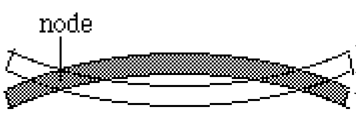
Simple Harmonic Motion: Chladni patterns for violin plates

Chladni patterns show the geometry of the different types of vibration of violin plates. This site has an introductory explanation of modes of vibration and a library of photographs of the Chladni patterns of the bellies and backplates of two different violins (one mass-produced and one hand-made). It also has photographs of plates with regular geometries which assist in understanding the violin modes. For some related history, see Chladni's law. For some Chladni patterns on metal plates, with sound files, see Acoustics of bell plates. To make your own Chladni patters, try this site.

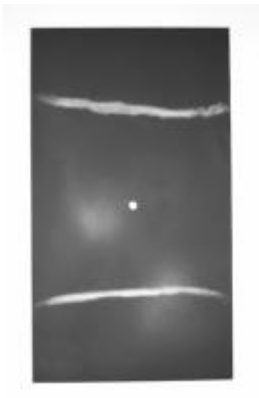
Modes of vibration

(See also the explanations of How a violin works, Bows and strings and Strings, harmonics and standing waves.) A **mode** of vibration is just a way of vibration. Think what happens when you strike a xylophone bar in the middle and set it vibrating. The bar is supported at two points towards the ends. The simplest mode of vibration is this: when the middle of the bar goes up (as shown by the solid lines in the figure) the ends of the bar go down. When the middle goes down (dashed lines), the ends go up. The two points that do not move are called **nodes** and are marked N in the diagram. (If "modes" and "nodes" sound confusing, remember that the **no**de has **no** motion.)



Here is a sketch of a simple mode of vibration of a bar. Think of it as a xylophone bar, which would be supported at the nodes, and you would excite this mode by striking it in the middle. This first mode of the bar is rather similar to one of the modes of vibration of a simple rectangular plate, one that is called the (0,2) mode (the naming convention is explained below.)

Now let's look at photographs of the Chladni patterns of (left) mode (0,2) of a uniform rectangular aluminium plate and (right) mode 2 of a violin back plate.

 . . 

In these pictures, the lines are formed from sand that has collected at the nodes, but has been shaken off the moving regions. The violin back is more complicated in shape, and so the nodes also have a more complicated shape. White sand was used for the black-painted aluminium plate, and black sand for the violin back.

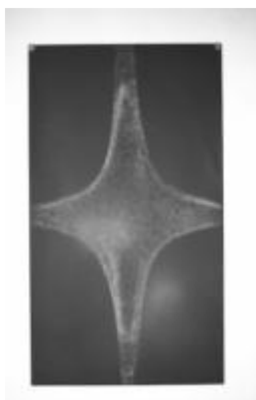
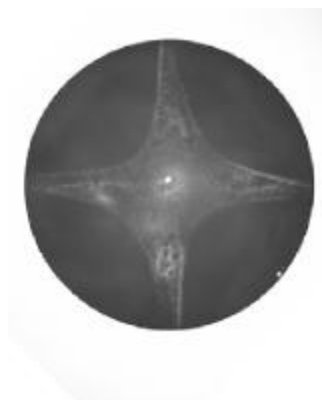
Why are there nodes?

The supports of the xylophone bar do not cause the nodes, rather they are placed at the positions which are nodes so as to facilitate this vibration. In an object which is not firmly clampled, a vibration cannot easily move the centre of mass of the object. It follows that, if some part is going up, another part is going down. In the simple motion at resonance, the point(s) that divide(s) these regions are nodes. When a violin or an isolated part is vibrating, the centre of mass doesn't move much, so once again it can be divided into parts that are going up and others that are going down. In these simple modes of vibration, the motion of different parts is either exactly in phase or exactly out of phase, and the two regions are separated by nodes. The nodes are points for a quasi one-dimensional object like a string, or lines for a quasi two-dimensional object like a plate. (There is more explanation in Strings, harmonics and standing waves.)

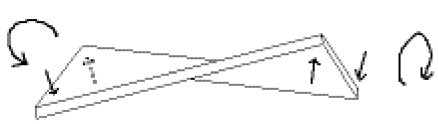
Modes of violin plates

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 and are included in this document. 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 below 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. In the animation, the mode of the circular plate is shown, with the vertical motion both slowed and exaggerated to make it clear.

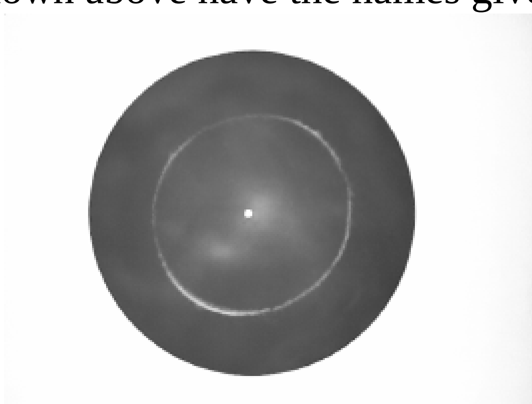


This sketch represents (with exaggerated amplitude) an instant in the motion of the mode for the rectangular plate which is shown in the second photo above.

The following links take you to a library of Chladni patterns for the first seven modes of the belly and back plates of two violins. One is a mass-produced "Lark" model from China. The other is a hand-made German violin from about 1870. For further comparisons between Chladni patterns of simple plates and violin plates, follow this link.

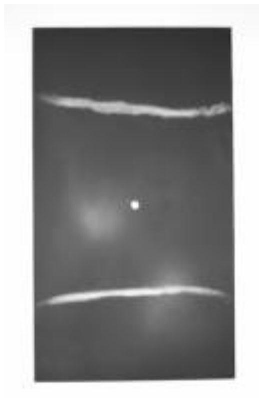
Naming of modes

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 below) The bass bar also breaks the symmetry for most of the modes of the belly.

How are Chladni patterns formed?

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.

For the photographs on this site, a small (0.2 g) magnet was fixed to the plate. An oscillating magnetic field (provided by a coil connected to an audio amplifier and a signal generator) is used to provide an oscillating force whose frequency is tuned to the resonance of the mode. Experiments using different masses showed that the mass of the magnets caused us to underestimate the frequency by about 1 Hertz.

In all cases, some finely divided material is placed on the plate. The material used in the photos on this site is fine sand. When the plate resonates, the motion becomes large over most of the surface and this causes the sand to bounce and to move about. Only at or near the node is the sand stationary. Thus the sand is either bounced off the plate or else collects at the nodes, as shown in the photographs. We used white sand from Coogee Beach to the East of the campus, and black sand from Rainbow Beach on Fraser Island. Emmanuel and Renaud are now leaving on a "research" trip to bring back supplies of diverse colours from Rainbow Beach.

This movie showing the ring mode of a violin back is provided by Atelier Labussiere.

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. See:

- "Research Papers in Violin Acoustics", CM Hutchings and V Benade, eds, Ac.Soc.Am. 1996
- "The acoustics of violin plates" by Hutchins, C.M. Scientific American, Oct.1981, 170-176.
- "Experiments with free violin plates" by Jansson, E.V., Moral, J.A. and Niewczyk, J. J. CAS Journal Vol 1 No 4 (Series II) 1988.
- "The Physics of Musical Instruments" by Fletcher, N.H. & Rossing,T.D. Springer-Verlag, New York, 1991.
- Mode Tuning for the Violin Maker by Carleen M. Hutchins and Duane Voskuil CAS Journal Vol. 2, No. 4 (Series II), Nov. 1993, pp. 5 - 9
- How do bell plates work? -- a question that is answered using Chladni patterns.

Source: http://www.phys.unsw.edu.au/jw/chladni.html