**Tianjin Daxue Xuebao (Ziran Kexue yu Gongcheng Jishu Ban)/**
**Journal of Tianjin University Science and Technology**
ISSN (Online):0493-2137
E-Publication: Online Open Access
Vol: 58 Issue: 03:2025
DOI: 10.5281/zenodo.15062484

# A COMPREHENSIVE REVIEW ON ACOUSTIC LEVITATION TECHNIQUES AND APPLICATIONS

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**Abstract**

This comprehensive review article explores the fascinating field of acoustic levitation, a technique that uses sound waves to suspend objects in mid-air without physical contact. The paper synthesizes recent advancements and applications of acoustic levitation across various scientific disciplines. It begins by elucidating the fundamental principles of acoustic levitation, including standing wave patterns and acoustic radiation forces. The review then examines cutting-edge research in single-axis and multi-axis levitation systems, highlighting innovations in transducer design and phased array technology. Applications spanning from materials science and chemistry to biotechnology and pharmaceuticals are critically analyzed, with particular emphasis on container less processing and the manipulation of sensitive samples. The article also addresses current limitations and challenges in the field, such as size constraints of levitated objects and environmental factors affecting levitation stability. Finally, it outlines promising future directions, including the integration of acoustic levitation with other technologies and its potential impact on manufacturing and space exploration. This review serves as a comprehensive resource for researchers and practitioners seeking to understand the current state and future prospects of acoustic levitation technology.

**Keywords:** Acoustic Levitation, Standing Wave Patterns, Acoustic Radiation Forces, Container less Processing, Phased Array Technology, Ultrasonic Transducers, Non-contact Manipulation.

## INTRODUCTION

Acoustic levitation, a phenomenon that employs high-intensity sound waves to suspend matter in a medium, has captivated researchers across various scientific disciplines since the turn of the millennium. This non-contact manipulation technique has evolved from a curiosity in physics laboratories to a versatile tool with applications ranging from materials science to biotechnology. The ability to levitate and manipulate objects without physical contact has opened new avenues for studying material properties, facilitating chemical reactions, and handling delicate biological samples. This review article traces the development of acoustic levitation highlighting key advancements, novel applications, and the expanding theoretical understanding that has propelled the field forward. By examining the progression of acoustic levitation research, we gain insights into its current capabilities and potential future impacts on scientific and technological landscapes.

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The 1st Levitation was illustrated by Bücks and Muller in 1933, the drops of alcohol was levitated between the quartz crystal and the cupboard. The later development came from Hilary St Clair, who was passionate about acoustic radiation and in particular their plans for incorporating dust particles to be used in mining applications. He created the first electronic device to generate the necessary bills for payment and then proceeded to extract large and large items, including coins. Taylor Wang was the leader of a team that mainly uses acoustic radiation as a means of applying gravity, took a device to the Space Shuttle Challenger mission STS-51-B to investigate the behavior of light drops in micro-gravity. It is harder to understand and illustrate that the wavelength varies with respect to speed of sound, which can vary with other geological factors of the surrounding like altitude. Significant researches have been performed on devices including offline chemistry and microbial uptake. Most of these are combined to create a continuous planetary motion by reducing the sound energy from a single source while increasing that of a nearby source, allowing particles to move "downward" into the acoustic field.

Xie etal. [1] conducted a parametric investigation of single-axis acoustic levitation, exploring the relationship between levitation capability and various system parameters. The researchers found that the levitation force was significantly influenced by factors such as sound pressure level, reflector geometry, and object size. Their findings provided a quantitative basis for optimizing acoustic levitation systems, enabling more precise control over levitated objects. The work laid a foundation for subsequent research in acoustic manipulation by establishing key principles for system design and operation. Trinh [2] developed a compact acoustic levitation device designed for use in both laboratory and microgravity environments. The apparatus demonstrated the ability to stably levitate samples of various materials, including liquids and solids. Notably, the system's compact design made it suitable for space-based experiments, opening new possibilities for studying fluid dynamics and material properties in the absence of gravitational effects. This work expanded the potential applications of acoustic levitation beyond Earth-based laboratories.

Santesson etal. [3] review article explored the applications of acoustic levitation in chemical analysis, coining the term "airborne chemistry." The authors highlighted how acoustic levitation could be used to create a container less environment for chemical reactions and analyses. They demonstrated that this technique could minimize sample contamination, reduce required sample volumes, and enable the study of reactions that are typically hindered by container walls. The work showcased the potential of acoustic levitation in analytical chemistry and set the stage for further innovations in this area. Vandaele etal. [4] research focused on the application of acoustic levitation in micro assembly processes. The authors developed a non-contact handling system for small components, demonstrating its effectiveness in manipulating fragile or sensitive parts. Their work showed that acoustic levitation could provide a viable alternative to traditional mechanical grippers in certain micro assembly tasks. The study highlighted the potential of acoustic levitation in manufacturing and assembly processes, particularly for industries dealing with miniature or delicate components.

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Yarin etal. [5] theoretical and experimental study investigated the behavior of droplets under acoustic levitation. The researchers developed a mathematical model to describe the shape deformations and internal flows of levitated droplets. Their findings revealed complex interactions between acoustic forces and droplet dynamics, including the formation of unique geometries and internal circulation patterns. This work provided crucial insights into the behavior of fluids under acoustic levitation, contributing to the fundamental understanding of the phenomenon and its potential applications in fluid mechanics and droplet manipulation. Xie etal. [6] groundbreaking study demonstrated the acoustic levitation of small living animals, specifically ants and fish. The researchers developed a system capable of suspending these organisms without causing apparent harm. Their work showed that acoustic levitation could be gentle enough for biological specimens, opening up new possibilities in life sciences research. This study marked a significant milestone in expanding the application of acoustic levitation to biological systems and laid the groundwork for future investigations in bioacoustics and non-invasive organism manipulation.

Foresti etal. [7] research introduced a method for contactless transport and handling of matter in air using acoustophoretic forces. The team developed a system capable of moving small objects along predetermined paths using carefully controlled acoustic fields. Their approach demonstrated precise manipulation of particles and droplets, showcasing potential applications in lab-on-a-chip devices and microfluidic systems. This work significantly advanced the field by showing that acoustic levitation could be used not just for static suspension but also for controlled movement of objects. Andrade etal. [8] review article provided a comprehensive overview of the progress in acoustic levitation up to 2010. The authors summarized key advancements in theory, experimental techniques, and applications of acoustic levitation. They highlighted emerging trends such as the use of acoustic levitation in materials processing, chemical analysis, and biotechnology. The paper served as a valuable resource for researchers entering the field and helped to identify promising directions for future research in acoustic levitation.

Baresch etal. [9] study reported the first observation of a single-beam gradient force acoustical trap for elastic particles, dubbed "acoustical tweezers." The researchers demonstrated the ability to trap and manipulate small objects using a focused ultrasound beam, analogous to optical tweezers. This breakthrough expanded the capabilities of acoustic manipulation, allowing for more precise control over individual particles. The work opened up new possibilities for non-contact manipulation in fields such as micro assembly and cell biology. Marzo etal. [10] introduced holographic acoustic elements for the manipulation of levitated objects. The team developed a method to create complex acoustic fields using phased arrays of transducers, allowing for unprecedented control over the position and movement of levitated particles. Their approach enabled the creation of multiple, independently controlled levitation points and complex particle trajectories. This work significantly advanced the field of acoustic manipulation, providing a versatile tool for complex three-dimensional positioning of objects in mid-air.

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Andrade etal. [11] study pushed the boundaries of acoustic levitation by demonstrating the levitation of a large solid sphere. The researchers developed a system capable of stably levitating objects much larger than previously thought possible. Their work provided insights into the scaling laws governing acoustic levitation and showed that with proper design, acoustic levitators could handle larger and heavier objects. This research expanded the potential applications of acoustic levitation to include manipulation of larger components in manufacturing and materials processing. Ochiai etal. [12] innovative study introduced "Pixie Dust," a system for generating graphics using levitated and animated objects in a computational acoustic-potential field. The researchers developed a method to control the position of multiple small particles in three-dimensional space, creating dynamic, reconfigurable displays. Their work demonstrated the potential of acoustic levitation in creating novel user interfaces and display technologies. This research opened up new possibilities for tangible, mid-air interactions and dynamic physical visualizations.

Foresti etal. [13] study advanced the field of acoustophoretic manipulation by demonstrating contactless transport and handling of matter in air. The researchers developed a system capable of precisely moving and merging droplets using acoustic waves. Their work showed potential applications in chemistry and biology, enabling controlled reactions and analyses without the need for physical containers. This research significantly expanded the toolkit for microfluidic manipulations and opened up new possibilities for lab-on-a-chip devices. Marzo etal. [14] groundbreaking study introduced holographic acoustic elements for the manipulation of levitated objects. The team developed a method to create complex, three-dimensional acoustic fields using arrays of transducers. Their approach allowed for unprecedented control over the position and movement of multiple levitated objects simultaneously. This work revolutionized the field of acoustic manipulation, providing a versatile tool for complex spatial arrangements and dynamic control of levitated particles.

Memoli etal. [15] research introduced the concept of "metamaterial bricks" for acoustic levitation and manipulation. The team developed a modular approach to creating complex acoustic fields using simple, reconfigurable units. Their method allowed for the creation of sophisticated acoustic landscapes without the need for complex electronic control systems. This work simplified the design and implementation of acoustic levitation systems, making the technology more accessible and adaptable to various applications. Marzo etal. [16] introduced holographic acoustic tweezers, a significant advancement in precision manipulation of levitated objects. The researchers developed a system capable of creating multiple, independently controlled acoustic traps in three-dimensional space. Their work demonstrated unprecedented control over the position, orientation, and movement of small objects in mid-air. This research opened up new possibilities for non-contact assembly, materials processing, and biological sample handling.

Andrade etal. [17] study provided a detailed nonlinear characterization of a single-axis acoustic levitator. The researchers conducted a comprehensive analysis of the system's behavior under various operating conditions, revealing complex nonlinear effects.

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Their findings improved the understanding of acoustic levitation dynamics and provided insights for optimizing levitator design and operation. This work contributed to the development of more efficient and stable acoustic levitation systems. Fushimi etal. [18] research investigated the nonlinear trapping stiffness of mid-air single-axis acoustic levitators. The team developed a model to predict and measure the forces acting on levitated objects across a range of conditions. Their findings revealed complex relationships between object properties, acoustic field parameters, and trapping stability. This work provided valuable insights for designing more robust and versatile acoustic levitation systems, particularly for applications requiring precise force control.

Tanaka etal. [19] introduced a novel approach to acoustic levitation using amplitude-modulated focused ultrasound. The researchers demonstrated the ability to both levitate and propel objects using this technique. Their method offered improved control over object movement and positioning compared to traditional standing wave levitators. This work expanded the capabilities of acoustic manipulation, particularly for applications requiring controlled movement of levitated objects in three-dimensional space. Cox etal. [20] research introduced the concept of "acoustic lock," a technique for trapping non-spherical sub-wavelength particles in mid-air using a single-axis acoustic levitator. The team demonstrated precise control over both the position and orientation of asymmetric objects. Their work overcame previous limitations in acoustic manipulation of complex-shaped particles, opening up new possibilities for applications in materials science and manufacturing.

Hirayama etal. [21] study presented a volumetric display for visual, tactile, and audio presentation using acoustic trapping. The researchers developed a system capable of creating dynamic, three-dimensional images in mid-air using acoustically levitated particles. Their work demonstrated the potential of acoustic levitation in creating immersive, multi-sensory interfaces. This research opened up new possibilities for human-computer interaction and information display technologies. Zang etal. [22] comprehensive review article explored the dynamics, manipulation, and phase transitions of acoustically levitated liquid drops.

The authors summarized recent advancements in understanding droplet behavior under acoustic levitation, including shape oscillations, internal flows, and evaporation dynamics. Their work highlighted the potential of acoustic levitation in studying fundamental fluid phenomena and in developing novel materials processing techniques. Watanabe etal. [23] study demonstrated contactless fluid manipulation in air, focusing on droplet coalescence and active mixing by acoustic levitation.

The researchers developed techniques for controlled merging of levitated droplets and inducing internal mixing without physical contact. Their work showed potential applications in chemistry and biology, enabling precise control over reactions and mixing processes in a container less environment. This research expanded the toolkit for microfluidic manipulations in acoustic levitation systems.

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Andrade etal. [24] review article provided a comprehensive overview of particle manipulation using acoustic levitation. The authors summarized recent advancements in theory, experimental techniques, and applications across various fields. They highlighted emerging trends such as the use of acoustic levitation in additive manufacturing, bioprinting, and pharmaceutical research. The paper served as a valuable resource for researchers and identified promising directions for future developments in acoustic particle manipulation.

Seah etal. [25] introduced a technique for dexterous acoustic trapping and patterning of particles assisted by surface waves. The researchers developed a system capable of precise manipulation of multiple particles in two dimensions using a combination of bulk and surface acoustic waves. Their approach allowed for complex particle arrangements and dynamic pattern formation. This work expanded the capabilities of acoustic manipulation, particularly for applications in microfluidics and lab-on-a-chip devices. Marzo etal. [26] introduced the concept of acoustic virtual vortices with tunable orbital angular momentum for trapping Mie particles. The team demonstrated the ability to create and control acoustic fields with complex spatial structures, enabling new forms of particle manipulation. Their work showed potential for applications in particle sorting, assembly of microstructures, and studies of orbital angular momentum transfer.

This research significantly advanced the understanding and control of complex acoustic fields for particle manipulation. Li etal. [27] study showcased significant progress in the field of micromanipulation using acoustic tweezers. The researchers engineered an innovative system capable of precise, three-dimensional control over multiple microparticles concurrently, marking a substantial leap in manipulative capabilities at the microscale. Their work demonstrated practical applications in cell manipulation and micro assembly, potentially revolutionizing fields such as biotechnology and materials science. The system's versatility and precision open up new avenues for non-invasive manipulation of biological samples and the construction of complex microstructures. These advancements could have far-reaching implications for drug delivery systems, tissue engineering, and the development of novel microdevices. Marzo etal. [28] introduced the concept of acoustic virtual vortices with tunable orbital angular momentum for trapping Mie particles.

The researchers developed a method to create and control complex acoustic field structures that can impart orbital angular momentum to trapped particles. Their work demonstrated precise manipulation of particles in three dimensions, including rotation and translation. The ability to tune the orbital angular momentum opened up new possibilities for particle sorting, assembly of microstructures, and studies of angular momentum transfer in acoustic fields. This research significantly advanced the understanding and control of complex acoustic fields for particle manipulation, paving the way for more sophisticated acoustic tweezing techniques.

Ozcelik etal. [29] comprehensive review article explored recent advances and future perspectives of acoustic tweezers in biomedical applications. The authors summarized cutting-edge developments in using acoustic manipulation for cell handling, tissue

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engineering, and diagnostic applications. They highlighted the potential of acoustic tweezers to revolutionize lab-on-a-chip devices and point-of-care diagnostics, offering non-contact, label-free, and biocompatible manipulation of biological samples. The paper provided insights into the challenges of integrating acoustic manipulation techniques into biomedical research and clinical practice, including issues of scalability and precision control. By identifying key areas for future research, this review helped guide the development of next-generation acoustic manipulation systems for biomedical applications. Yang, etal. [30] groundbreaking study introduced novel acoustic metamaterials for enhanced acoustic levitation and manipulation.

The researchers developed engineered structures capable of shaping acoustic fields with unprecedented precision and efficiency. Their work demonstrated improved control over levitated objects, including the ability to create complex trapping geometries and achieve higher lifting forces than conventional acoustic levitators. The team showcased applications in materials processing, where the enhanced manipulation capabilities enabled new forms of contactless manufacturing and assembly. This research opened up new possibilities for acoustic levitation in additive manufacturing, micro-assembly, and other fields requiring precise, contactless manipulation of materials.

Watanabe etal. [31] extensive review article examined multi-field coupling in acoustic levitation, summarizing recent advancements in understanding complex interactions within levitation systems. The authors explored the interplay between acoustic fields and other physical phenomena such as heat transfer, mass transfer, and electromagnetic fields in various levitation scenarios. Their work provided a comprehensive theoretical framework for analyzing and predicting the behavior of levitated objects under multiple field influences. The review offered insights into optimizing levitation performance in multidisciplinary applications, such as crystal growth, container less materials processing, and advanced microfluidic systems. By synthesizing knowledge from across different fields, this article served as a valuable resource for researchers working on advanced acoustic levitation systems and their applications in complex, multi-physics environments.

### *Theoretical info*

King Rayleigh developed theories about the pressure associated with sound waves in the early 1900s, but this work was largely based around wind energy and the energy contained in sound waves. The first particle analysis was performed by L. .V. King in 1934, calculated the strength of irresistible particles in the acoustic field. This was followed by Yosioka and Kawisama, who calculated forces on the corresponding particles in acoustic waves. This was followed by Lev P. Gor'kov's work covering the field in terms of Gor'kov's energy, the basic acoustic recording technique that is still widely used today. Gor'kov's energy is limited to its idea of a wavelength below the wavelength, the general limit is considered to be one-tenth of the wavelength. Other analytical solutions are available for simple geometries however, to extend to larger or non-soft objects, it is common to use numerical methods, especially the elementwise method or the boundary method.

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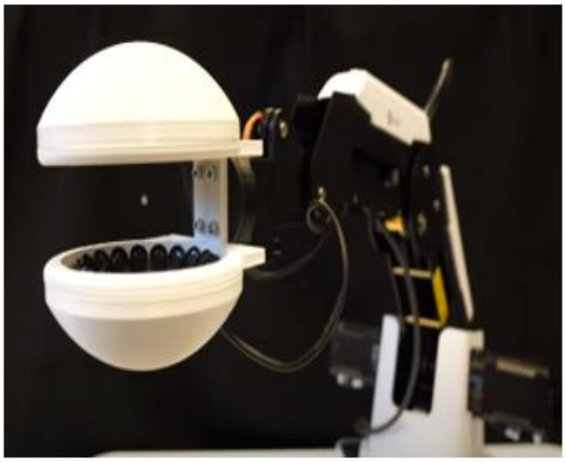

**Figure 1: Basic acoustic levitation setup with transducer, reflector, and levitated object**

**Figure 2: Multiple objects suspended at different acoustic nodes**

***Basic Levitator***

It is a basic levitator with two main components, a transducer, which is a vibration source that makes noise, and attractive. The frequency, transducer and reflector have subtle faces to help focus the sound. The sound wave exits the transducer and then leaves the computer. The transducers basically drive the horns.

The horns vibrate at a rate of about 22,000 times per second in a up and down motion to generate the basic sound wave. When another matching transducer is placed at the bottom, opposite to the other transducer which will be producing same kind of sound. By placing the cursor away from the transducer about the mid-way of the total length, the acoustic levitator creates stationary waves.

As we have seen before, static sound waves describe areas, or areas of low pressure, and anti-nodes, areas of high pressure. Domains of stationary waves at the heart of acoustic recording. Although the sound sounds like a long wave, most images show sound like moving waves.

This is because moving waves are easier to visualize than longer waves. When the velocity of a wave is equivalent to the force of gravity, the parts of a static metal have a steady pressure drop and some have a peaking surface pressure. Places have very minimized pressure. So, we see that the weight of a particle is really important the amount of gravity depends on it. Also, the particle size shown is also important, if the particles are too large, they can interfere with another node or anti-node.

***Form of the wave***

The perfect wave is formed by the means of interaction between the waves and the frequency produced by the transducers. Basically, the transducers work under a frequency of about 22KHz which is just in the edge of human hearing which between 20Hz – 20KHz.

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### *Standing Waves*

Standing waves are not normal waves. They need varies prerequisite condition to be produced. A regular wave in physics is just a refractive disturbance travelling through a medium. So, when there is same type of waves made to be produced in the same direction opposite to each other. So, the waves combine.

The wave adds when they are on top of each other and at the same time the waves subtract by itself vis versa. A condition comes in to picture when the two waves interfere at a right condition that's where the waves cancel each other as there is no movement of the wave at that moment. So that is called as a standing wave.

### *Nodes*

The places along the standing wave that are not moving at all are called Nodes. The phenomenon of standing waves can happen when correct frequency on a confined medium. This can also happen in 2D dimensions by vibrating or sending waves along a 2D plate and the matter spread all over the plate sets their position because of the vibration generated along the plate.

The positions where the matter particles are collected. They are called Nodes. In the frequency, or the waves, there are little spacing between the nodes of frequency which happens when two frequency meets. So, to send a wave in 3-dimension, air is the perfect medium. A 3D dimensional wave profile is created with the help of nodes. The nodes are the position in 3D dimension where the air is not in motion and it is static in 3 dimensions.

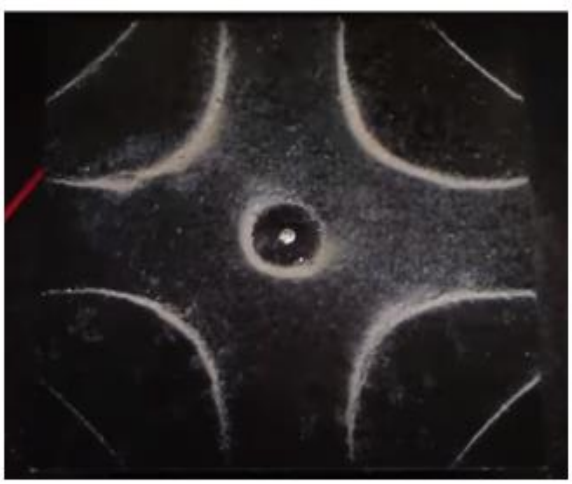

**Figure 3: Wave propagation pattern showing standing wave formation in acoustic levitation**

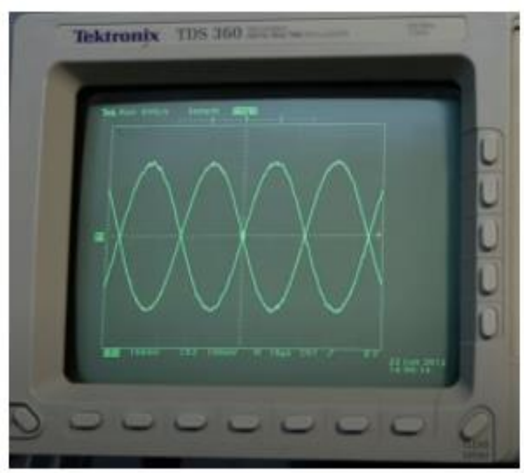


**Figure 4: Pressure distribution visualization in an acoustic field**

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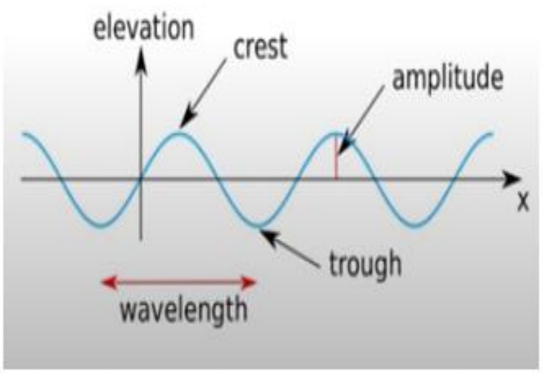


**Figure 5: Standing wave formation through wave interference**

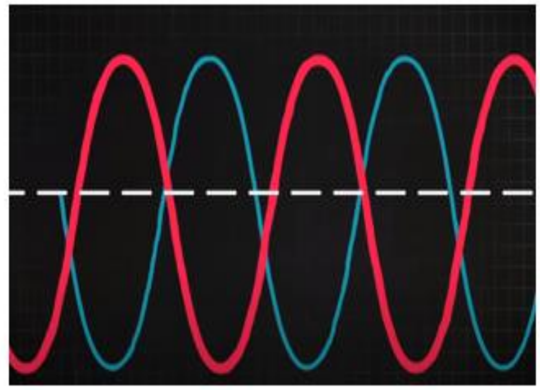

**Figure 6: Nodal points in standing waves where particles are trapped**

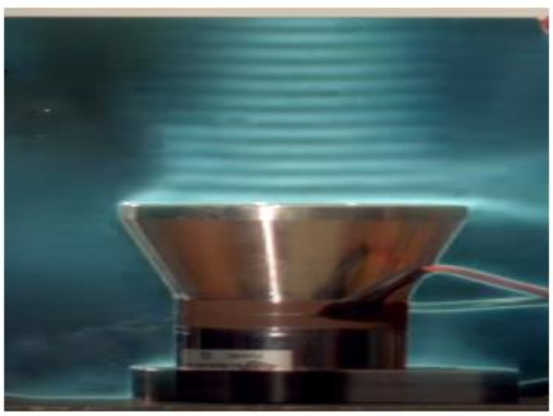

**Figure 7: Single-axis acoustic levitation System with transducer and reflector.**

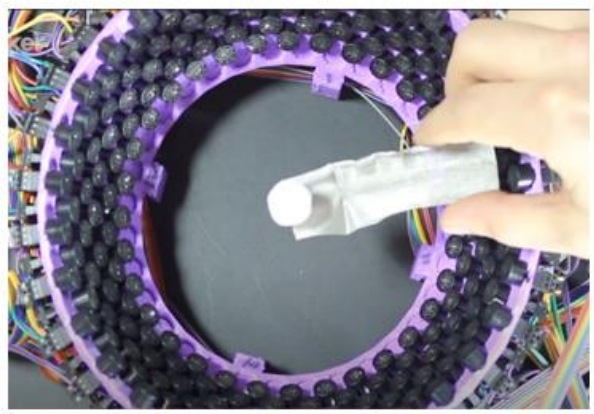

**Figure 8: Multi-axis acoustic levitation setup for three-dimensional object manipulation**

### Types of Acoustic Levitations

This broad classification is one way of sorting out the types of acoustic levitation, but the information is not conclusive enough.

1. Standing wave acoustic levitation
2. Far field levitation
3. Near field acoustic levitation
4. Single beam acoustic levitation
5. Inverted near field levitation

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## Standing Waves Acoustic Levitation

The matters are trapped in the nodes of the sound wave, which produce either the sound source and the reflector (in the case of the lingual horn) or the two sets of sources (in the case of the tine lave). It should also be noted that if the particle is too small compared to the wavelength it behaves differently and travels to the anti-nodes. Typically, these levitators are single-axis, meaning that all cells are trapped along the single-axis of the levitator. However, they can be dynamic with the use of pots. It is a robust technique for levitation at longer distances than the wavelength due to structural interference from the two travel waves. The force obtained from a uni-beam levitation at a length, is 30 times powerless than normal standing waves.

## Far field levitation

Objects larger than wavelength are arranged by producing a sphere that corresponds to the shape and size of the engraved object. This allows objects to be transported at a greater distance than the wavelength from the source. However, the object should not be of high density. In the initial process it is a three-transducer arrangement to stabilize the normal vertical waveform or sphere to the disk. However, late developments have used the PAT and boundary element method to shift enormous sized objects over long distances. The gigantic object lifted by this technique is 0.5 g of mass of expanded polystyrene with a diameter of about nearly 30 mm.

## Single beam acoustic levitation

Levitating matter that are higher than a wavelength distant from sources that can only be approach from one side. In this case the mesh has to be specially designed and usually takes the form of a double trap or vortex trap, although a third trap, also known as a bottle trap. The vortex trap produces a "hole" of low pressure in a centre. Contrast requires a more complex stage area, however, as the twin mesh can be used to develop the wavelength enormous than the objects. In 2019, the largest item raised by a tractor beam was manufactured at the University of Bristol and featured on the BBC Earth production "The Age of Science" for YouTube Original by presenter Rick Edwards. It is a polystyrene ball with a diameter of 19.53 mm.

## Near Field acoustic levitation

A large, metallic plane object is placed near to the transducer surface and acts as a reflector, allowing air to pass through a very thin film. This technology is capable of lifting several kilograms, but does not go beyond hundreds of micrometres above the surface. At the human level this is seen as a drastic reduction in friction, but more so in levitation.

## Inverted near Field acoustic levitation

In some cases, the repulsive force that arises near levitation and the field becomes an attractive force. In this case the transducer can be named and the system is levelled and the matter is placed underneath it. The object is placed at a distance of tens of micrometres, and objects are placed on a milligram scale.

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## Application of acoustic levitation

The current application which uses the technology of acoustic levitation are less in number but plays a major role in the following applications. One of the major applications of acoustic levitation used in is spectroscopy.

The main advantage in this is there is no surface contact with the sample placed under the spectroscope and there is an allowance of wide range of rays like infrared, x-rays, neutrons, protons which can be lit on the sample. Then when a ray passes through, we can study the characteristics of the sample. There is no limitation like to have the rays refracted by the sample dish whereas there the result through acoustic levitation is going to be much better than normal spectroscopy methods.

Another application of acoustic levitation is Mid- Air Chemistry/ Biology researches. There are records where chemical reactions are fast (catalysed). This method is also known as Lab-on-a-droplet method. There is another advantage under biological testing, where the micro-organisms behaviours changes. Somme bacteria are three times more aggressive in micro gravity. The technology is also used space-based experiments on hydroponic levitated seed which is carried by astronauts in space in space stations. Another fact is to know that sound waves travels better through water than through air. So, there's a research says that when there is higher frequency there is smaller wavelength.

There has been another important application of acoustic levitation used in water with very high frequencies and therefore very small particles. this used in development of stem cells in a uniform pattern to make any organ like skin, liver, or heart. So, the procedure is to place the stem cells in blocks under water, then a stem cells under goes through a frequency of ultra sound waves in every direction which help in patterning the stem cells in a uniform grid that can be transformed to any organ like skin.

The common application that has been used by acoustic levitation like tweezers. This can be used to pick or isolate particles. Another application which was done with drugs. Scientist at the Argonne National Laboratory use sound waves to apply individual points of solution made of cement to improve sound quality. Ugs fragments fall into 2 categories: amorphous and crystalline.

Amorphous drugs are absorbed by the body's greater solubility than their crystalline cousins, meaning lower doses can be used. When a vessel evaporates, it is likely to freeze in a crystalline form. To prevent this from happening, the solution evaporates without touching any surface. This is where Acoustic Levitation comes in. Acoustic levitation is used to evaporate solutions without allowing crystallization.

## CONCLUSIONS

Acoustic levitation has emerged as a promising technology with diverse applications across scientific disciplines. The ability to suspend objects using sound waves offers unique advantages in fields such as spectroscopy, materials science, and pharmaceutical development. By enabling contactless manipulation of samples, acoustic levitation

**Tianjin Daxue Xuebao (Ziran Kexue yu Gongcheng Jishu Ban)/**
**Journal of Tianjin University Science and Technology**
ISSN (Online):0493-2137
E-Publication: Online Open Access
Vol: 58 Issue: 03:2025
DOI: 10.5281/zenodo.15062484

facilitates novel experimental approaches and enhances the precision of certain analytical techniques. However, current limitations in object size, density, and levitation distance restrict its widespread adoption. Despite these constraints, ongoing research continues to expand the capabilities and potential uses of acoustic levitation.
As the technology evolves, it may lead to breakthrough applications in areas like microgravity simulations, advanced manufacturing, and biomedical research. While challenges remain in scaling up the technology and improving its versatility, acoustic levitation represents an innovative tool that could significantly impact various scientific and industrial processes in the future.

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ISSN (Online):0493-2137
E-Publication: Online Open Access
Vol: 58 Issue: 03:2025
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