole moments of some solvents:-**

- Benzene 0
- DMSO 3.9
- Acetone 2.69
- Hydrogen fluoride 1.83
- Water 1.83
- THF 1.75

Green solvents & its definition

- GOALS OF GREEN CHEMISTRY:-

i. To reduce hazards associated with product & process, this is to maintain not only quality of life but also technical achievements.

ii. Reduction of risk:

RISK= HAZARD × EXPOSURE.

Solvents in Green Chemistry

Solvents define a major part of the environmental performance of processes in chemical industry and also impact on cost, safety and health issues. The idea of "**green**" solvents expresses the goal to minimize the environmental impact resulting from the use of solvents in chemical production.

CONTI.......

- An ideal green solvent must possess following criteria:

i. Must have human safety.
ii. Reduced hazard.
iii. Easily degradable.
iv. Provide high product yield.

- Criteria for solvent selection:

i. Must have less human & environmental absorption.
ii. Its environmental toxicity should be understood.
iii. Environmental fate should be understood.

Greener Solvent Alternatives

Supercritical fluids

Ionic liquids

Water

No Solvent

Perfluorinated hydrocarbons

Lactate esters

Green Solvents in Green Chemistry:-

- Water
- Methanol
- Nitromethane
- Acetone
- Ethanol
- DMF
- DMSO
- HMPA
- Acetonitrile
- Pyridine
- Ammonia

APPLICATION OF GREEN SOLVENTS:-

- New syntheses of Ibuprofen and Zoloft.
- Integrated circuit production.
- Removing Arsenic and Chromate from pressure treated wood.
- Many new pesticides.
- New oxidants for bleaching paper and disinfecting water.
- Getting the lead out of automobile paints.
- Recyclable carpeting.
- Replacing VOCs and chlorinated solvents.
- Biodegradable polymers from renewable resources

Water : A Green Solvent With A Difference........

Water is the best solvent among all the green solvents because of its many advantages such as.....

* *Environmental benefits*
* *Safety*
* *Synthetic efficiency*
* *Simple operation*
* *Cost effective*
* *Potential for new synthetic methodologies*

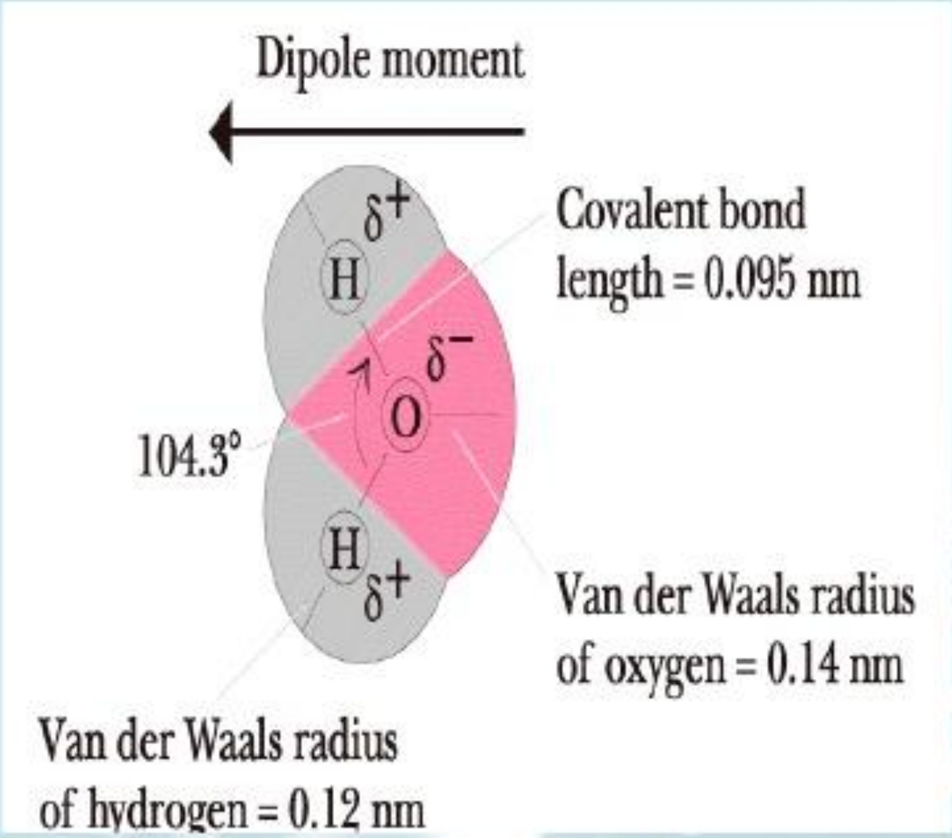
Water : A solvent for chemical reactions

- Chemical reactions means breaking and formation of bonds.
- Water is the "Universal solvent" in nature.
- Living cell represents the most complex chemical reactions termed as *biochemical reactions* – All such reactions occur in environment with >90% water, with use of enzymes that also contain water inside their protein structure.
- Inorganic reactions are carried out generally using water as solvent.
- Water was not preferred for organic reactions because of poor solubility of most organic compounds in water.

Water as a solvent with a difference

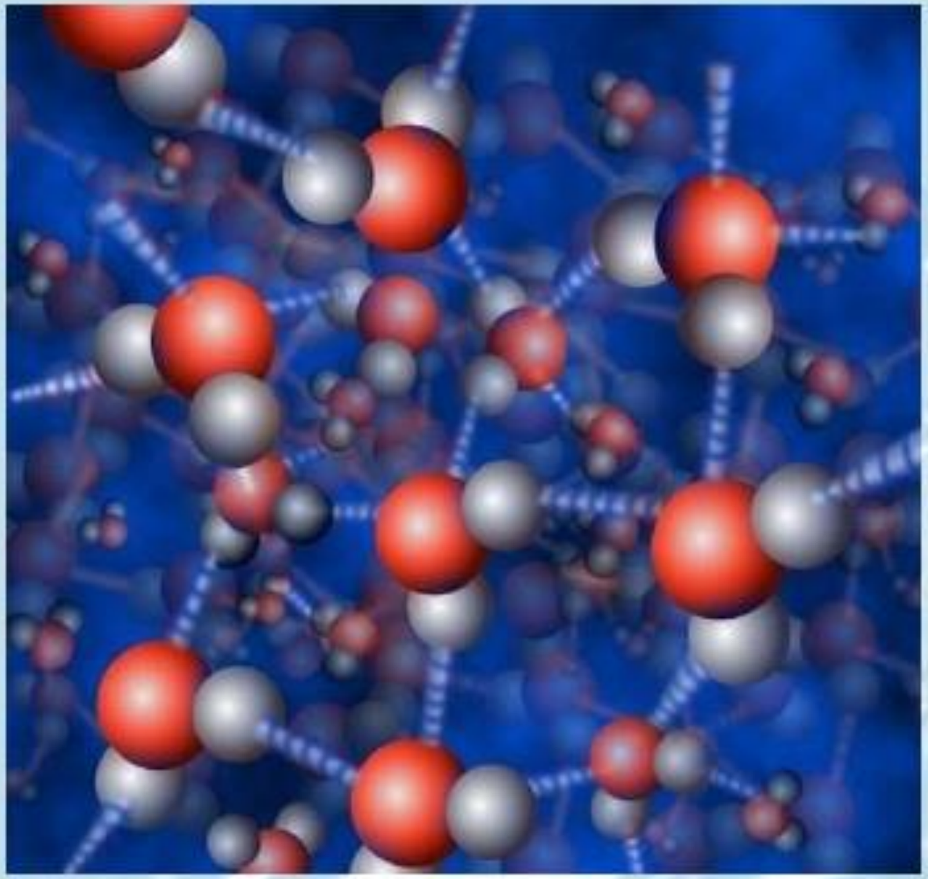
- Physical properties :-
  - Low *viscosity* – Ease of solute movement
  - High *specific heat* – Better temp. control
  - High *surface tension* – Wetting phenomena
  - High *dielectric constant* - Solvation
  - Large *cohesive energy density*
  - *Internal pressure* of water
  - Anomalously strong hydrogen bonding is the central phenomena around which most of its physicochemical characteristics arise.

Structure of Water molecule



- Water has two hydrogen atoms covalently linked to a central oxygen atom.
- Two lone pairs of electrons occupy other two sp^3 orbitals.
- Structure is a distorted tetrahedron.
- This geometry, and the electronegativity of the oxygen atom induces a net dipole moment.
- The tetrahedral bond angle is 104.3°
- Because of the dipole moment, water can serve as both a hydrogen bond donor and acceptor.

Hydrogen Bonding in Water



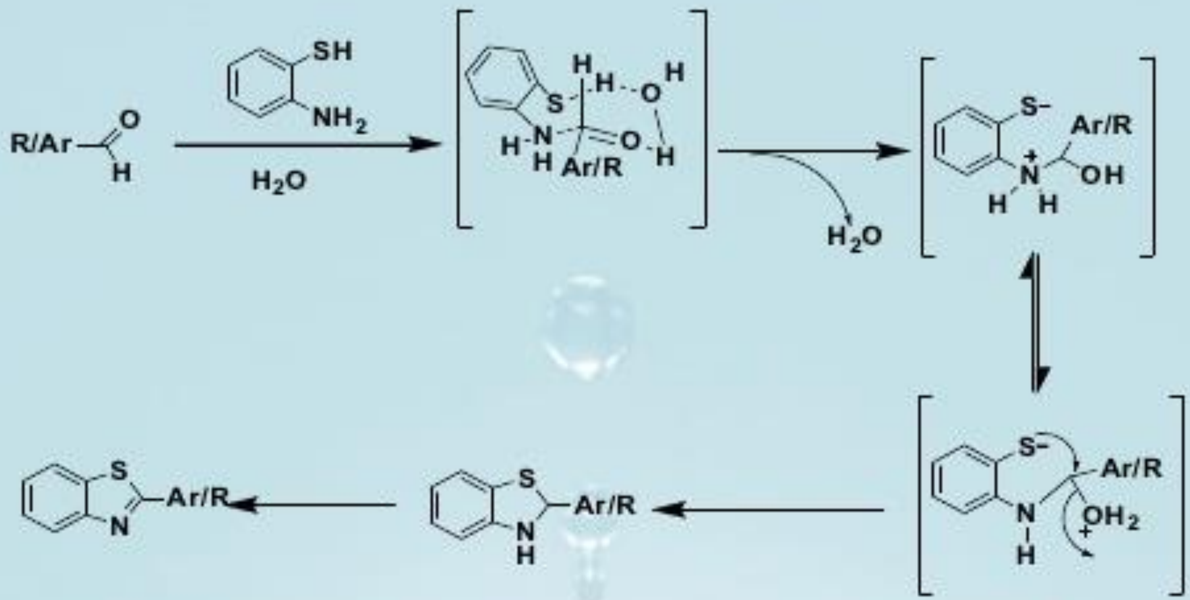
- One water molecule can form 4 hydrogen bonds with other water molecules as shown here.
- It is the potential to form four H-bonds per water molecule that endows it with the anomalously high boiling point, melting point, heat of vaporization, and surface tension, cohesive energy density.
- Hydrogen bonds between neighboring molecules are weak (23 kJ/mole) relative to the H–O covalent bonds (420 kJ/mol)

Water as *dual activator* medium

* Hydrogen bonding in water endows a unique characteristic - dual activator property.
* Water can activate both – nucleophiles & electrophiles, and hence accelerates polar reactions.

For example, the role of water in the reaction of an aldehyde with 2-aminothiophenol for benzothiozole synthesis.

Water as *dual activator* medium



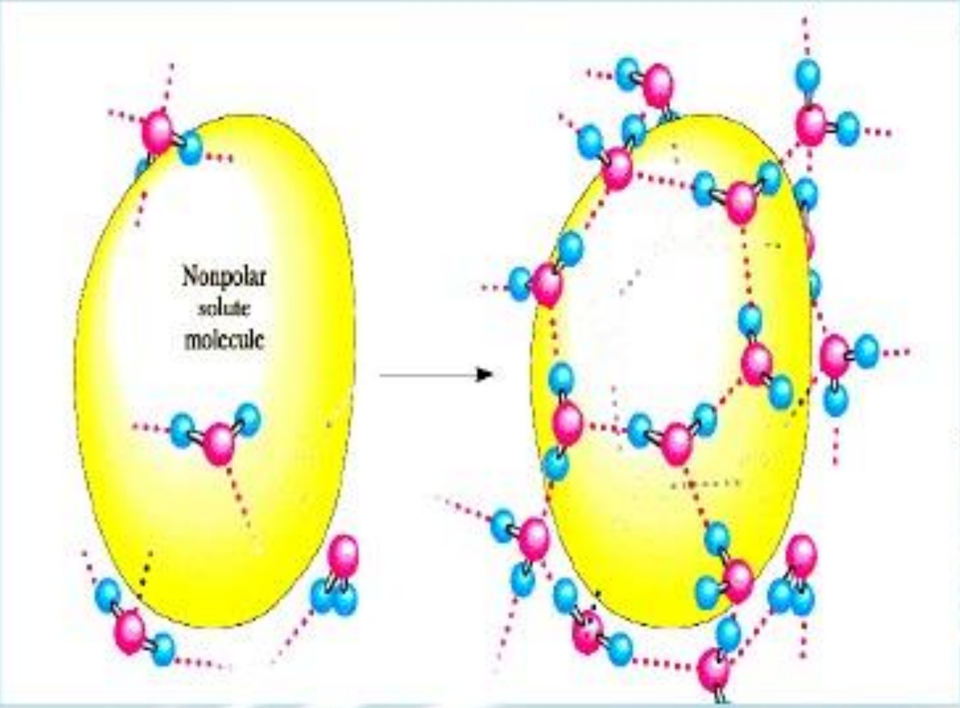
- Hydrogen bond formation between water and the carbonyl oxygen atom of the aldehyde causes "***Electrophilic activation***" making the carbonyl group more susceptible to nucleophilic attack.
- The oxygen atom of water in turn forms hydrogen bond with the SH hydrogen atom of 2-aminothiophenol and increases the electron density at the sulfur atom endowing "***Nucleophilic activation***".

Chankeshwara S. V., Rudrawar S., Chakraborti A. K.;
12th ISMAS-WS-2007, March 25-30, 2007, Cidade de Goa, Dona Paula, Goa

Forced hydrophobic interactions

- Interaction between hydrophobic molecules and water is not possible, because **ΔG > 0**.
- In fact, due to large **cohesive energy density**, water molecules prefer to react with other water molecules only and thus to exclude hydrophobic molecules.
- Because of high cohesive energy density, it is also very energy consuming (costly) for hydrophobic molecules to create cavity within the water phase, hence they are always under a pressure, termed as **internal pressure of water**, due to which hydrophobic molecules occupy the smallest possible volume.
- Water forms a clathrate or *hydration shell* around hydrophobic substances.
- In this hydration shell, the water molecules are very ordered, which makes this an entropically costly i.e. unfavorable condition.

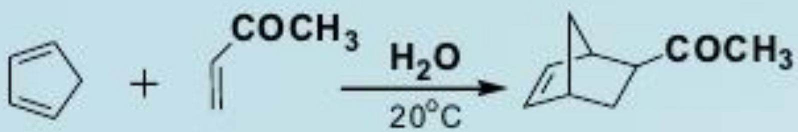
Forced hydrophobic interactions

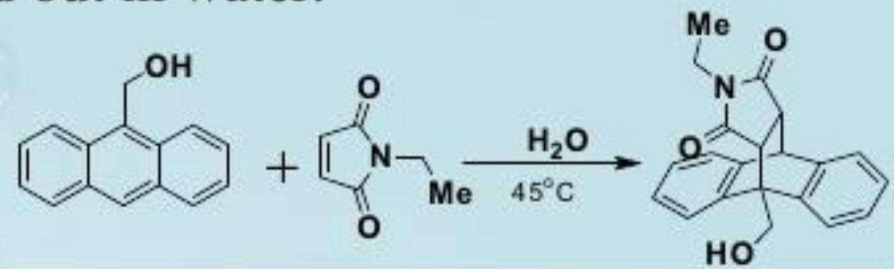


- It is entropically less costly to have one big hydration shell rather than many smaller ones, because a joint hydration shell will have less surface area.
- Therefore, due to all such factors, hydrophobic molecules experience a net attraction which is entropically driven. This phenomena is called the **forced hydrophobic interactions** in water.

Acceleration of Diels–Alder reaction in water : Pioneer example of Forced hydrophobic interactions

- Breslow et al. showed that rate of Diels-Alder reaction increases more than 700 times when carried out in water.



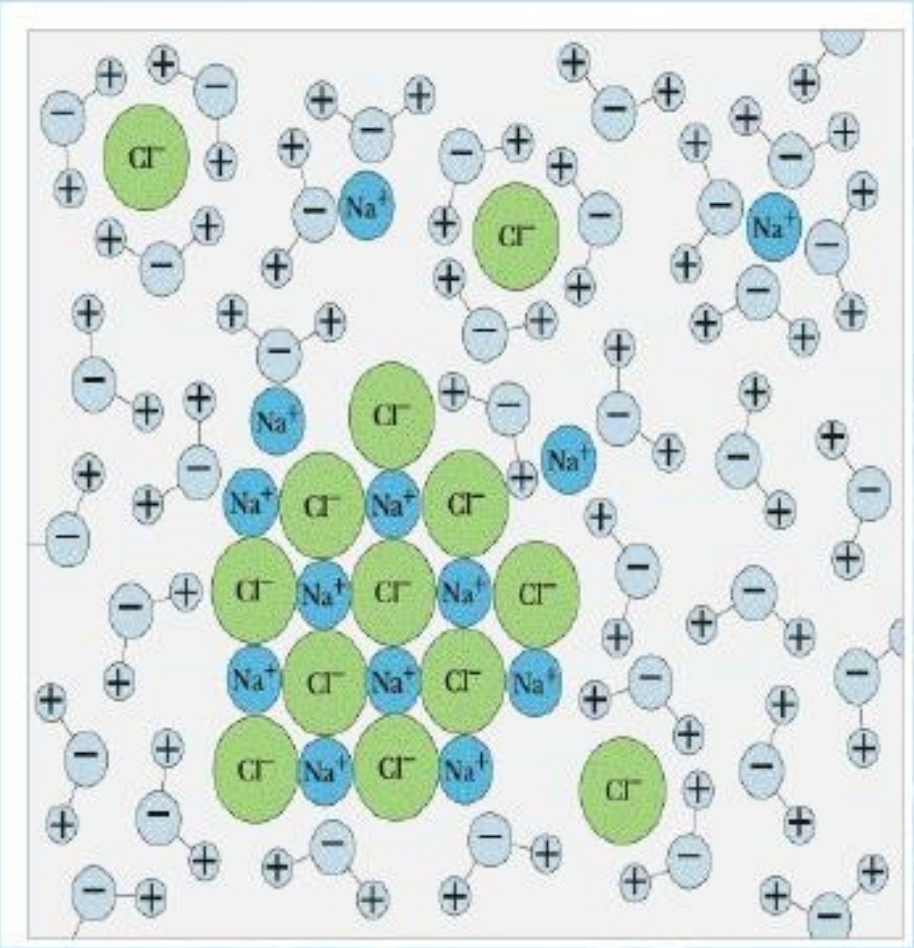


Solvent	Additional component	Rate constant K_2 X 10^5 $M^{-1}S^{-1}$
Isooctane	-	5.94
MeOH	-	75.5
Water	-	4400
”	LiCl (4.86 M)	10800
”	β-Cyclodextrin	10900
”	α-Cyclodextrin	2610

Solvent	Additional component	Rate constant K_2 X 10^5 $M^{-1}S^{-1}$
Isooctane	-	796
MeOH	-	666
Water	-	22600
”	β-Cyclodextrin	13800

J. Am. Chem. Soc., **1980**, *102*, 7816

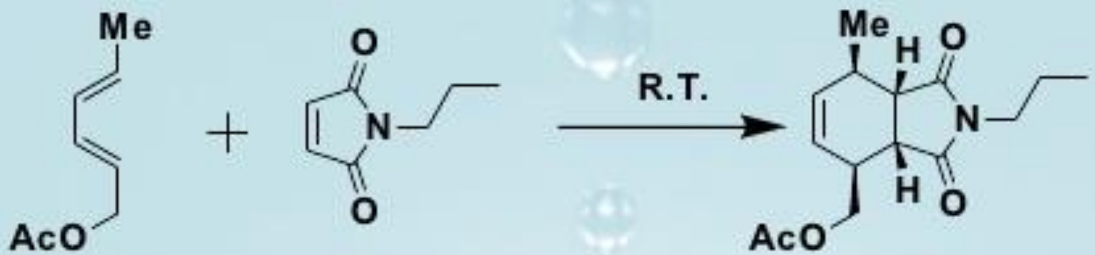
Solvation by water



- Because water is highly polar, it is an ideal solvent for ionic substances, or polar substances such as sugars, small alcohols, amines, and carbonyl-containing molecules such as aldehydes and ketones.
- Water dissolves salts because of strong electrostatic interactions.
- The attraction between water molecules interacting with ions is much greater than that of the ion with its oppositely charged partner.
- The diminished attraction is a measure of water's ***dielectric constant.***

Pericyclic reactions

A. Diels-Alder reaction :-



trans, trans-2,4-hexadienyl acetate

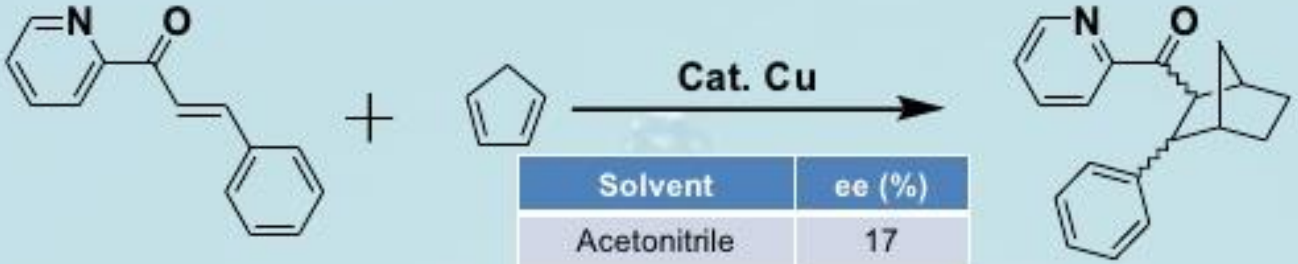
N-propylmaleimide

Solvent	Conc. (M)	Time (h)	Yield (%)
Toluene	1	144	79
Acetonitrile	1	>144	43
MeOH	1	48	82
Neat	3.7	10	82
Water	3.7	8	81

Angew. Chem. Int. Ed. **2005**, *44*, 3275 –3279

Pericyclic reactions

A. Lewis acid catalysed Diels-alder reaction :-



3-phenyl-1-(2-pyridyl)-2-propen-1-one

Solvent	ee (%)
Acetonitrile	17
THF	24
Ethanol	39
Chloroform	44
Water	74

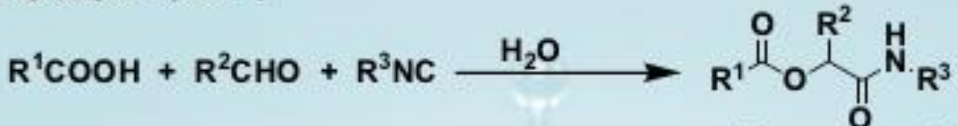
- As a solvent, water not only a enhances the endo selectivity of the reaction.
- density functional theory studies show that the computed endo preference is enhanced to 2.4 kcal/mol in an aqueous solution.
- The endo/exo selectivity partly arises from hydrogen bonding, and partly from the bulk-phase effects, which includes enforced hydrophobic interactions and anti-hydrophobic co-solvent effects.

J. Am. Chem. Soc.,**1999**, *121*, 6798.
J. Am. Chem. Soc., **2000**, *122*, 10418

Multicomponent reactions

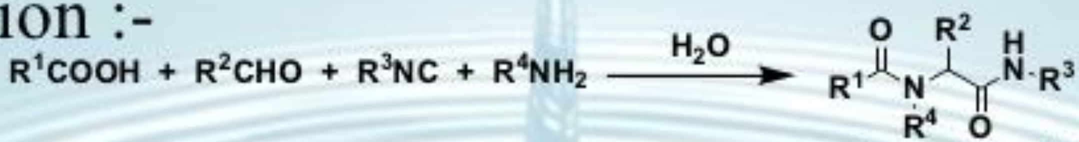
- Rate of Passerini reaction & Ugi reactions increases nearly 300 times when carried out in water.
- β-lactam derivatives can also be prepared when β-amino acids are taken.

Passerini reaction :-



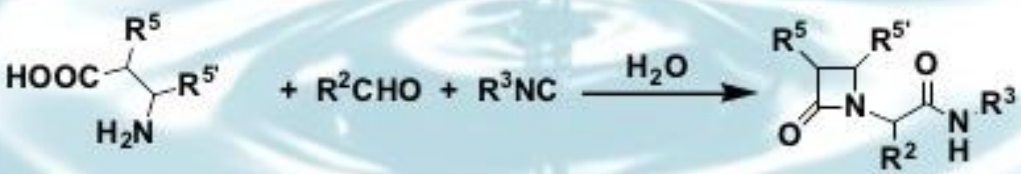
32 compounds (72-93 % yield)

Ugi reaction :-



48 compounds (83-99 % yield)

β-lactam deri. synthesis :-



32 compounds (71-89 % yield)

J. Am. Chem. Soc. **2004,** *126*, 444

Conclusions

- Water is versatile solvent in nature, however, in synthetic organic chemistry, it was taken for granted to be solvent of very limited use because of many previous experiences with highly reactive reagents (e.g. Grignard reagent) along with less solubility of most organic compounds. But now the scenario has changed considerably.
- Since the pioneer discovery by Breslow, there has been remarkable development with view to use water as solvent.
- Most of the important reactions in organic synthesis have been tried using water as solvent or as one of the components in the solvent mixture, of course, with some modifications in the conventional methodologies -- and the show will go on…
- Water has many physicochemical characteristics which make it a unique solvent and such characteristics can be modified as per requirement for reaction by using various catalysts and additives like surfactants.
- With increasing attention towards greener approaches for organic synthesis, adaptation of greener methods is the demand of modern chemistry and in such a scenario, water is going to be the solvent of choice because of its unique advantages.