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LEVITATING OBJECTS USING SOUND

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YOUNG REVIEWER:

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AGE: 13

Acoustic levitation uses sound waves to hold objects in mid-air. We are all familiar with the power of sound to make us dance and change our moods, but sound can also exert a physical force that is strong enough to levitate objects. To harness this force, we use loudspeakers to form a sound pattern so that the object is surrounded by very loud sound. Scientists have used these ideas to levitate small objects such as insects, as well as extremely small objects like individual cells. They can then manipulate these objects, much like a robot would, but without any moving parts. So far, only relatively small levitating forces have been generated but, in theory, much higher forces could be produced and levitation of objects even the size of humans might be possible. Despite this exciting possibility, you might not want to be acoustically levitated yourself, for good reason!

WHAT IS ACOUSTIC LEVITATION?

The idea of hovering gently in mid-air is an exciting one. You could travel large distances with little or no effort, visit inaccessible places, or just sit back and relax! People have been thinking about levitating themselves or objects for a very long time, but these ideas still seem a long way from being possible. Levitation is also popular in films, usually

with no explanation of how it works. Some people have claimed to have this seemingly magical power, but these claims have not stood up to scientific investigation. However, **acoustic levitation**, which means using sound waves to hold objects in the air, is a scientific fact. This article describes how acoustic levitation works and what might be possible now and in the future.

Sound is created when something vibrates and creates waves of energy. The vibrations travel through the air to our ears. The stronger the vibrations of the air molecules, the louder the sound. Sound waves carry forces, although these are usually too small to feel. An extreme version of this effect is an explosion. The explosive force is carried by a shock wave, which is a very high amplitude sound wave. This tells us that sound waves can carry forces through the air and that these forces can be quite large. As you can imagine, these forces will act on any material, including living things. But how can we harness this force in a safe and controllable way?

Loudspeakers are sources of sound that we are all familiar with. If we could find a powerful enough loudspeaker, could it help us achieve levitation? The answer is part yes and part no! Yes, in that a powerful loudspeaker could apply a force to an object placed in front of it. No, in that a single loudspeaker would provide a pushing force only, and the object would be uncontrollably blasted forwards. To stabilize the levitation, the trick is to use lots of loudspeakers and combine the sounds from all of them.

A group of loudspeakers arranged to combine the effects of their sounds is called an **array** (Figure 1). We must carefully control the timing of the sound coming from each loudspeaker. If we get this timing right, the sound waves will come together to form the pattern of loud and quiet regions needed for acoustic levitation. The key ingredients of this sound pattern are a quiet region where the object will sit and loud regions that will surround the object, like a cage of loud sound. If the object tries to move, it is pushed back by the sound to the quiet region.

To levitate even light objects, we need very loud sounds. Sound loudness is measured in **decibels**. Normal speech is around 60 decibels, loud rock music 140 decibels, and a rocket during launch 180 decibels. Levitation of extremely light things starts when the sound is around 145 decibels, which is just above a loudness level called the threshold of pain. At this loudness, the sound will be not just loud, but painful and potentially damaging to our ears! The solution is to use **ultrasound**, which is sound with a pitch too high for humans to hear; although animals such as cats and dogs can hear it. Even though we cannot hear it, ultrasound still contains energy in the form of vibrating air molecules, which can be used for levitation (Figure 2).

ACOUSTIC LEVITATION

The use of high amplitude sound waves to overcome gravity and hold objects in mid-air.

ARRAY

Many sources used together to create a combined effect. The term applies to any energy source, but here we use it to mean a collection of loudspeakers, each contributing to create a loud sound at a point.

DECIBEL (dB)

The international unit of measurement for sound loudness. For example, normal conversation is 60 dB, a police siren is 120 dB and fireworks or very loud music is 140 dB.

ULTRASOUND

Sound at pitches above 20 kHz. This is the typical upper limit of hearing for healthy adults. Many animals such as cats, bats, insects, and dolphins can hear these sounds.

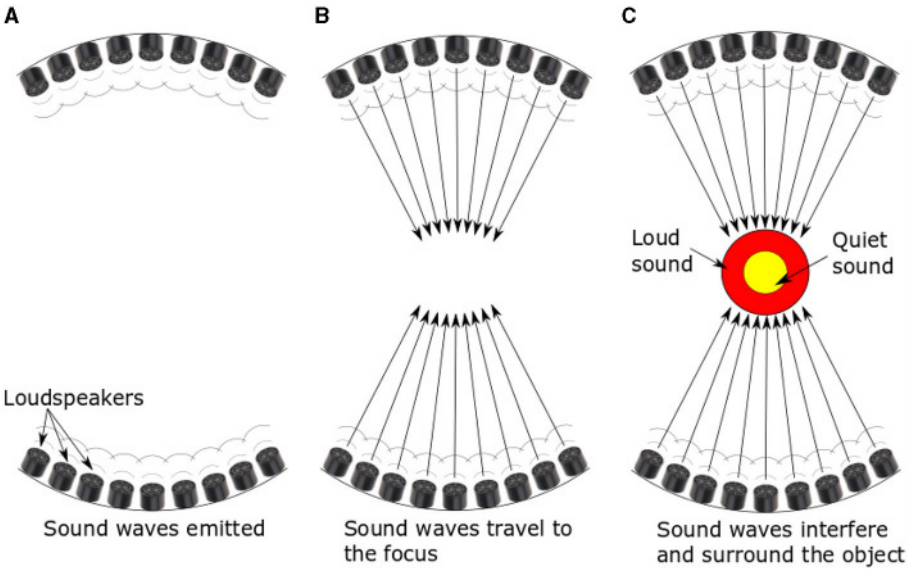

Figure 1

How acoustic levitation works. **(A)** Two arrays of loudspeakers, each shaped like a bowl, are activated to emit a loud sound. **(B)** The bowl shape causes the waves travel to travel to a center point, where the loudness is even greater. **(C)** The waves mix together in a process called interference. If the timing of the waves is just right, this interference creates a quiet zone surrounded by very high loudness. Objects sitting in the quiet zone can be levitated, if the sound is loud enough, because the force of the loud sound will keep them in the quiet zone.

CAN MAGNETS BE USED FOR LEVITATION?

When you use a magnet, you quickly find that forces can be applied to certain metal objects at a distance. The magnet will attract certain metals with a force that is hard to resist. Hold a magnet in each hand, then bring them together and you really get a sense of this force. Scientists found that these magnetic forces can be used to levitate objects, but that it only works on objects made from magnetic materials, such as iron. Normal magnets cannot apply forces to living things. However, if the strength of the magnet is extremely high, an effect called **diamagnetic levitation** can occur and act on living things. In diamagnetic levitation, the strength of the magnet is so high that it causes the water molecules in the living thing to stretch out and become tiny magnets. The tiny magnetized water molecules can then be pushed by the original magnet. Figure 2 shows a famous experiment in which a 20-millimeter-long frog was held in mid-air using diamagnetic levitation [1]. But a huge amount of power (enough for around 500 homes!) was needed to power the magnet.

DIAMAGNETIC LEVITATION

The use of very strong magnetic fields to magnetize materials and then hold them in mid-air. This effect has been used to levitate living things such as a small frog.

IS IT DIFFICULT TO MAKE AN ACOUSTIC LEVITATOR?

It may surprise you to learn that you can build your own acoustic levitator at home. A group of researchers have written instructions and made a video explaining the steps involved [2–4]. The main parts needed are loudspeakers, an amplifier, and a signal generator (Figure 3). These are the same parts that make up a radio or any sound system. First, the signal generator makes the wave as an electrical signal. The signal is boosted by the amplifier and fed to the loudspeakers. If the electrical signal is increased, the loudness coming from the

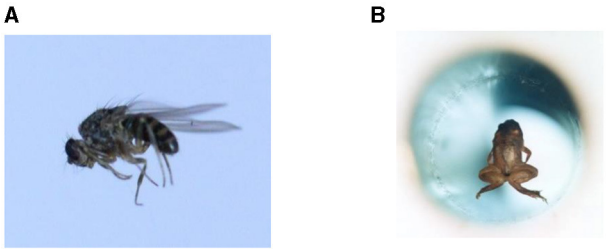

Figure 2

Figure 2

(A) Acoustic levitation of a 5-mm-long fruit fly. **(B)** Levitation of a 20-mm-long frog, with another type of levitation called diamagnetic levitation. The fly and frog were not harmed (Image credit: [1]).

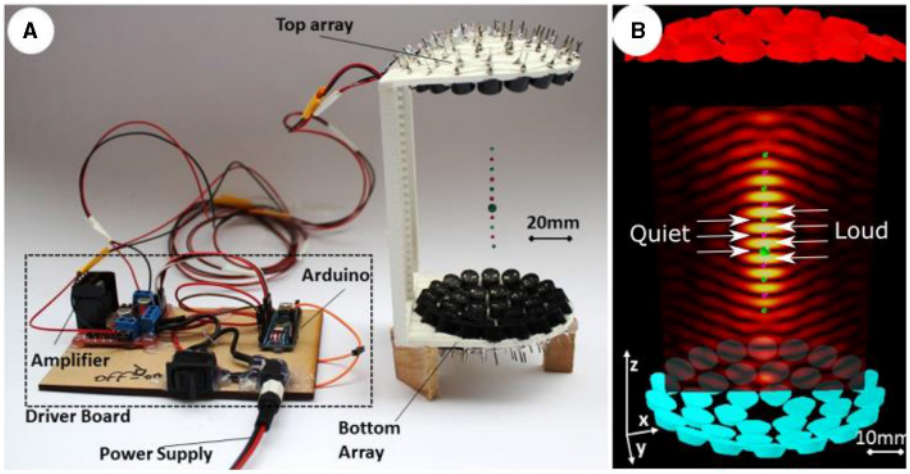

Figure 3

Figure 3

An acoustic levitator that can be built at home. **(A)** The parts on the driver board include an Arduino computer that generates the electrical wave and an amplifier to boost the wave. This electrical signal is sent to an array of ultrasound loudspeakers assembled into bowl shapes. The levitator can be powered by a battery or a household electrical socket. **(B)** Map of the loudness pattern. Yellow is loud, black quiet, and red in-between. The levitated objects sit in the quiet regions, held in position by the loud regions above and below (Image credit: [3], CC BY).

loudspeakers increases. This is just what happens when you turn up the volume on your car radio.

The loudspeakers used in a levitator are a bit special because they emit ultrasound. They are originally made as parking sensors for cars, but we repurpose them as ultrasound loudspeakers. If we connect enough of them together and feed them with strong enough electrical signals, we can create sound loud enough for levitation. This experiment uses ultrasound, so it is beyond anything humans can hear. This makes the experiment seem quiet to humans. But, in the area where the levitation happens, the air molecules are shaking violently.

When building a levitator, it is important to get the right pattern of quiet and loud regions. In the home-built levitator, this is done by arranging the loudspeakers in two focusing bowls, which concentrate the energy into a point. When the two bowls are facing each other, a repeating pattern of quiet and loud sound is formed. This is known as a **standing wave**, and it forms when waves meet and mix together in a process called **interference**. You can create a standing wave yourself by shaking a skipping rope or a slinky spring. At certain shaking speeds, you see a fixed pattern of highly vibrating parts and stationary parts. This pattern is exactly what is needed for levitation, with the objects being levitated in any of the quiet regions.

STANDING WAVE

A wave that has a fixed pattern of high and low amplitudes. This can be seen by shaking a slinky up and down at the right speed. You will see a series of points where the slinky is stationary and between them other points where the slinky is moving wildly.

INTERFERENCE

The result of two or more waves of any type mixing. Drop two stones in a pond. The circular waver waves will spread out. When they mix it is called interference.

WHAT ARE THE APPLICATIONS OF ACOUSTIC LEVITATION?

So far, scientists and engineers interested in acoustic levitation have put most of their efforts into levitating objects only a few millimeters in size, such as insects or electronic parts. Holding insects and other living things in place allows us to carefully study them under a microscope without touching them, which is important if they are extremely delicate. We can also levitate the small parts used to build a mobile phone, using the levitation device to pick them up and move them from one place to another, just like a robot arm.

Acoustic levitation can also be used to manipulate even smaller things, such as living cells. These devices are being used like microscopic grippers. One particularly exciting application is in tissue engineering, in which scientists are trying to find ways of recreating skin or muscle. In this case, the acoustic levitation device is used to arrange the cells into specific patterns. Cells have recently been assembled into lines, to form a new piece of muscle [5]. Muscle grown in this new way was shown to be better than muscle grown with any other known laboratory method.

THE FUTURE OF ACOUSTIC LEVITATION

Exciting discoveries can be expected in the next few years in the field of acoustic levitation. Now that acoustic levitation has been used to make simple tissues like muscle, the next step is to use it to assemble more complex structures, such as artificial hearts. Ideas like this will require engineers to collaborate closely with medical researchers.

What might be possible in terms levitating larger objects? Might it ever be possible to levitate humans? Although hard to believe, levitation of humans is possible in theory–we just need to produce loud enough sound over a human-sized area. Calculations suggest that the loudest loudspeakers ever made would allow us to levitate frogs. There is no reason that even louder loudspeakers could not be made, given the will and the money! If possible, would *you* like to be levitated?

A wide variety of small insects and even fish have been acoustically levitated. They have also been carefully observed under a microscope and found to be unharmed. To levitate larger objects, louder sound is needed, which means more energy. The danger is that the energy must go somewhere, and it could be absorbed by the objects or the air around the objects. All this energy could result in dramatic and rapid heating, which might be harmful. In addition to this heating danger, the effect of such loud sounds on living things is just not known. So, while acoustic levitation of humans is possible *in theory*, there is still work to be done before we can do it safely.

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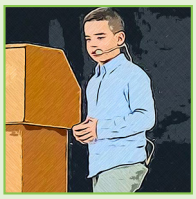
YOUNG REVIEWER



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I was born and raised in Israel. My main hobbis are KAMI (israely martial art) and rhetoric. I have a brown belt in KAMI and I won second place in the Israeli "young speaker" competition. I am also in the scouts and I like to sing.

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Bruce Drinkwater is Professor of Ultrasonics at the University of Bristol. He has a passion for all things ultrasonic and acoustic. As an engineer, he is particularly interested new ultrasonic technology and new applications. He has used ultrasonics

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