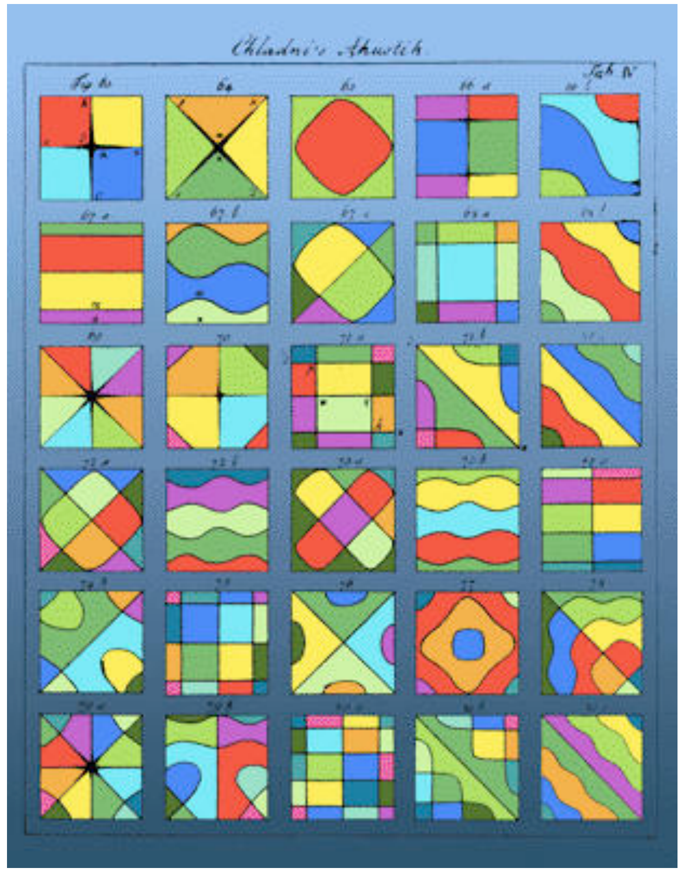
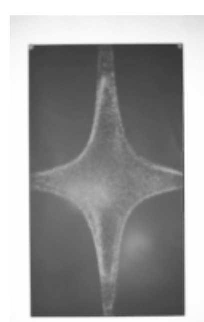
PreLab 8 – Chladni Plates

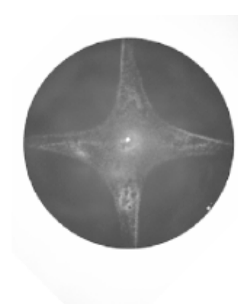
When a flat plate of an elastic material is vibrated, the plate oscillates not only as a whole but also as parts. The boundaries between these vibrating parts, which are specific for every particular case, are called node lines and do not vibrate. The other parts are oscillating constantly. If sand is then put on this vibrating plate, the sand collects on the non-vibrating node lines. The oscillating parts or areas thus become empty.



History

The diagrams of Ernst Chladni (1756-1827) are the scientific, artistic, and even the sociological birthplace of the modern field of wave physics and quantum chaos. Educated in Law at the University of Leipzig, and an amateur musician, Chladni soon followed his love of science and wrote one of the first treatises on acoustics, "Discovery of the Theory of Pitch". Chladni had an inspired idea: to make waves in a solid material visible. This he did by getting metal plates to vibrate, stroking them with a violin bow. Sand or a similar substance spread on the surface of the plate naturally settles to the places where the metal vibrates the least, making such places visible. These places are the so-called nodes, which are wavy lines on the surface. The plates vibrate at pure, audible pitches, and each pitch has a unique nodal pattern. Chladni took the trouble to carefully diagram the patterns, which helped to popularize his work. Then he hit the lecture circuit, fascinating audiences in Europe with live demonstrations. This culminated with a command performance for Napoleon, who was so impressed that he offered a prize to anyone who could explain the patterns. More than that, according to Chladni himself, Napoleon remarked that irregularly shaped plate would be much harder to understand! While this was surely also known to Chladni, it is remarkable that Napoleon had this insight. Chladni received a sum of 6000 francs from Napoleon, who also offered 3000 francs to anyone who could explain the patterns. The mathematician Sophie Germain took he prize in 1816, although her solutions were not completed until the work of physicist Kirchoff thirty years later. Even so, the patterns for irregular shapes remained unexplained. Government funding of waves research goes back a long way! (Chladni was also the first to maintain that meteorites were extraterrestrial; before that, the popular theory was that they were of volcanic origin.) One of his diagrams is the basis for image, which is a playfully colored version of Chaldni's original line drawing. Chladni's original work on waves confined to a region was followed by equally remarkable progress a few years later.





Modes of violin plates

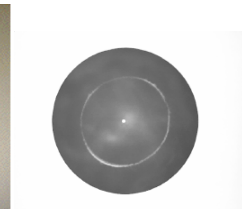
The violin plate has many modes of vibration, and in general each one occurs at a different frequency. About seven of them (those with lowest frequency) are well studied. Of these, three or more are considered useful in the process of shaping the plates by violin makers. For several different types of plate, the mode with the lowest frequency has two node lines, both approximately straight, which intersect at about ninety degrees.

The three photographs above show the lowest frequency mode for a violin back [mode 1], a uniform rectangular plate [mode (1,1)] and a uniform circular plate [mode (2,0)]. In this mode, opposite sectors of the plate are going up together, while adjacent sectors (separated by one node) are always moving in

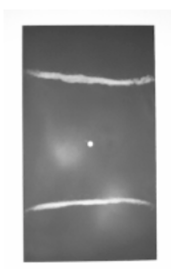
opposite directions. This sketch represents (with exaggerated amplitude) an instant in the motion of the mode for the rectangular plate which is shown in the second photo above.

Naming the modes

The modes of plates of different geometries have different systems of naming. For a rectangular plate, they are identified by two numbers (n,m) where n is the number of modes running parallel to the long axis and m the number in the perpendicular direction (see the examples above). For a circular plate, they are called (n,m) too, but in this case n is the number of nodes that are diameters (straight lines) and m is the number of circular nodes. For the violin plates, the modes have more complicated shapes. They are numbered in a way that, for most violins, corresponds to increasing frequency. That is why the modes in the photographs shown above have the names given in square brackets.



Mode 5 for the violin (called the ring mode) is comparable with the (0,1) mode of a circular plate. For a free plate, the centre of mass does not move, so when part of the plate moves up, another part moves down. In this mode, the central region moves in the opposite direction to the perimeter and only a ring remains motionless, as the animation shows.



The modes for the belly are complicated by the presence of the f-holes (which make the plate more flexible to bending of the short axis) and the bass bar (which makes the plate less flexible to bending of the long axis). Compare the second mode, in which the modes of the top plate could be considered to have rotated by 90 degrees. (see the photographs on the left) The bass bar also breaks the symmetry for most of the modes of the belly.

There are at least three different methods.

The plate can be made to resonate by a powerful sound wave which is tuned to the frequency of the desired mode.

The plate can be bowed with a violin bow. This is easiest if one choses a point that is a node for most of the modes that one doesn't want, but not for the desired node.

The plate can be excited mechanically or electromechanically at the frequency of the desired mode.

Why are Chladni patterns useful?

The shaping the back and belly plates is very important to the properties of the final instrument. Chladni patterns provide feedback to the maker during the process of scraping the plate to its final shape. Symmetrical plates give symmetrical patterns; asymmetrical ones in general do not. Further, the frequencies of the modes of the pair of free plates can be empirically related to the quality of the completed violin. Many scientists have been interested in the acoustics of violins, and many violin makers have been interested in science, so a lot has been written about the acoustical properties of violins and their parts.

LAB 8 & Lab Report

Name: ___________________________ **Section**: _______________

Chladni Plates

Equipment: Violin Chladni plate, frequency generator, sand.

Procedure

Attach the plate to the driver by gently removing the screw from the top of the driving rod, placing the plate on the rod and then returning the screw. Make sure that the driver is sitting in the box provided for it. We want to recycle as much of the sand as possible and by keeping the driver in the box we will be able to keep a lot of the sand. Turn the generator on and turn the amplitude knob about a third of the way up. Starting with the frequency at about 100 Hz slowly increase the frequency until you hear a resonance (the point where the sound is the loudest. Reduce the amplitude and sprinkle a SMALL amount of sand onto the plate.

1) Sketch the resonance patterns and write down the frequency.
2) Increase the frequency slowly to find the next resonances. Find at least 6 more resonances. For each resonance sketch the resonance patterns and write down the frequency.
3) Sketch the resonance patterns and write down the frequency.
4) For each resonance sketch the resonance patterns and write down the frequency.

Report:

1) Comment on any patterns or general features you notice for the violin shaped plate.

2) Did the sand gather at the nodes or anti-nodes of displacement?

3) Find the relationship between the resonant frequencies the violin shaped plate.

4) Is there any relation between the resonant frequencies and the harmonic series that we've been studying?

5) Do you think that real violins have the same nodal patterns that you observed on the plate? (Think about the fact that our plates have free edges.) If yes, why? If not, why not?

6) What are the differences that make violins more pleasing to hear than, say, a box with a hole in it? (Think about the patterns you saw and the number of resonances you found.)