INTERACTIVE MUSICAL PERIODIC TABLE: SONIFICATION OF VISIBLE ELEMENT EMISSION SPECTRA

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ABSTRACT

Is the periodic table a musical instrument? While this may seem like an absurd question, the process of data sonification can be used to convert the visible spectra of chemical elements into sounds. Each element releases distinct wavelengths of light depending on its electron energy levels—a sort of "chemical footprint" unique to every element. These frequencies of light, which we perceive as different colors, can be scaled to the audio regime, allowing us to "hear" each distinct color as a sine wave with a unique frequency. This research project involved the construction of an interactive musical periodic table, combining visual representations with sonifications of elemental spectra from high-resolution spectral datasets. Implemented in Max/MSP and Jitter, this program can synthesize real-time audiovisual displays of every element from its rich spectral data, allowing us to hear the unique sounds of the chemical building blocks of our world. DSP algorithms allow the user to hear all spectral lines of an element simultaneously (as a "chord") or for individual lines to be played in succession (as a "melody"). This work has been implemented in several K-12 classrooms as an interdisciplinary teaching tool bridging STEM and the Arts, and it is currently being developed into a museum exhibit at WonderLab Museum of Science in Bloomington, Indiana.

1. INTRODUCTION AND PRIOR WORK

The Interactive Musical Periodic Table is a natural extension of the author's "Sound of Molecules" project [1], a 45-minute immersive educational performance combining chemistry and music to answer the question, "What do atoms and molecules *sound* like?" Part of this show features the rainbow-clad character "Roy G. Biv," who explains how we can *hear* light by scaling different frequencies of light-waves (which we perceive as different *colors*) to frequencies of sound (which we perceive as different musical *pitches*). This light→sound conversion, outlined in **Methods**, was used to create a "Helium Dance Party," with chords and melodies created from the "notes" of helium's spectrum. [2] These melodies are synchronized to an audiovisual display, creating an unforgettably colorful, musical, and educational experience.

The "Sound of Molecules" project combines a rigorous data sonification of chemical datasets with a fun and accessible approach to science communication. With the success and impact of the *Sound of Molecules* project—including its performance to several thousand students at Bloomington's WonderLab Museum of Science and a half dozen schools—the author sought to design a new audiovisual instrument based on the periodic table, allowing curious people of all ages to discover connections between light, sound, and chemistry—and even make their own music with the elements. Thus, the idea for the Interactive Musical Periodic Table was born!

2. METHODS

2.1. Mapping light to sound

The idea of "hearing light" might not be as ridiculous as it initially seems. In fact, analogies between light and sound extend so far into scientific history that Newton's assignment of the discrete "ROY G. BIV," colors to the continuous spectrum was done so that it would match the Western 7-note diatonic scale. [3] However, even if we pretend that we can "hear" the electromagnetic waves that constitute light, the frequencies of visible light waves range from 380—750 THz, which is on the order of 10^{10} times larger than the frequencies we can hear. By multiplying the frequencies of light by $\sim 10^{-10}$, we can place them comfortable into the human hearing range of 20—20,000 Hz. Interestingly, the visible spectrum spans very nearly one "octave" of light; that is, the highest frequency violet light has roughly double the frequency of the lowest-frequency red light. As the human hearing range spans 9-10 octaves, this gives us a choice of into which octave of sound we choose to move light—and therefore the elemental spectra. For this work, the range of 380—750 Hz (obtained by multiplying the light frequencies by exactly 10-10) was chosen. These frequencies correspond roughly with the notes in the middle of the piano (approx. F#4 to F#5). This sits within the range of 250—4000 Hz, where the human ear has the greatest frequency discrimination (the average normal hearing adult can discriminate frequency differences of 0.2-0.3%). [4] This is important as the ultimate goals are to (1) be able to discern differences in elemental spectra purely by listening and (2) associate differences in sound with visual differences in the spectra. At the lower end of this range, the spectra are very pleasant to listen to, and represent the best aesthetic decision.

2.2. Sonification Methods

For each element, the atomic emission spectrum is a series of lines with discrete frequencies of light (colors) that result from electrons changing energy levels within atoms (select emission spectra included in Figure 1). Spectral data was obtained from an online database [5] of high-resolution emission spectra (compiled from datasets from MIT Wavelength Tables [6] and the NIST Atomic Spectrum Database [7]), in the visible range of 380-760 nm. These data were collected into TSV files, which are read in the Max/MSP patch. For each spectral line, a unique sinusoid is generated with the frequency corresponding to the frequency of the light, and the amplitude corresponding to the line's brightness. The sonification of helium's emission spectrum via this process is shown in Figure 2. The Max object oscbank~ is used to generate the large numbers of unique sine waves, which can be up to 2000 for some elements.

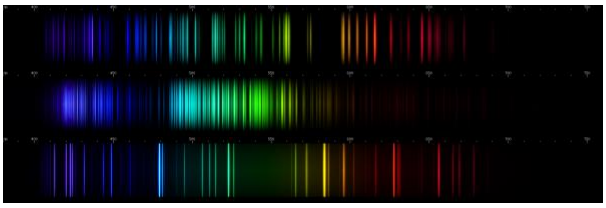


Figure 1: Examples of element visible emission spectra. From top to bottom: oxygen, iron, gold.

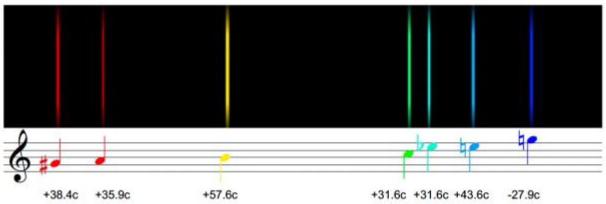


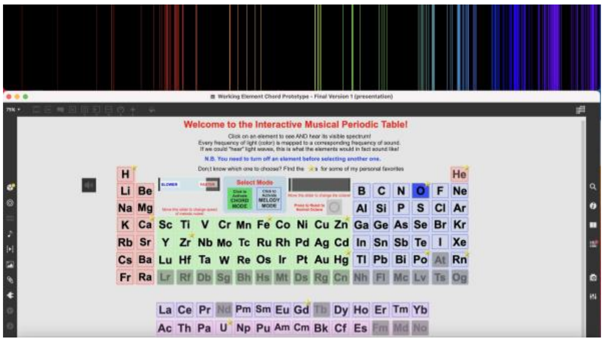
Figure 2: Sonification of helium visible emission spectrum by scaling the frequencies of light down by 10^{-12} to produce a unique musical pitch for each color.

2.3. Visual Synthesis

The visual display is generated using Jitter, with the width of each line scaled proportionally to its brightness. It is impossible to accurately represent every single spectral color using the RGB color space used in computer visuals (the spectral colors are an infinite-dimensional color space while the RGB color space is only three-dimensional), so an approximation method [8] was used to convert wavelengths of light into RGB values.

3. FEATURES OF THE MUSICAL PERIODIC TABLE

In the main window of the Max patch (Figure 3), users can click on an element to see its beautiful spectrum and hear a sonification of it. The spectrum is displayed in a separate jit.world window, which can be displayed on the same screen, but ideally on a separate monitor or with a projector in a dark room for best effect. A user can select "CHORD MODE" to see and hear all spectral lines at once, or "MELODY MODE" to iterate through the lines one-by-one (with a short sinusoidal pulse synchronized to each line appearing). With elemental spectra ranging from 4 lines to over 1800, the sounds of these elements range from simple chords to dense sound masses. Within "CHORD MODE" one can also scale the octave of sound that the visible light is scaled to, and press a button to return to the default range of 380—750 Hz. Finally, within "MELODY MODE," the user can also alter the speed of playback of the lines.



Welcome to the Interactive Musical Periodic Table!

Click on an element to see AND hear its visible spectrum!
Every frequency of light (color) is mapped to a corresponding frequency of sound.
If we could "hear" light waves, this is what the elements would in fact sound like!

N.B. You need to turn off an element before selecting another one.

Don't know which one to choose? Find the ★s for some of my personal favorites

Figure 3: GUI for the Interactive Musical Periodic Table, designed and displayed in Max/MSP and Jitter.

4. RESULTS AND DISCUSSION

The most surprising result of the interactive periodic table is the variety of sounds produced from the elements. While all the spectra (from the author's view, at least) just look like similar collections of brilliant-colored lines—the sounds are quite rich and varied. Simpler elements like hydrogen and helium yield recognizable chords—hydrogen sounds almost like a minor add^9 chord, and helium like a diatonic cluster. There are also many surprises—Zinc, despite having a very complex spectrum with hundreds of lines, gives an angelic chord (very close to major add^9). Most heavier elements with many spectral lines, however, sound like varying shades of noise. For example, iron's 1800 sine waves in the span of a single octave yields and incredibly dense sound mass. Even so, differences in elements become apparent with continued and attentive listening. In the author's experience, it is sometimes easier to distinguish between elements by listening to their spectra rather than looking at them. Of course, this is a sample size of one, and the author's musical background presents a bias, but nevertheless this suggests that this sonification method may be used to develop alternative tools for blind or visually impaired students to interpret spectroscopy data, and future work aims to explore this.

This work has been employed as a teaching tool with great success in both STEM and Music classroom settings. It has been presented to an 8th-grade music technology class at Brown County Middle School, and to an audience of 500 students aged pre-K to 8th grade at The Project School in Bloomington. The value of the work is apparent in the students' enthusiastic response and the incredible questions it prompts them to ask. For instance, after one presentation a nine-year old girl approached me and asked, "what does dark matter sound like?" This type of presentation encourages students to think outside of traditional discipline boundaries and make connections between ideas in science and music/art.

5. APPLICATIONS AND FUTURE DIRECTIONS

This work can find continued application in areas spanning education, research, science communication, and composition. Continued refinement of the program and presentation of the tool to schools, along with surveys and assessments to gauge students' learning and interaction with the software, are in progress. After the most recent presentation, a survey was distributed to students to assess what they learned, how this helped them connect ideas in art/music to science, any questions they have, and any concepts that they find confusing. These results are still being analyzed, and future presentations at schools with additional surveys are planned.

This is also currently being developed into an exhibit at WonderLab Museum of Science in Bloomington. This is a truly unique exhibit that combines an interactive audiovisual instrument with an educational tool illuminating concepts in chemistry, physics, and spectroscopy.

Compositionally, this is an incredible repository of microtonal pitch collections that can be used as chords or melodies. This is demonstrated clearly in the "Helium Dance Party," where helium and other elements are used to make fun, groovy melodies. Additionally, this method of representing sound spectra visually can be applied outside of chemistry entirely, purely to develop colorful and eye-catching audiovisual representations of music. For example, if octave equivalence is applied, each pitch class in a piece of music (with infinite microtonal resolution) can be represented as a single line with a unique color, which can flash on screen when the note is played. Such a program has been developed by the author, where users can upload a MIDI file and render a synchronized light show based on it. [9]

This work also has potential utility for spectroscopic data analysis. Prior research has shown sonification to allow blind or visually impaired people to interpret spectral data, and these results may even provide an alternative or supplementary analysis method that can reveal new aspects of these spectra. Sonification of spectral data is especially promising due to the fact that our ears essentially have a built-in Fourier transform; the basilar membrane in our ears deconstructs audio signals into their component sine waves. In contrast, our eyes do not possess this unique ability of spectral decomposition—that is why it is impossible for our eyes to separate out the red and yellow components from an orange paint, and why computer RGB displays can fool our eyes into thinking we see every color. We need prisms and/or computers to see the spectral components of light mixtures, but our ears pick out these spectral components automatically.

Sonification of scientific data provides an alternative method of analysis that can expand access of such data to blind and visually impaired people. Research by Pereira et. al showed that sonification of infrared spectra could allow blind and visually impaired students to interpret these spectra, and even that these tools performed better in some metrics than conventional methods such as Braille. [10] Sonification can even enhance data analysis via traditional data visualization by providing a supplementary layer of auditory information, and sonification-based learning models have been shown to improve student engagement and understanding of scientific concepts like protein folding. [11]

In this avenue, future work will involve experiments with focus groups to evaluate the ability of people (from musical and non-musical backgrounds) to distinguish between spectra visually and/or aurally to determine if sonification of visible element emission spectra is as effective (or potentially even more effective) than visualization of the spectra.

6. ACKNOWLEDGMENT

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7. SUPPLEMENTARY MATERIALS

A short video demonstrating the interactive musical periodic table in action, with examples of the element sonifications, can be found here.

8. REFERENCES

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