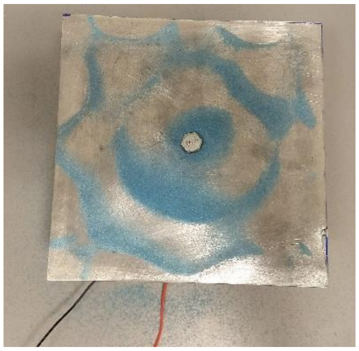
Chladni Plates: Speaker Version

Demonstration



Speakers are a modern way to vibrate a plate and see an abundant number of patterns.

Number of Participants: 2 - 20

Audience: Elementary (ages 5-10) and up

Duration: 5 - 30 mins

Difficulty: Level 4

Materials Required:

- Metal sheet or plate with center hole
  - thickness between 22ga and 28ga
  - there's no wrong size length / width. The 2018 SOCK is 6"x 6".
- 8 Ω, 2W speaker (3" diameter)
- 2" styrofoam ball (one slightly smaller radius than that of speaker)
- 1/4" nut and bolt
- Fine sand or salt
- Hot glue gun
- Amplifier (gain of 20)* See separate demonstration on how to make this circuit
- Output - phone with frequency generator app OR function generator

Setup:

Figure 1 Materials for setting up the speaker version of the Chladni plate. Not pictured is the input mechanism (phone or frequency generator), amplifier, and sand.

1. Gather all materials listed above, as shown in Figure 1. Note that some metal sheets will have a protective coating on them. It might be necessary to lightly sand the surface of what will be glued to ensure stability. Optional: dry graphite powder can be sprinkled on plate before sand, to help sand slide easier on the plate when creating patterns.

2. Cut Styrofoam ball in half, and hot glue flat side onto speaker head. Pre-make a shallow hole in top of Styrofoam ball for bolt, as in Figure 2a.
3. Place bolt through plate, and secure with nut as 2b.
4. Secure the plate down onto the speaker by placing the bolt with plate attached down into the Styrofoam ball as Figure 2c. Hot glue in the Styrofoam ball's hole may be necessary to ensure sturdiness.

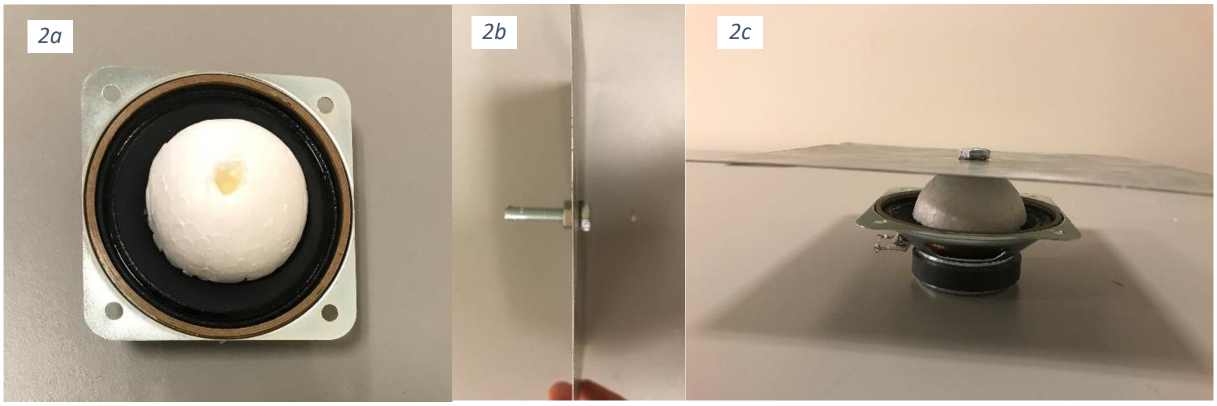


Figure 2 Set up of the Chladni plate on a speaker. ***Left:*** *Top view without metal sheet.* ***Middle:*** *Side view of metal plate, nut, and bolt.* ***Right:*** *Speaker/foam assembly attached to the metal plate/bolt.*

5. Make amplifier if needed. Hook up speaker to amplifier and then into phone or frequency generator. If using a phone, download a frequency generator app.

6. Sprinkle sand on plate. To get clear patterns, one frequency at a time must be played (songs are fun for playing, but not good for patterns). There are many frequencies in which the plate will resonate at and create distinct patterns.

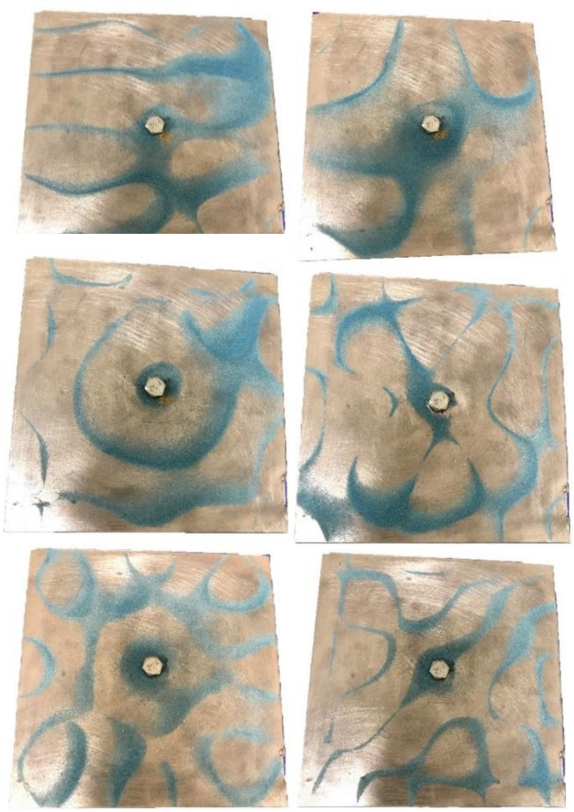


Figure 3 Various Chladni patterns on metal sheet. For this particular setup included in the 2018 SOCK, some frequencies shown are 665 Hz, 905 Hz, 1090 Hz, 1180 Hz, and 1640 Hz.

Presenter Brief:

Understand sound waves, longitudinal waves, resonance, normal modes, and if making the amplifier, be familiar with electronics and circuit diagrams.

Vocabulary:

- Longitudinal waves – waves with excitations parallel to their direction of propagation, e.g. sound waves.
- Transverse waves – waves that move in a direction *perpendicular* to their direction of propagation.
- Node – point of zero amplitude, or zero movement. Every point on a wave is moving except for the node.
- Anti-node – point of highest amplitude and movement.
- Resonance – a condition where the frequency applied to the system is the same as the natural frequency of the system
- Restoring Force – a force that acts in the direction that restores the system to its equilibrium position.
- Frequency – how many cycles per time an oscillation happens, measured in Hz or cycles/second.

Physics & Explanation:

Elementary (ages 5-10):

When you push someone on a swing, you know that there's *just* the right time to push them to make them go higher. Turns out, everything has just the right timing, or frequency, in which they will oscillate, or vibrate, with high amplitude. This is called resonance. We not only see it on the playground, but with the ocean waves, when we play instruments, and resonance is what experts think about when designing earthquake-proofing infrastructure; they need to make sure a building, bridge, or other structure's natural frequency is unlikely to have a resonant frequency that matches up to an earthquake's.

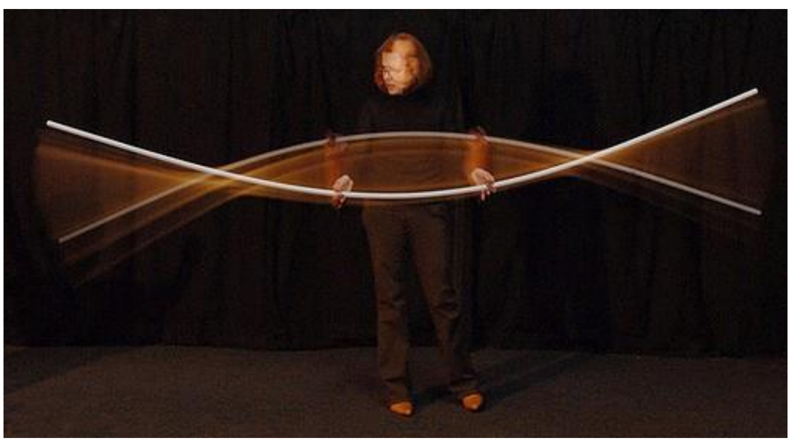


Figure 4 An illustration of nodes and anti-nodes, and how certain frequencies cause waves and vibrations. If shaken a little bit differently, the pattern would look different or not there at all. Photo courtesy of Sebastian Martin.

In the same way, vibrational plates can resonate, but they have many resonance frequencies, like how instruments can play multiple notes. When the speaker plays one of the plate's resonant frequencies, there is a distinct way the plate vibrates, where certain parts vibrate, and certain parts don't. The sand reveals this pattern by bouncing off the vibrating parts.

You can illustrate with smaller kids how not all frequencies work to make waves, using a couple volunteers and a rope. See if they can get the rope to vibrate in the fundamental or any harmonics. In the same way of the rope, the plate won't vibrate at every single frequency or pace.

Not all frequencies "work" and create patterns. There are special resonant frequencies, where objects absorb and vibrate sound better.

Great for younger audiences, you can hand out sticky paper for kids to stick on the plate pattern, so they can take the sand pattern home with them.

Middle (ages 11-13) and general public:

E.F.F. Chladni was a Hungarian physicist and musician who spent the late 1780s and 90's publishing literature and lecturing physics around Europe. His signature demonstration was sprinkling powder or sand onto a glass plate, and then setting the plate into vibration with a violin bow, creating patterns in the sand. These patterns are called Chladni patterns, and this demo is named after him (but of course, he was not the first one to perform this; Robert Hooke did 80 years earlier).

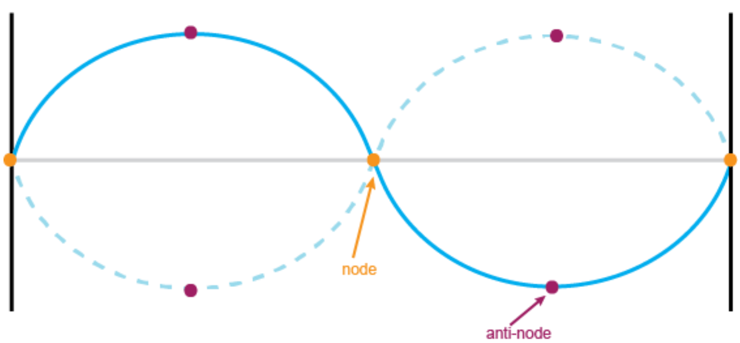


Figure 5 Wave on a string, showing nodes and anti-nodes.

The patterns are a product of waves moving sand on the vibrating surface. Just like waves on a string, the plates have nodes and anti-nodes for a given resonance. In places where there is no surface motion the sand will not be disturbed and collect, while other areas will cause the sand to move into these low motion, or nodal, lines.

On a flat surface, sand on the plate is agitated by the vibrations and will tend to collect along nodal lines, where the vibrations are minimal.

All waves transport information and energy, without actually moving material (such as water waves in the ocean). In the case of the Chladni plate, the speaker creates longitudinal sound waves which vibrate the air and we hear as sound. The transverse mechanical waves on the plate move the sand grains up and down into nodal lines. Many forms of kinetic energy are exhibited: compression/rarefaction of air, sand motion, and deformation of the plate.

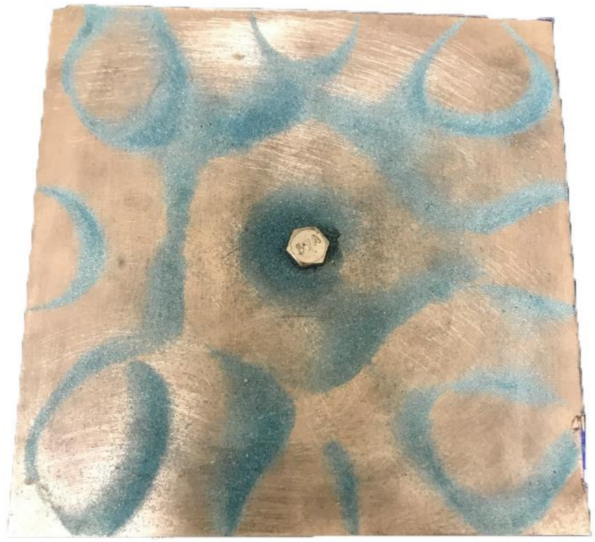


Figure 6 Blue sand settles on the nodal lines. For the plate, anti-nodes are hard to distinguish since all places on the plate are moving somewhat except the nodal positions.

Waves transport energy.

> Optional discussion topic: what would happen if you played the Chladni plates in space? Would you still see the patterns? Would you hear the sound?

Sound waves need a medium to travel in, so you won't hear sound in space (contrary to all those sci-fi space explosions). Mechanical waves also need a medium to propagate through, regardless if they're transverse of longitudinal. So, if an instrument such as the Chladni plate got put in space, you wouldn't hear the sound, but the sand particles would still move. Since there's no gravity, the pattern would be less pronounced; the sand would just be accelerated off the plate rather than move over into the nodal positions.

Highschool and up (14+):

For each distinct resonant frequency, there will be an associated pattern of vibration. These vibrational characteristics for plates are determined by its material properties, geometry, size, and thickness. There are many normal modes (resonances) for most metal plates. Since normal modes are independent of each other, at higher frequencies patterns can be a combination of normal modes, resulting in increasingly complex patterns with higher frequencies. Note that the frequencies of the vibrating modes are generally not harmonic, like they are for waves on a 1-D string or 2-D membrane.

Any periodic vibration (however complicated) can be built up from a series of simple vibrations. Cymatic patterns are increasingly complex with increasing frequency.

Observing modes of vibration is not unique to Chladni plates. The sand is a means of visualizing an already existing phenomenon. These types of patterns, or cymatics, can be found in numerous places, including: the earth during earthquakes, the surface of the sun, drum heads, cymbals, bells, and any other musical instrument. Scientists use this same idea of looking at Chladni patterns for things such as creating violins, to look at the patterns of different notes, analyzing if the symmetry is there, indicating the desired sounding harmonics. It's called hologram interferometry.

There is an intricate relationship between harmonic sounds and symmetry, and these patterns can tell us useful information.

Additional Resources:

- Rossing Moore & Wheeler, *The Science of Sound* 2002.
- Tacoma Narrows Bridge as an example of resonance in building structures https://www.youtube.com/watch?v=nFzu6CNtqec
- Illustrations of wave motions including simple longitudinal, transverse, and water waves https://www.acs.psu.edu/drussell/demos/waves/wavemotion.html