Sound-Controlled Chladni Patterns in Blue Bottle Reactions and Acid-Base Systems

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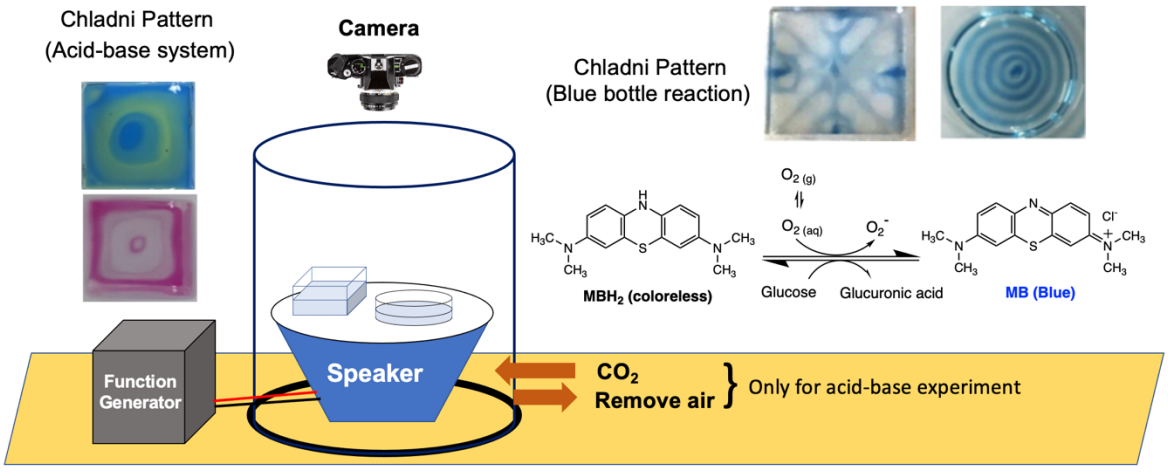
Abstracts

Sound is important in our daily life because it delivers information, creating music and in regulating various biological processes. Sound is also a mechanical wave which travels through the vibration of particles of the medium. When sound vibrations are applied to a fluid from the bottom, the standing wave patterns formed on the surface of a vertically oscillated fluid enclosed by a container. The modes are a spatial and a temporal patterning. In this study, we successfully demonstrate a reaction–diffusion system that produces Chladni Pattern induced by a self-design audible sound-controlled system. The reaction–diffusion system is based on a redox-sensitive chemistry of blue bottle reaction or a pH-sensitive chemistry of acid–base indicators. Vertical vibrations can control the dissolution of atmospheric gases (O_2 or CO_2) in water and segregate the solution into spatiotemporal domains corresponding to different redox states or pH values to generate Chladni patterns in the bulk of the blue bottle solution or acid-base system. Blue bottle variation in concentration in Chladni Patterns was obtained from the cross-sectional study through RGB absorbance.



1. Introduction

Sound is a mechanical wave which travels through the vibration of particles of the medium. When sound vibrations are applied to a fluid from the bottom, the standing wave patterns formed on the surface of a vertically oscillated fluid enclosed by a container. The modes are a spatial and a temporal patterning. In this study, we successfully demonstrate a reaction–diffusion system that produces Chladni Pattern induced by a self-design audible sound-controlled system. The reaction–diffusion system is based on a redox-sensitive chemistry of blue bottle reaction or a pH-sensitive chemistry of acid–base indicators.

2. Experimental

2.1 Faraday wave and Chladni Pattern

Faraday waves are nonlinear standing waves (Fig. 1) which formed on the surface of a vertically oscillated fluid enclosed by a container have long been a subject of fascination. In circular containers, stable and radially symmetrical Faraday wave patterns are resonant phenomena, and occur at the vibrational modes where whole numbers of waves fit exactly onto the surface of the fluid sample.

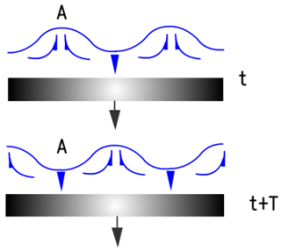


Fig. 1 Schematic diagram of Faraday waves

With standing waves on two-dimensional membranes, the nodes become nodal lines, lines on the surface at which there is no movement, that separate regions vibrating with opposite phase. These nodal line patterns are called Chladni patterns. (Fig. 2)

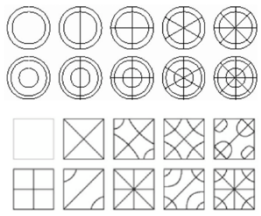


Fig. 2 Chladni patterns on a round plate and a square plate.

2.2 Blue bottle reaction

In the presence of oxygen or air, 3 drops of methylene blue (MB) solution were added into a mixture of 1.0 M glucose 8 mL and 1.0 M NaOH solution 2 mL. Allow to stand and the blue color in the container slowly disappears forming a colorless solution. If the container is shaken a few times, then the blue color is restored. This cycle of color change can be repeated many times.

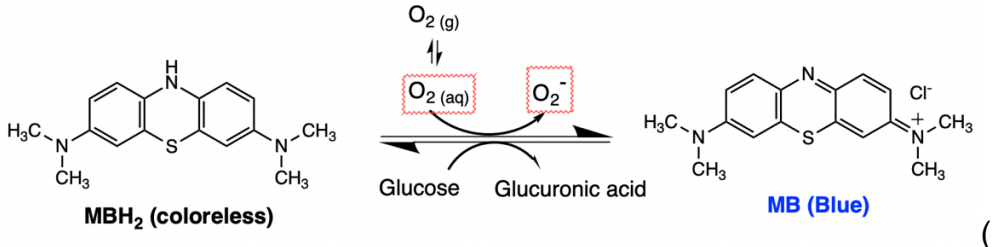
2.3 Sound-controlled spatiotemporal patterns

Blue bottle reaction solution was kept in a grand container with an inner diameter of 35.0 mm in which the height of the solution remained 5.0 mm at room temperature in the presence of oxygen or air. Put this solution undisturbed in a container on the vibrating plate of a self-design sound-controlled system. Patterns generated when sound was applied.

3. Results and Discussion

3.1 The Chladni patterns in blue bottle reaction

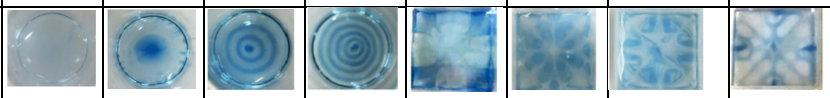
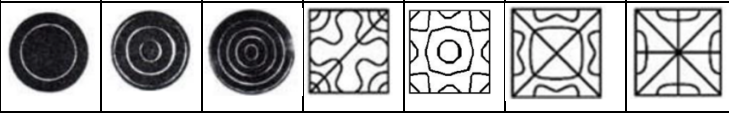
Blue bottle reaction is a redox reaction by using methylene blue (MB) as an indicator. An alkaline solution of glucose acts as a reducing agent and reduces MB from a blue to a colorless form, MBH_2. Then the oxygen dissolved in the mixture oxides the MBH_2 back to its blue form, MB. (Eq. 1) When the dissolved oxygen has been consumed, the MB is slowly reduced back to its colorless MBH_2 by the remaining glucose, and the cycle can be repeated many times.



(Eq. 1)

Put the undisturbed blue bottle reaction mixture in a container on the vibrating plate of a self-design sound-controlled system and exposed to air, vibrated the solution, and then the intense blue solution gradually reorganized into a pattern. The spatiotemporal patterns exhibited a 'self-healing' property that restored the original pattern structure after being manually disturbed. The formation of patterns is influenced by frequency, amplitude as well as the container size including internal diameter and the depth. Clear Chladni Patterns are observed with a sound source operating at a specific frequency which results from the vibrated vertically by resonant driving frequency. (Table 1)

Table 1 Frequency-dependent Chladni pattern in blue bottle reaction.

The Shape of container	Round				Square			
Frequency (Hz)	0	8	28	48	31	35	38	41
Experimental Photograph								
Chladni pattern								

When the shape of container is ground, the pattern shows subsequent refuelled cycles consisting of concentric vertically aligned blue and colorless rings. At high-blue regions, antinodes of the standing wave, the vertical vibration of the sound had a larger amplitude, which promotes oxygen in the air to dissolve into the solution where the color becomes blue in presence of MB. On the opposite, at zero-blue regions (nodes) colorless reduced form, MBH_2, was the main species because of a steady supply presence of reducing agent, glucose.

Blue bottle variation in concentration in Chladni Patterns was obtained from the

cross-sectional study through RGB absorbance. (Fig. 3) In the central region of circle (n = 0), the concentration of MB is 1.52 x 10^{-4} M，which is 1.55 times higher than other high-blue regions (n = 1, 2, 3), 9.75 x 10^{-5} M.

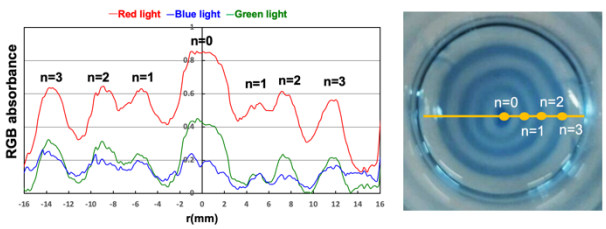


Fig. 3 The spatial - RGB absorbance spectrum of blue bottle reaction during Chladni patterns generation.

3.2 The patterns in acid-base system

Next, we controlled the dissolution and diffusion of CO_2 in to an alkaline solution in which a universal indicator or Phenolphthalein is used as indicator by using sound. The patterns in an acid-base system were shown in Fig. 4. When an alkaline solution under CO_2 atmosphere is placed on a vertical vibrating plate, driven by resonant frequency, the antinodes of the standing wave will turn to be acidic owing to more CO_2 dissolved by larger amplitude.

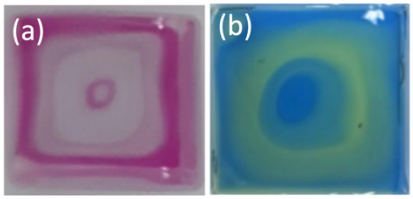


Fig. 4 The patterns in an acid-base system using (a) Phenolphthalein or (b) universal indicator as indicator.

4. Conclusions and Future Research

In summary, we successfully demonstrate a reaction–diffusion system that produces Chladni Pattern induced by a self-design audible sound-controlled system. The reaction–diffusion system is based on a redox-sensitive chemistry of blue bottle reaction or a pH-sensitive chemistry of acid–base indicators. Vertical vibrations can control the dissolution of atmospheric gases (O_2 or CO_2) in water and segregate the solution into spatiotemporal domains corresponding to different redox states or pH values to generate Chladni patterns in the bulk of the blue bottle solution or acid-base system. Blue bottle variation in concentration in Chladni Patterns was obtained from the cross-sectional study through RGB absorbance.

In the future, we wish to investigate other chemical systems, the mechanism as well as fluid dynamics of the formation of sound-controlled spatiotemporal patterns. This approach would be utilized to biology, for instance, the formation of biofilm and the development of acoustofluidic devices.

5. References

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