IJCRT.ORG ISSN : 2320-2882

INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)
An International Open Access, Peer-reviewed, Refereed Journal

"Harmonizing The Future: Exploring The Echoes Of Sonochemistry"

Pranita Jagtap*, Pallavi Dhekale, Dr. Sanjay Chaudhari

KJEI's Trinity College of Pharmacy, Pune.

ABSTRACT:

Sonochemistry employs safer substances and eco-friendly solvents, enhances reaction conditions and precision, avoids generating harmful sludge, reduces energy consumption for chemical processes, thereby significantly contributing to environmentally conscious research and material sustainability. Ultrasound is a sophisticated method applied in water and wastewater treatment, effectively tackling pollution from persistent materials through oxidation and aiding in sludge management. Pre-treatment technologies in wastewater treatment plants facilitate biogas production. Moreover, the environmentally friendly approach of sonochemical nanoparticle synthesis has recently gained considerable attention. This study explores the principal applications of ultrasonography in environmental conservation and remediation.

KEYWORDS:

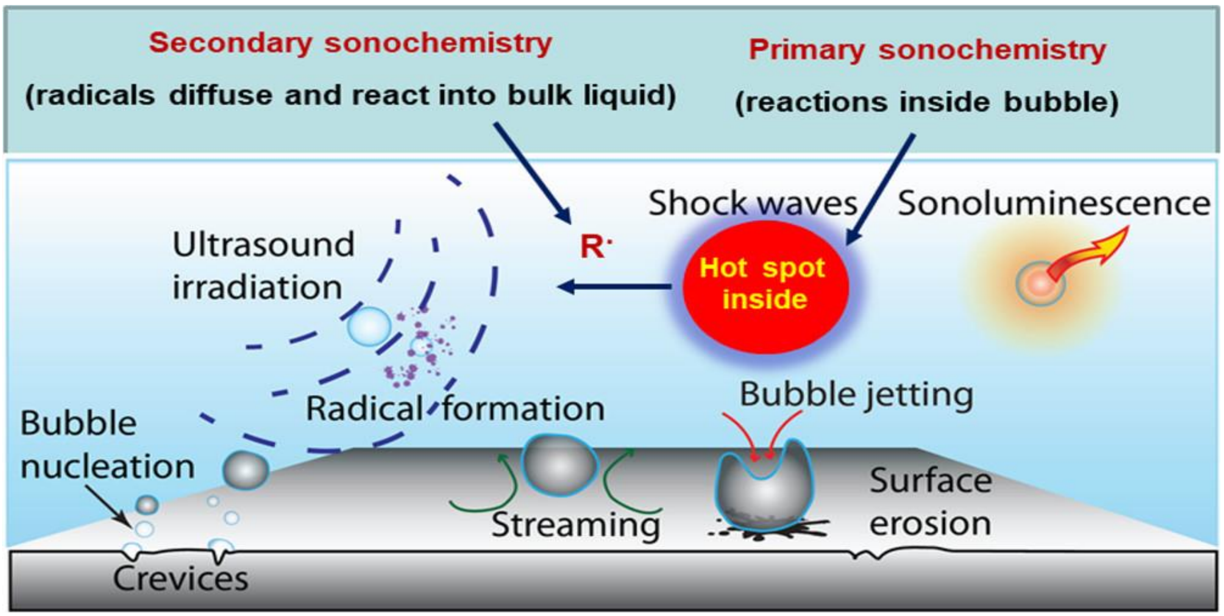
Ultrasound, Sonication, Catalysis, Sludge, Solvent.

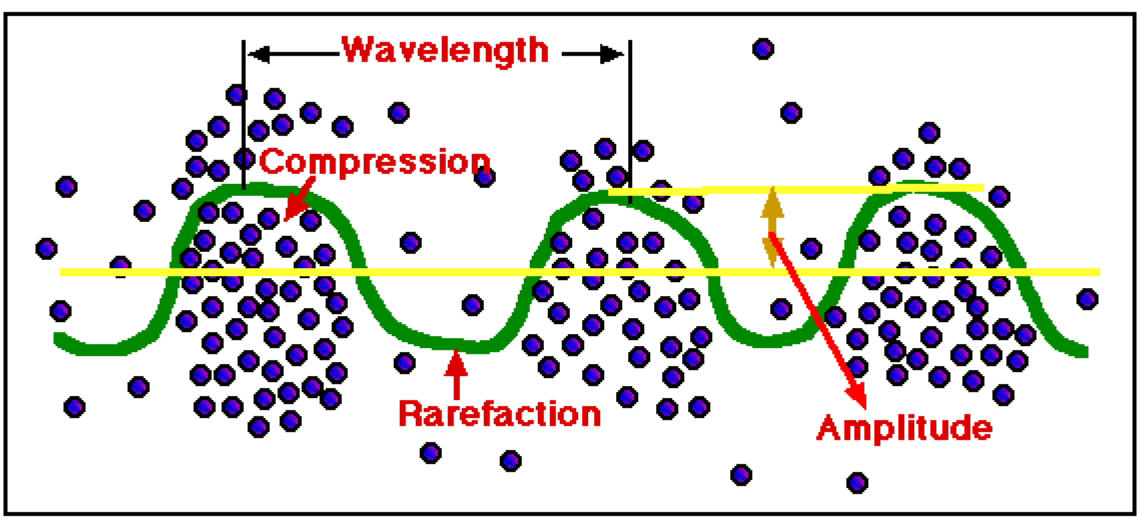
1.INTRODUCTION:

The discipline of sonochemistry investigates how different ultrasonic settings can improve mass transfer and chemical reaction speeds[6]. Any sound wave at a frequency higher than the range of normal human hearing is considered ultrasound (i.e., over 16 kHz)[7]. The phenomenon of sonic cavitation is the process responsible for sonochemical phenomena in liquids. To provide energy to the liquid phase, ultrasonic waves cause a recurring sequence of compressions and rarefactions as they propagate through a liquid medium[8-11]. Cycles of compression and rarefaction apply positive and negative pressure to the liquid, respectively pushing and pulling molecules toward or away from one another[12]. Sonochemistry is understanding the impact of sonic waves and wave characteristics on chemical processes is the goal of the study of sonochemistry in chemistry[13-14]. The atomic and molecular chemistry that corresponds to the distinct physical characteristics of sonic waves is also unique. These effects frequently show up best in ultrasonic systems. Sonoluminescence, ultrasound, sonication, and sonic cavitation are examples of phenomena that illustrate this.

Sonochemistry is a dynamic area of study in the pharmaceutical and organic synthesis industries. The phenomenon known as acoustic cavitation—the formation, growth, and implosion of microbubbles inside a liquid—causes high pressure and temperature, approximately 5000 K and 1000 atm, respectively[15].

Sonochemistry is a synthetic technique that can be used to create a wide range of molecules with diverse uses[16]. A criticism from traditional methods for the synthesis of organic compounds is that one of those applications is the green approach, which is being utilized to speed up the synthesis of organic compounds and reduce environmental pollutions. The utilization of substitute materials, such as catalysts, solvents, and reagents, is one of the green chemistry tools[17-18].





1.1 SONOCHEMISTRY:

Sonochemistry refers to the study of the effects of sound waves on chemical systems and is a relatively new topic in the field of chemistry. Before understanding why sound waves affect chemical systems in the way they do, it is important to understand their basic propertiesproperties[19].

Sound waves are caused by the vibration of an object, such as a string. Vibration refers to a repetitive back-and-forth motion that usually occurs very quickly. For example, consider using a vertical guitar string where the end points of the strings are fixed. However, the center of the string moves several times to the right and then to the left[20].The air immediately to the right of the string, because the string is moving to the right, forces the air particles to move to the right as well. This region moves to the right when air particles collide with other air particles, forcing them to the right. Then, when the string vibrates, the string moves to the left[21-22]. Particle move causes compression, or when particles move closer together, and ratio, or when particles move apart. Compresses also cause high pressure areas because they have a higher concentration of particles. Rarely they also cause low pressure areas.sound waves are also called as pressure waves. .

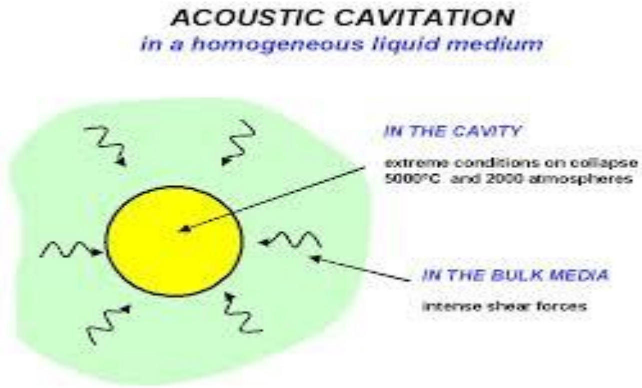
The high-pressure component of sonochemistry raises the possibility that the same macroscopic conditions of high-temperature pressure "bomb" reactions or explosive processes may be produced on a small scale[23].

substantial shockwave generation in solids. Sonochemical reaction control is governed by the same constraint of any thermal process: the energy is determined by the Boltzmann energy distribution.

per specific molecule will differ significantly. However, one may easily regulate the intensity Measuring the heating caused by sonic cavitation utilizing a range of physical characteristics, such as thermal the ambient pressure, the solvent vapor pressure inside the bubble, and the conductivity of the dissolved gases.

1.2 Acoustic Cavitation:

The chemical effects of ultrasound do not result from direct interaction with molecular species. Ultrasound covers frequencies from about 15 kHz to 1 GHz. At the speed of sound in liquids typically around 1500 m s1 , acoustic wavelengths range from approximately 10 cm to 104 cm[24].They are not molecular dimensions. Therefore, there is no direct connection between the acoustic field and chemical substances at the molecular level, sonochemistry or sonoluminescence can be explained. Instead, sonochemistry and sonoluminescence mostly originate from acoustic cavitation, which acts as an effective means of concentrating scattered sound energy[25]. Compression the gas produces heat. If bubble compression occurs during cavitation, it is more faster than thermal transport, which creates a short-lived local hot spot. Rayleigh is early descriptions of the mathematical model of cavity collapse in incompressible fluids predicted enormous local temperatures and pressures.13 Ten years later Richard and Loomis reported the first chemical and biological effects of ultrasound.14 If the amplitude of the acoustic pressure of the propagating acoustic wave is relatively large (larger than 0.5 MPa), local fluid inhomogeneity can cause a a nuclear site in a cavity of macroscopic dimensions, which is mainly filled with steam. Such bubble is inherently unstable and its subsequent collapse can lead to massive concentrations of energy (Figure 1). This violent cavitation event is often referred to as "transient cavitation"[26]. Normal The result of this unstable growth and subsequent collapse is the cavitation bubble itself destroyed But the gas-filled remnants of the collapse could restart the process.



2.Green sonochemical Approaches for Organic synthesis :

1. The applications of ultrasound have long been known in both industry and academy, the “green” value of the non-hazardous acoustic radiation has been recognised by synthetic and environmental chemists only recentlyrecently[27].
2. The chemical and physical effects of ultrasound arise from the cavitational collapse which produce extreme conditions locally and thus induce the formation of chemical species not easily attained under conventional conditions, driving a particular radical reactivity.
3. This rationale, accessible in a non-mathematical manner, anticipates the advantages of using this technology in a variety of processes that include milder reactions with improved yields and selectivities, easy generation of reactive species and catalysts or replacement of hazardous reagents[28].
4. Sonication enables the rapid dispersion of solids, decomposition of organics including biological components, as well as the formation of porous materials and nanostructures.
5. ultrasound can be harnessed to develop an alternative and mild chemistry, which parallels the ability of acoustic waves to induce homolytic bond cleavage.
6. Sonochemistry is thought to be a practical approach for conducting chemical reactions without the need for solvents.
7. Among the main benefits of these sonochemical processes are their high yields, low energy requirements, minimal waste, and solvent-free operationoperation[29].
8. The application of ultrasonography in particular activation is produced by chemical reactions in solution based on a physical phenomenon:cavitation caused by sound .
9. During the process of cavitation, mechanical stimulation destroysthe liquid phase's molecules' attraction force.
10. Chemical catalysts that are heterogeneous have a physical phase that differs from the reactant and/or product phases of the chemical reactions[30].

3. Solvent -Free Sonochemical Protocol-

3.1 Heterogeneous Catalysis in Organic:

When the catalyst is in a separate phase from the reactants and products, this is referred to as heterogeneous catalysis. This can be used to immiscible fluids as well as the physical phase (solid, liquid, or gas).

Heterogeneous catalysts are essential to the manufacturing of industrial chemicals. They are favored because of their durability and reduced operating costs, especially because it is simpler to recover or separate them from the products, which streamlines chemical operations[31].

Chemical catalysts that are heterogeneous have a physical phase that differs from the reactant and/or product phases of the chemical reactions they catalyze. Heterogeneous solid phase catalysts are typically used to speed up the chemical reaction between two gaseous reactants. The catalysis in these reactions occurs in the following three steps:

- The gaseous reactants' adsorption on the solid heterogeneous catalyst's surface.
- The product is created as a result of the chemical reaction between the adsorbed reactants.
- The catalyst's active catalytic surface regenerates when the resultant compound is desorbent from its surface[32].

Because they make it possible to produce a number of commercially significant compounds on a relatively large scale, heterogeneous catalysts are very helpful. For instance, iron oxides deposited on alumina, a chemical substance having the formula Al2O3, are frequently employed as heterogeneous catalysts in the Haber process, which produces ammonia for industrial use.

Ethylene and oxygen undergo a reaction on alumina that is catalyzed by silver and a number of other promoters to produce ethylene oxide[33].

3.1.1 Examples of Heterogeneous Catalysis:

The following list contains some typical instances of heterogeneous catalysis-related reactions, or processes where the catalysts and reactants are in distinct physical states:

- Vanadium oxides catalyze the interaction between oxygen and sulfur dioxide in the contact process that results in sulfuric acid.
- Iron oxides on alumina catalyze the reaction between hydrogen and nitrogen in the Haber-Bosch process, which produces ammonia for industrial use.
- An unsupported platinum-rhodium gauze catalyzes the reaction between ammonia and oxygen in the Ostwald process, which produces nitric acid.

- Methane and water react in a process called steam reformation, which is aided by potassium or nickel oxide to produce hydrogen.

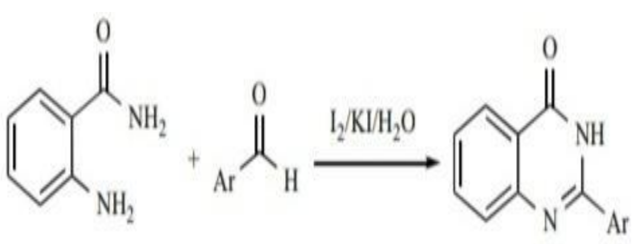
3.2 Heterocyclic Synthesis in Water:

One of the most effective synthetic techniques and green chemistry protocols for building a variety of molecular scaffolds from a small number of readily available starting materials or intermediates is the use of multicomponent reactions (MCRs). MCRs have a wide range of potentials, including the ability to generate complexity, the effectiveness of resources and energy, intrinsic convergence, operational simplicity, atom-economy, sustainable technology, and sizable chemical libraries of compounds with druglike properties[34].The features of aza-heterocycles, an important class of organic compounds, include calcium channel blockers and antagonists, antitumor, anticancer, anti-inflammatory, and antibacterial effects. A few conventional one-pot and stepwise MCR techniques are found in the literature.

A heterocyclic compound has at least two different elements as a member of its ring.The most common hetero atoms found on a cyclic ring are Oxygen (O), Nitrogen (N) and Sulphur (S).

3.2.1 Example: Synthesis of Quinazoline -

Bakavoli et al. have reported oxidative cyclocondensation of o-aminobenzamide with various aldehydes in water using I2/KI as catalyst and oxidizing agent to obtain the corresponding quinazolin-4(3H)-ones Quinazolin-4(3H)-one derivatives were previously prepared by thermolysis of 3-arylideneamine-1,2,3-benzotriazine- 4-ones in paraffin oil at 300o
C or by condensation of aryl, alkyl and heteroaryl aldehydes in refluxing ethanol in the presence of CuCl2, but both these methods require high-temperature reaction, low yield, long-reaction time as well as were not environment friendly[35].



3.3 Solvent Free Reactions-

Solvent-free approaches involve grinding, ultrasonic irradiation and microwave irradiation of undiluted reactants, or
catalysis by the surfaces of inexpensive and recyclable mineral supports such as alumina, silica, clay, or doped aluminosilicates.

One of the most promising ways to achieve this goal is the solutionless technique is a strategic position because solvents are often toxic, expensive, matic to use and remove. This is the main reason for its development modern technologies[36]. These approaches can also allow for experimentation works without strong mineral acids (eg HCl, H2SO4) that can enter in turn causes corrosion, safety, handling and contamination problems as waste. These acids can be advantageously replaced by solid, recyclable acids such as than clay.

3.3.1 Solvent-free Techniques-

Three types of experimental conditions without solvents can be considered.

1) Reactions on Solid Mineral Supports :
   Reactants are first impregnated as neat liquids onto solid supports such as aluminas, silicas and clays or via their solutions in an adequate organic solvent and further solvent removal in the case of solids. Reaction in "dry media" is performed between individually impregnated reactants,followed by a possible heating.

2) Reactions Without any Solvent, Support, or Catalyst:
   These heterogeneous reactions are carried out between pure reactants in quasi- corresponding amounts without addition. In solid-liquid mixtures A reaction means either dissolution of a solid in a liquid phase or adsorption liquid on a solid surface as an interfacial reaction.
3) Solid-Liquid Phase Transfer Catalysis (PTC) :
   Reactions occur between pure reactants as quasi-equivalents complexation of a catalytic amount of tetra-alkylammonium salts or cations If carried out without a solvent, the liquid organic phase contains consists of an electrophilic reactant and then eventually a reaction product .Nucleophilic anionic species can be produced in situ by subjecting their conjugate acids with solid bases, whose strength is increased due to the exchange of ion pairs R4N+X–.

Scott et al. To make your point, make the following distinctions clear:

a) solid phase reaction- which is a reaction molecule of the liquid phase with the solid substrate, such as a polymer-supported synthetic peptide.

b) solvent- free reaction, which is any system in which reactants react with each other without using a solvent.

c) solid reaction or solid-solid reaction which is when two macroscopic solids interact directly without assistance to form a liquid or vapor phase to form a third, solid product.

Advantages:

I. No reaction means are available to collect, clean or recycle
II. The manufactured chemicals are often quite pure avoid thorough chromatographic purification and en in certain situations, recrystallization is not even necessary.
III. Sequential solvent-free in high-performance systems reactions are possible
IV. Compared to organic solvents, reactions are fast, sometimes reaching a remarkable completion in minutes
V. Specialized equipment is often not required
VI. Energy consumption can be significantly lower
VII. Preformed salts and metal-metal complexes often are unnecessary
VIII. Surgery may be prevented group protection removal;
IX. At the time of establishment industrial processes may have less capital equipment;
X. Methods without solvents can become more economically viable and ecological friendly by significantly reducing sets and processing costs[37].

Disadvantages:

1) Formation of "hot spots" and the possibility of runaway reactions. Rather than continuing to operate under the outdated paradigm in which a reaction medium or solvent is used as a heat sink or agent for heat transfer, it would be preferable to work on designing reactors for continuous flow systems. In solvent-free processes, it is obvious that quantifying reaction heat is just as important.

3.4 Reactions in Organic Solvents:

Organic chemical reaction: Since many organic compounds react with water and the reagents and products are typically not soluble in water, organic reactions are typically carried out in organic solvents.With the use of this procedure, they have carried out nucleophilic substitution reactions, alkene reactions, cycloadditions, and Claisen rearrangements.

Everyone uses organic solvents in most of their daily operations, from sanitizing procedures to removing stubborn grease stains. The perfume or cologne we use, the detergents used to keep our clothes fresh and clean, all these products contain ingredients called organic solvents[38].

Organic solvents are those chemical compounds that have a carbon-based molecular structure. They are widely used to dissolve a material to create a solution or even to extract one material from another. In general, a solvent refers to a substance that can dissolve any other substance. But since all these solvents are carbon-based, these compounds have carbon atoms in their structure. Consider the example of the organic solvent benzene, which has six carbon atoms in the organic solvent. The molecular structure of an organic solvent always contains a carbon atom and some have a hydrogen atom. These solvents are mainly classified into natural and synthetic solvents based on their molecular structures.

Natural solvents – These are the solvents which are naturally produced by living organisms. **Synthetic Solvents** – These are the solvents that are produced as a result of chemical reactions occurring in various organic compounds.

3.4.1 Properties of organic solvents: Organic solvents have different physical and chemical properties as shown below.

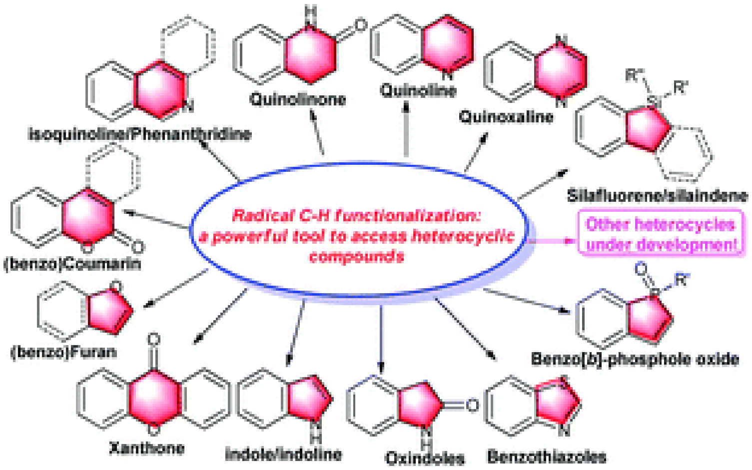
Organic solvents are volatile in nature - volatile solvents are those that have the ability to evaporate. Organic solvents have these properties. Due to their volatile nature, organic solvents emit odors when exposed to air. Organic solvents have low boiling points - Organic solvents are said to have very low boiling points. Because of this low boiling point, they are very volatile. Organic solvents are colored liquids - they are clear liquids and have a lower molecular weight.

3.4.2 Applications of organic solvents:

Organic solvents are used in various fields. They are used in coatings, polishes, paint thinners and removers (toluene), cleaning agents, nail polish removers (acetone, ethyl acetate, methyl acetate), industrial and consumer degreasers, detergents, perfumes, stains and various chemical syntheses and processes.

3.5 HeterocyclicFunctionalization: Functionalization is the process of adding new functions, characteristics, features or properties to a material by modifying them. surface chemistry of the material[39].It is a fundamental technique used in chemistry, materials science and biology technology, textile technology and nanotechnology. Heterocyclic compounds are widely found in natural products, drugs and bioactive molecules.

Heterocyclic compounds are widely found in natural products, drugs and bioactive molecules. Thus, organic and pharmaceutical chemists have dedicated great efforts to the construction of these heterocyclic frameworks, developing versatile and efficient synthetic strategies. Direct C–H functionalization via the radical route has emerged as a promising and dramatic approach to heterocycles with high atomicity and step economy. Heterocyclic compounds such as coumarins, furans, benzofurans, xanthones, benzothiazoles, indoles, indolines, oxindoles, quinolines, isoquinolines, quinoxaline, and phenanthridines have been successfully synthesized by C-H functionalization via the radical route.



Heterocyclic compounds are widely present in the basic structures of several natural products, drugs and agrochemicals, and therefore efforts have been made to synthesize them in a much easier and simpler way. Over the past decade, significant progress has been made in the field of heterocyclic synthesis using CH–H functionalization as an emerging synthetic strategy[40]. Transition metal-catalyzed CH functionalization of arenes with various directing groups has recently emerged as a powerful tool for the creation of various classes of heterocycles. This review focuses primarily on recent advances in the synthesis of N,O heterocycles from olefins and allenes using nitrogen-based and oxidative directing groups.

3.6 Organometallic Reactions: "It is defined as a compound containing a covalent bond between a carbon atom and a metal." Organometallic compounds are used stoichiometrically in research and industrial chemical reactions and as catalysts which increase the reaction rate. A broad classification of organometallic compounds is main group, transition metal, lanthanide, and actinides. Based on Based on the nature of the bond, organometallic compounds are classified as sigma, pi and combinations.

compound with a sigma and pi bond**.**Organometallic compounds are chemical compounds that contain at least one bond between a metallic element and a carbon atom in an organic molecule. Even metalloid elements such as silicon, tin and boron can form organometallic compounds that are used in some industrial chemical reactions. Reactions where the target molecules are polymers or drugs can be catalyzed by organometallic compounds, which leads to an increase in the reaction rate[41]. Generally, the bond between the metal atom and the carbon attached to the organic compound is covalent in nature. When metals with a relatively high electronegativity (such as sodium and lithium) form these compounds, the carbon attached to the central metal atom has a carbanionic character.

3.6.1 Properties of organometallic compounds :-

The bond between the metal and the carbon atom is often highly covalent in nature. Most organometallic compounds exist in solid form, especially compounds in which the hydrocarbon groups are aromatic or have a cyclic structure. Compounds made of highly electropositive metals such as sodium or lithium are highly volatile and can ignite spontaneously. In many cases, organometallic compounds have been found to be toxic to humans (especially those compounds that are naturally volatile). These compounds can act as reducing agents, especially compounds formed by highly electropositive metals[42].

Grignard reagents are *extremely useful* organometallic compounds in the field of organic chemistry. They exhibit strong nucleophilic qualities and also have the ability to form new carbon-carbon bonds. Therefore, they display qualities that are also exhibited by organolithium reagents and the two reagents are considered similar.

3.6.2 Reactions of Grignard Reagents:

1. Reactions with a carbonyl group : These reagents form different products when reacting with different carbonyl compounds[43].The most common reaction of Grignard reagents is the alkylation of ketones and aldehydes with R-Mg-X. Reactions of Grignard reagents This reaction described above is also called the Grignard reaction. The solvents used in this reaction are tetrahydrofuran and diethyl ether.

2. Reactions with non-carbon electrophiles : Grignard reagents and some organolithium compounds are very useful for forming new carbon-heteroatom bonds. These reagents can also undergo a transmetalation reaction with cadmium chloride to give dialkylcadmium. This reaction can be written as $2R\text{-}Mg\text{-}X + CdCl_2 \rightarrow R_2Cd + 2Mg(X)Cl$ Alkyl chains can be attached to many metals and metalloids using these reagents.

3. Reactions with organic halides :- Usually, these reagents are quite unreactive towards organic halides, which differs significantly from their behavior towards other halides. However, carbon-carbon coupling reactions occur with Grignard reagents, which act as reactants when a metal catalyst is added[44]. An example of such a coupling reaction is the reaction between methyl p-chlorobenzoate and nonylmagnesium bromide, during which the compound p-nonylbenzoic acid is formed in the presence of a catalyst - blTris(acetylaceto)iron (III).

4. APPLICATION OF SONOCHEMISTRY:

Sonochemistry has been used for synthesis of composites for energy storage applications like:

1)Ultrasound assisted synthesis has been used for preparation fuel cell and electrodes[45-48].

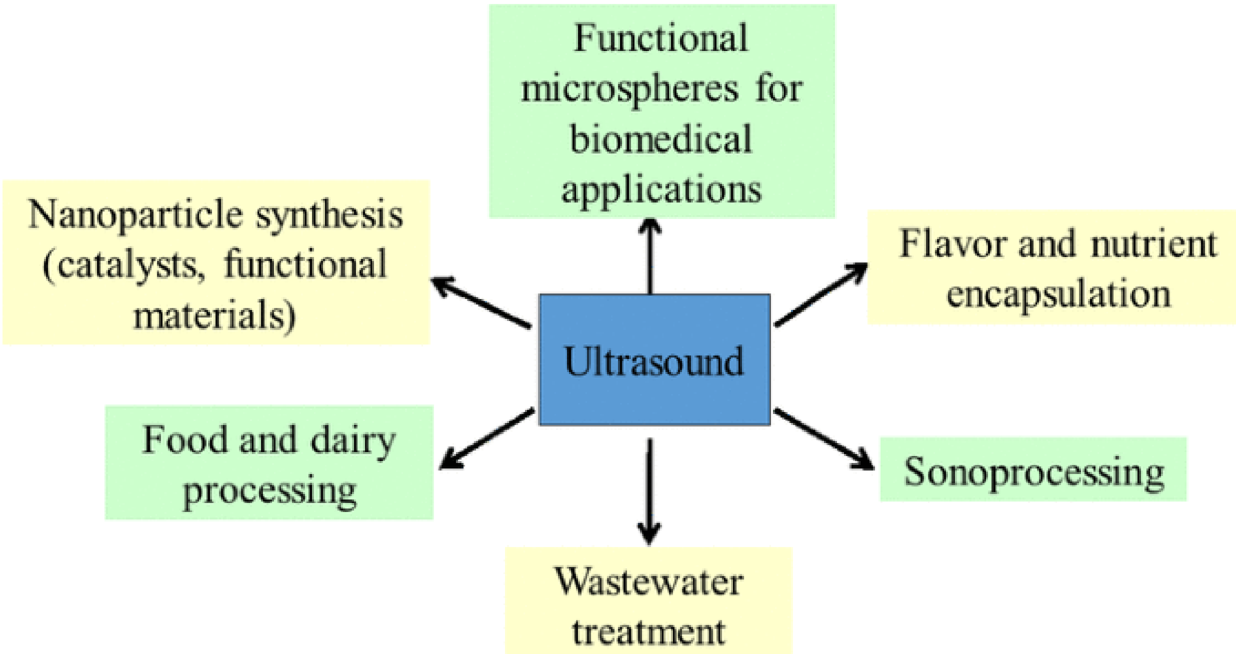
2) Recent stretchable super capacitors possessing excellent electrical and mechanical qualities.

3)Sonoporation: enhancement in permeation due to acoustic cavitation and thus used for modifying the permeability of cell plasma membrane[49].

3) Sonolysis: application in purifying water because of formation of reactive species when ultrasound reacts with water.

Primary, binary, ternary nano composites which gave good specific capacitance, power density, energy density and cyclic stability applicable for electrode material in super capacitors[50].

4)Any "mixed-phase" reaction, such as one in which a solid substance is dissolved in a liquid, can benefit greatly from the use of ultrasound. For instance, sonication accelerates Grignard reactions—organic halides reacting with magnesium metal—much more quickly than it would otherwise.



REFERENCE:

1. Basak Savun-Hekimoglu. (2020, October 25). A Review on sonochemistry & Environmental Applications. Acoustics.
2. Suslick, K. S. (1990). Sonochemistry. Science.
3. Shut, V. N., & Mozzharov, S. E. (2017). Properties of ultrafine copper-containing powders prepared by a sonoelectrochemical method. Inorganic Materials.
4. Mason, T. J., & Peters, D. (2002). Practical Sonochemistry: Power Ultrasound Uses and Applications. Woodhead Publishing.
5. Mason, T. J. (1990). Chemistry with Ultrasound. Elsevier Applied Science.
6. Fischer, C. H., Hart, E. J., & Henglein, A. (1986). Ultrasonic irradiation of water in the presence of oxygen 18, 18O2: isotope exchange and isotopic distribution of hydrogen peroxide. Journal of Physical Chemistry, 90, 1954–1956.
7. Lorimer, J. P., Mason, T. J., & Fiddy, K. (1991). Enhancement of chemical reactivity by power ultrasound: An alternative interpretation of the hot spot. Ultrasonics.
8. Ameta, S. C., Ameta, R., & Ameta, G. (Eds.). (2018). Sonochemistry: An Emerging Green Technology. CRC Press.
9. Menshawy A. Mohamed. (2019, December 25). Sonochemistry. Journal of Pharmaceutical Research International.

10. Menshawy A. Mohamed. (2016). Sonochemistry (Applications of ultrasound in chemical synthesis and reactions): A review part I. Az J. Pharm. Sci.
11. Menshawy A. Mohamed. (2017). Sonochemistry (Applications of ultrasound in chemical synthesis and reactions): A review part II. Advances in Bioresearch.
12. Baker, K. G., Robertson, V. J., & Duck, F. A. (2001). A review of therapeutic ultrasound: Biophysical effects. Physical Therapy.
13. Cobbold, R. S. (2007). Foundations of Biomedical Ultrasound. Oxford University Press.
14. Cartee, R. E., Selcer, B. A., Hudson, J. A., Finn-Bodner, S. T., Mahaffey, M. B., Johnson, P. L., & Marich, K. (1996). Practical veterinary ultrasound. Williams & Wilkins.
15. Wood, R. J., Lee, J., & Bussemaker, M. J. (2017). A parametric review of sonochemistry: Control and augmentation of sonochemical activity in aqueous solutions. Ultrasonics Sonochemistry, 38, 351–370.
16. Hyeon, T., Fang, M., & Suslick, K. S. (1996). J. Am. Chem. Soc., 118, 5492–5493.
17. Cao, X., Prozorov, R., Koltypin, Y., Kataby, G., Felner, I., & Gedanken, A. (1997). J. Mater. Res., 12, 402–406.
18. Shafi, K. V. P. M., Koltypin, Y., Gedanken, A., Prozorov, R., Balogh, J., Lendvai, J., & Felner, I. (1997). J. Phys. Chem. B, 101, 6409–6414.
19. T. J. Mason, Sonochemistry, Oxford University Press, Oxford, UK, 1999, 96.
20. T. J. Mason, Advances in Sonochemistry, Vol. 5, Elsevier, Jai Press Inc. Stamford, Connecticut, 1999, 310.
21. J.-P. Bazureau, M. Draye, Ultrasound and Microwaves: Recent Advances in Organic Chemistry, Transworld Research Network, Kerala, 2011.
22. K. S. Suslick, D. A. Hammerton, D. E. Cline, J. Am. Chem. Soc. 1986, 108, 5641–5645.
23. T. J. Mason, D. Peters, Practical Sonochemistry: Power Ultrasound Uses and Applications, 2nd Ed., Woodhead Publishing, Cambridge, UK, 2002, 166.
24. T. J. Mason, Practical Sonochemistry: User's Guide to Applications in Chemistry and Chemical Engineering, Ellis Horwood Ltd, New York, 1992
25. . J. L. Luche, Synthetic Organic Sonochemistry, Plenum Press, New York, 1998.
26. P. R. Gogate, A. B. Pandit, Sonocrystallization and its application in food and bioprocessing, In: Ultrasound Technologies for Food and Bioprocessing, (Eds: H. Feng, G. V. Barbosa-Cánovas, J. Weiss) Food Engineering Series, New-York, USA 2011, 467–493.
27. A. Henglein, M. Gutierrez, J. Phys. Chem. 1993, 97, 158–162.
28. T. J. Mason, Sonochemistry, Chemistry Primers, Oxford, 2000.
29. S. I. Nikitenko, C. Le Naour, P. Moisy, Ultrason. Sonochem. 2007, 14, 330–336.
30. S. de La Rochebrochard d'Auzay, J.-F. Blais, E. Naffrechoux, Ultrason. Sonochem. 2010, 17, 547–554.
31. P. R. Gogate, P. A. Tatake, P. M. Kanthale, A. B. Pandit, AIChE J. 2002, 48, 1542–1560.

32. T. J. Mason, Ultrason. Sonochem. 2003, 10, 175–179. 15. G. Cravotto, P. Cintas, Angew. Chem. Int. Ed. 2007, 46, 5476–5478.
33. T. J. Mason, E. Cordemans de Meulenaer, Practical considerations for process optimisation, In: Synthetic Organic Sonochemistry, (Ed.: J.-L. Luche) Plenum Press, New York, 1998, 301–328.
34. T. Freegarde, Introduction to the Physics of Waves, Cambridge University Press, Cambridge, UK, 2013.
35. F. Galton, Inquiries into Human Faculty and its Development, Macmillan, London, UK, 1883.
36. J. Thorneycroft, S. W. Barnaby, Inst. Civil Eng. 1895, 122, 51–55. 20. L. Rayleigh, P. Mag. 1917, 34, 94–98.
37. R. Woods, A. Loomis, Philos. Mag. 1927, 4, 414–436.
38. T. Richards, A. Loomis, J. Amer. Chem. Soc. 1927, 49, 3086–3100. 23. S. Brohult, Nature 1937, 140, 805–810.
39. T. J. Mason, Ultrason. Sonochem. 2016, 29, 519–523. 25. E. Neppiras, Phys. Rep. 1980, 61, 159–284.
40. T. J. Mason, J. P. Lorimer, Sonochemistry, Theory, Applications and Uses of Ultrasound in Chemistry, Ellis Horwood Publishers, Chichester, 1988.
41. T. J. Mason, Chem. Soc. Rev. 1997, 26, 443–451.
42. T. J. Mason, J. P. Lorimer, Applied Sonochemistry, Wiley-VCH Verlag GmbH, Weinheim, 2002.
43. J.-L. Luche, Synthetic Organic Sonochemistry, Plenum Press, New York, 1998.
44. EPA, Pollution Act of 1990, United States Code Title 42, 1990.
45. P. T. Anastas, T. C. Williamson, Green chemistry: An overview, In: Green Chemistry, American Chemical Society, Washington, 1996, 1–17.
46. P. T. Anastas, J. C. Warner, Green Chemistry: Theory and Practice, Oxford University Press, Oxford, 1998.
47. P. T. Anastas, N. Eghbali, Chem. Soc. Rev. 2010, 39, 301–312.
48. R. A. Sheldon, I. Arends, U. Hanefeld, Green Chemistry and Catalysis, Wiley-VCH, Weinheim, 2007.
49. R. Luque, J.-C. Colmenares, An Introduction to Green Chemistry Methods, Future Science Ltd, 2013. 39. A. Matlack, Introduction to Green Chemistry, 2nd Ed., CRC Press, USA, 2010.