Christine Boone, Melodie Galloway, and Michael J. Ruiz, "Fun with Singing Wine Glasses" *Physics Education* **53**, 035025 (May 2018).

# Fun with singing wine glasses

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**Abstract**

A fun activity is presented using singing wine glasses for introductory physics students. Students tune a white wine glass and a red wine glass to as many semitones as possible by filling the glasses with the appropriate amounts of water. A smart phone app is used to measure the frequencies of equal-temperament tones. Then plots of frequency against water volume percent are made using a spreadsheet. Students can also play combinations of pitches with several glasses. A video (Ruiz M J 2018 *Video: Singing glasses* https://mjtruiz.com/ped/wineglasses/) is provided which includes an excerpt of a beautiful piece written for singing glasses and choir: *Stars* by Latvian composer Ēriks Ešenvalds.

## Brief history of singing glasses

The act of producing tones with glasses of water has been known for centuries. In 1638 Galileo wrote in *Two New Sciences* "... a glass of water may be made to emit a tone merely by the friction of the finger-tip upon the rim of the glass ..." [1] "Musical glasses in the West were evidently derived from Asian antecedents, particularly in Persia from the 11th century onwards" [2]. Ancient instruments such as Chinese cups and Arabic jars were struck with sticks [3]. The music scholar Sir John Hawkins in 1776 suggested that rubbing the rims of glasses to produce tones may have evolved from experiments agitating fluids with different densities in glasses by applying a moist finger to glass rims. [4, 5] Hawkins points out this experiment described in the Latin text *Musurgia Universalis (Rome, 1650)* by Athanasius Kircher: "From this experiment it may be supposed the invention of music on glasses is derived" [4].

The set of musical glasses developed by Irish inventor Richard Pockrich in 1741 [4] were popular in England c. 1760. An excellent glass performer was Ann Ford (later Mrs. Philip Thicknesse).[3] *The Public Advertiser* issue of November 2, 1761 (London, England) announced performances of Miss Ford accompanying her singing on music glasses[4] as well as performing on the viola da gamba[5] and English guitar [7]. The issue also described a pamphlet by Ann Ford on how to play musical glasses. Benjamin Franklin, inspired by hearing musical glasses, invented the glass armonica c. 1760. The instrument consists of enclosed water vessels that rotate along an axis so chords can be played with both hands [8]. Mozart composed a solo piece for Ben Franklin's armonica (K 356) and a quintet, where one of the five instruments is the armonica (K 617) [3].

**Physics of singing glasses**

It is common today to use wine glasses filled with proper amounts of water to obtain aethereal tones characteristic of singing glasses. Rossing in a physics paper on wine glasses, bells, and Lord Rayleigh, points out that ‘a wine glass can be both simple and complex’ [9]. A classic paper on the physics of wine glasses is the publication by French in 1983 [10]. This paper is ‘based on observations and related analysis stemming from a high school science project undertaken by

[3] Philip Thicknesse was a friend of the English painter Thomas Gainsborough, who painted in 1760 a portrait of Ann Ford, Philip's fiancée. The painting is in the Cincinnati Art Museum, Cincinnati, Ohio, USA [6].

[4] In addition, the issue advertised daily performances of ‘Music upon the Glasses’ by a Mr. Schuman.

[5] A precursor to the cello.

the author and his son' about 15 years earlier [10]. The author goes on to explain that his paper presents the detailed theory laid out by Lord Rayleigh [10, 11] nearly one hundred years earlier. The reader is referred to this paper for a fairly advanced analysis of tones produced by wine glasses where a cylindrical model is taken for the wine glasses.

In contrast, our experiment is geared to introductory students with little mathematical background. Nevertheless, we arrive at an empirical graph for an actual non-cylindrical wine glass. See figure 1 for coauthor Christine Boone (center) and music majors playing tones with wine glasses. Producing single tones, two simultaneous tones (musical intervals), and more than two simultaneous tones (musical chords) are a fun component of the lab project. The group shown in figure 1 are practicing the piece *Stars*, by Latvian composer Ēriks Ešenvalds, with an accompanying choir.

**Figure 1.** Coauthor Christine Boone (center) with students in her music theory club performing tones on wine glasses.

**Music theory and physics background**

For the experiment with singing glasses, students must first know about some basic music theory and physics. Figure 2 provides a section of the piano keyboard that contains the tones relevant to the study. A C on the piano is a white key to the left of the nearby pair of black keys. The C situated closest to the middle of the entire piano keyboard is called middle C. This key is also designated as $C_4$ since it is the fourth C on the piano starting from the left end. White keys are labeled A through G and repeat. The # symbol is the sharp symbol, which means the immediate key to the right. The key $A_4$ is the concert reference pitch set to 440 Hz.

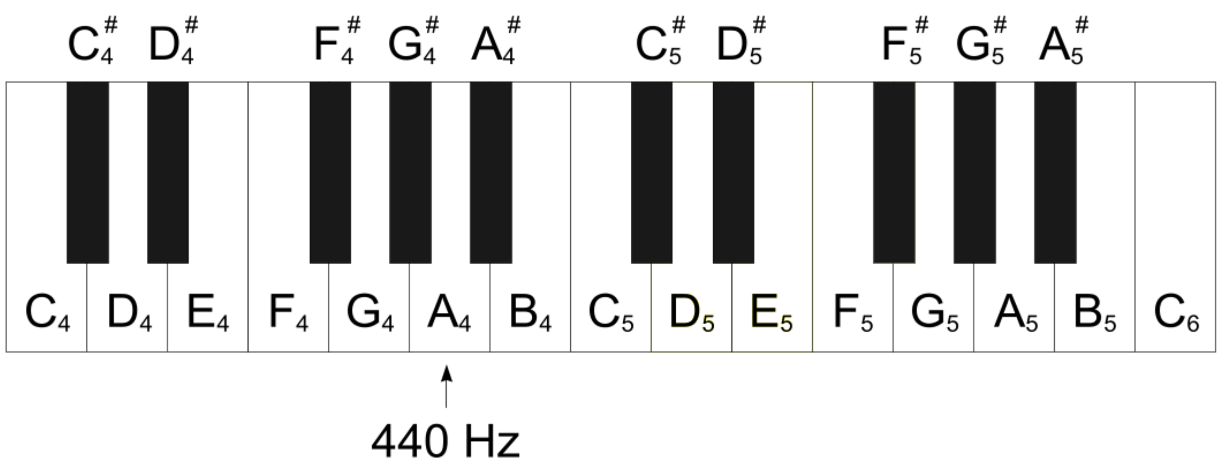


**Figure 2.** Portion of the music keyboard. Middle C on the piano is $C_4$ and $A_4$ is the concert reference pitch set to 440 Hz.

In order to obtain the frequencies above $A_4$, start on $A_4$ = 440 Hz and keep multiplying by the twelfth root of 2 for each higher neighboring note. This tuning is called equal temperament because the ratio of the frequency of any note to the frequency of its lower neighbor is $a = \sqrt[12]{2} = 1.059...$ . This factor is chosen since there are 12 steps (half steps or semitones in musical terminology) from $A_4$ to $A_5$ and $A_5$ is an octave higher, which means its frequency needs to be 880 Hz, twice that for $A_4$. To descend by adjacent notes (half steps), one divides by $a = \sqrt[12]{2} = 1.059...$ for each descending step.

**Filling the wine glasses with water**

For the experiment, two common wine glasses are used. Our wine glasses were inexpensive white and red wine glasses. We found a box set of 4 white wine glasses and a similar box set of red wine glasses, both from the Luminarc line manufactured by Arc International, a world leading glass company with headquarters in France. Our glasses were made by the company's division in Millville, New Jersey, USA. The glasses are shown in figure 3. Both wine glasses hold 12 oz (355 ml), but the white wine glass is taller and the red wine glass wider.

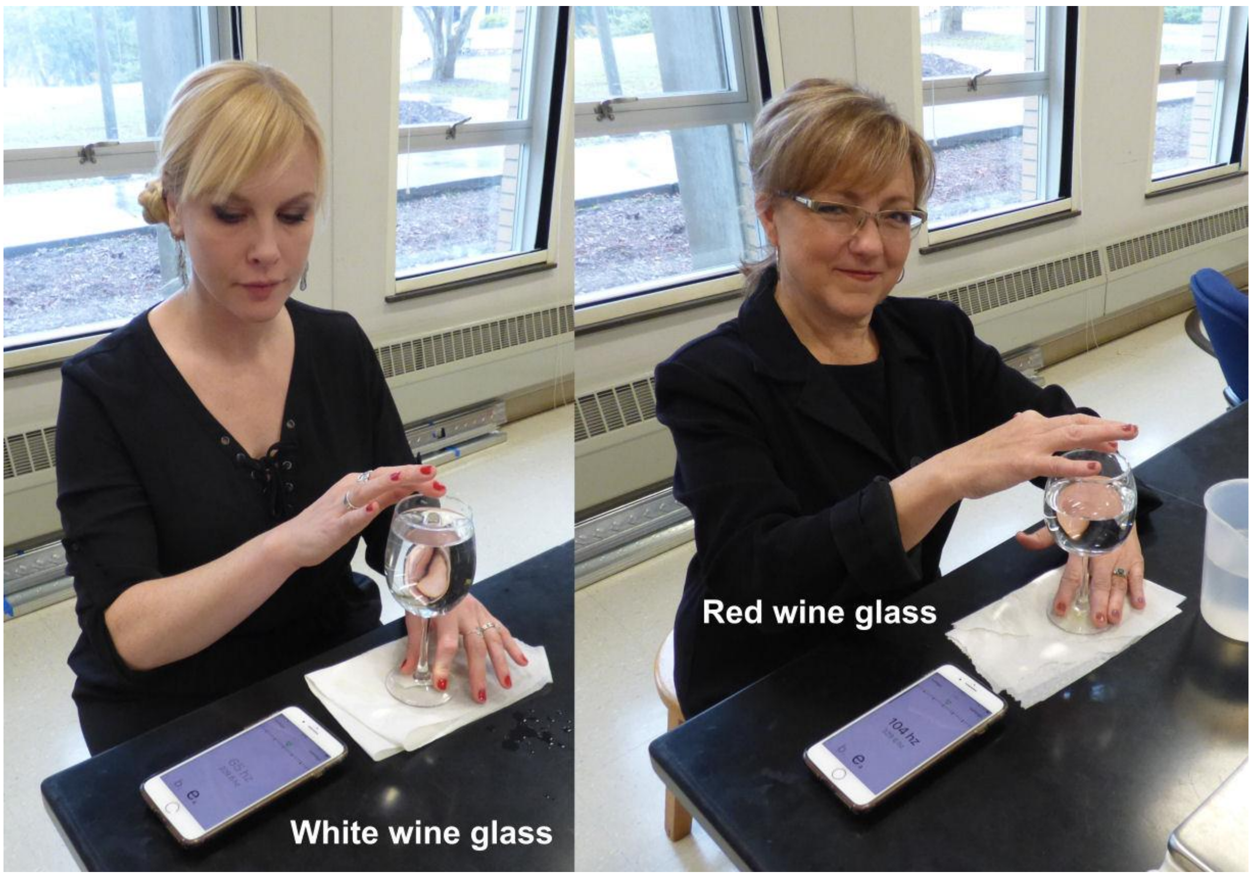


**Figure 3.** Coauthors Christine Boone (left) and Melodie Galloway (right) with respectively a white wine glass and red wine glass. A smart phone for measuring frequencies is on the table.

In the experiment, the wine glasses are filled with various amounts of water in order to obtain as many semitone pitches as possible from figure 2. Smart phone apps are readily available that give both the frequency of a tone and the corresponding closest musical note in figure 2. Therefore, the students have a powerful measuring device in their smart phones. The amount of water added is determined by measuring the mass of the glass with and without the water. Since 1 ml of water has a mass of 1 g, a metric scale can be used to quickly measure water volumes. The difference in mass measurement between the glass with water and empty glass gives the water volume in ml.

There is a trick to obtaining nice tones. Students should wash their hands to remove oils and can dip their forefingers in vinegar to further remove oils. Then, with a moist forefinger, rubbing along the rim of the glass produces the magic tone. With little practice, one can find the right amount of pressure. Too much pressure gives a thudding sound, while too little pressure does not produce a tone.

During the lab, students noticed with certain pressures that the water surface became bubbly with a nice spraying effect. Such a phenomenon was described by Lord Chancellor Sir Francis Bacon in his volume *Natural History* (1627), published one year after his death.

> Take a glass, and put water into it, and wet your finger, and draw it round about the lip of the glass, pressing it somewhat hard; and after you have drawn it some few times about, it will make a water frisk and sprinkle up in a fine dew. [12]

Bacon does not mention that tones can be produced as Galileo [1] does a decade later. This fact supports the supposition of Sir Hawkins that the experiment described by Sir Francis Bacon came first and musical glasses derived from such experimentation [14].

**The data**

The red wine glass produced the equal-tempered pitch $\mathrm{G}_5^{\#} = 831\ \mathrm{Hz}$ when empty. Then to the surprise of all, the glass had to be almost half full to get the next tone, a half step lower in pitch. Some students were familiar with the cylindrical resonance tube experiment in introductory physics, where standing waves in air give higher pitches as the water level rises and the air column shortens. They were surprised to hear the pitch lower as the water level rose in the wine glasses. Chen *et al* [13] point out that one must be careful with the simple explanation that as water is added, the inertia of the vibrating system increases due to the presence of the water, thereby lowering the frequency. They add that 'increased fluid pressure' between the vibrating glass and incompressible water 'retards the glass vibration and lowers the frequency' [14].

Students measured frequencies with their smart phones after adding or pouring out water as needed. The frequencies displayed on the smart phone typically can vary by a few hertz during each measurement. Students aimed for the desired frequency to be the central frequency of the variation displayed on the smart phone app. Variations by a few hertz for a measured value in the hundreds of hertz indicate experimental errors on the order of 1%.

The scales employed were accurate to 1 g, with the empty red and wine glasses having masses 157 g and 163 g respectively, indicating uncertainty less than 1% for the water volume measurements. However, when students measured the full volume to check the advertised 12 oz (355 ml), they found discrepancies of several ml. The authors found that filling the glass to the top gave the nominal value 355 ml; however, one could force more water on top due to the surface tension of water. In such cases, the water curved above the top of the glass (the meniscus effect), and the measured water volume slightly exceeded the total volume contained by the glass. For example, with one wine glass, a water volume of 361 ml could be poured into the glass. Therefore, for our data we used the manufacturer's 355 ml as the total volume capacity of the glass.

The data is given in table 1 for a white wine glass and red wine glass. A total of 12 semitones could be produced for each glass, just one semitone short of an octave in each case.

The white wine glass could not reach the $A_5^{\#} = 880\ \mathrm{Hz}$, an octave higher than $A_4^{\#} = 440\ \mathrm{Hz}$. Similarly, the red wine glass just missed reaching $C_6^{\#} = 1046\ \mathrm{Hz}$, an octave higher than $C_5^{\#} = 523\ \mathrm{Hz}$.

**Table 1.** Data for singing glasses, where each glass has a maximum of 355 ml.

| Note | Frequency (Hz) | White wine glass percent filled (%) | Red wine glass percent filled (%) |
|---|---|---|---|
| $A_4$ | 440 | 92 | --- |
| $A_4^{\#}$ | 466 | 88 | --- |
| $B_4$ | 494 | 85 | --- |
| $C_5$ | 523 | 81 | 95 |
| $C_5^{\#}$ | 554 | 77 | 92 |
| $D_5$ | 587 | 74 | 90 |
| $D_5^{\#}$ | 622 | 70 | 86 |
| $E_5$ | 659 | 65 | 83 |
| $F_5$ | 698 | 59 | 80 |
| $F_5^{\#}$ | 740 | 52 | 74 |
| $G_5$ | 784 | 42 | 69 |
| $G_5^{\#}$ | 831 | 0 | 63 |
| $A_5$ | 880 | --- | 55 |
| $A_5^{\#}$ | 932 | --- | 44 |
| $B_5$ | 988 | --- | 16 |

Plots of frequency against percent full with water are given in figure 4. The graphs clearly illustrate that frequency decreases as the glass is filled with more and more water. Students interested in exploring trend lines on a spreadsheet will find that the data points are described empirically rather well by inverted parabolas.

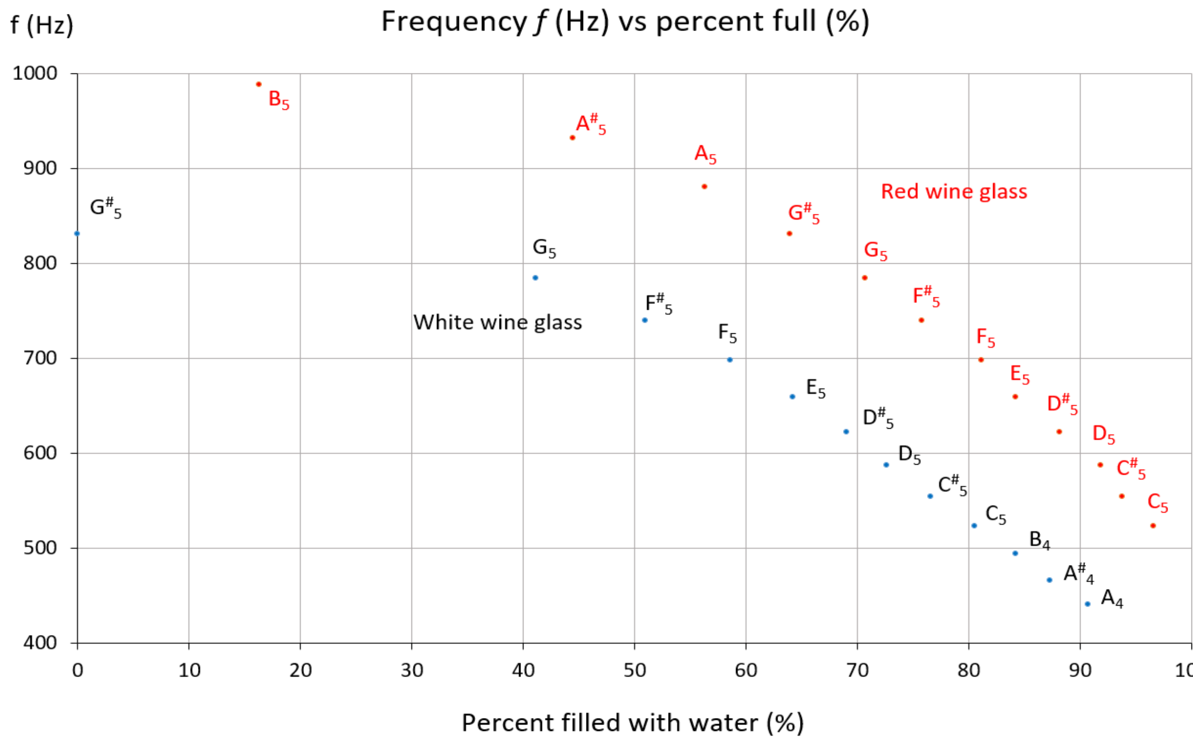


**Figure 4.** Frequency of singing glass versus percent filled with water for a white wine glass and red wine glass.

**Music and singing glasses**

This lab project was necessary for us because coauthor Melodie Galloway wanted to direct her 'Asheville Singers' in a performance of *Stars* by Ēriks Ešenvalds. *Stars* is a composition for choir and musical glasses, where six different pitches are needed for the glasses. Ešenvalds composed the music for *Stars* in 2011 and the piece was published in 2012 by Musica Baltica, Riga, Latvia. The music is set to text written by Sara Teasdale (1884-1933). See figure 5 for a partial view of the choir performing *Stars* in the Fall of 2016 at our school. Coauthor Christine Boone is seen in the first row with a singing water glass. The hands of the conductor, coauthor Melodie Galloway, can be seen at the left edge of figure 5.

The six glass pitches called for in *Stars* are $G_4$, $A_4$, $B_4$, $D_5$, $E_5$, and $F_5^{\#}$. We could not get $G_4$ on our particular wine glasses. Therefore, when the piece required all six tones played together, the three lower pitches were replaced by the three corresponding pitches an octave higher: $G_5$, $A_5$, and $B_5$.


**Figure 5.** Partial view of the Asheville Singers performing *Stars* by Ēriks Ešenvalds, directed by Coauthor Melodie Galloway. The work calls for a choir and singing glasses with six distinct pitches. Coauthor Christine Boone is in the first row playing a red wine glass. Note the different water levels in the two red wine glasses seen in the first row.

The glass tones at the beginning of *Stars* are $B_4$ and $D_5$. Then, as this interval is played, $A_4$ and $E_5$ join in, drop out, join in, drop out, and join in. Students can play this sequence. Students can also try the six tones $D_5$, $E_5$, $F_5^\#$, $G_5$, $A_5$, and $B_5$ simultaneously. Most likely there will be a musician or two in the class than can play simple tunes and guide the other students in forming chords. One traditional chord is the inverted G-triad: $G_5$, $B_5$, and the lower pitch $D_5$, which we demonstrate in our accompanying video [15]. If there are many students in the class, several students can play the same pitch for each note in a chord, forming an orchestra of singing glasses.

## Conclusion

An interdisciplinary lab has been described involving music and physics. The beauty of the activity is the equal importance of the music and the physics. One needs to know basic music notes and equal temperament, with specific frequencies in hertz. In other words, the students need to know the basic language of music and physics regarding tones. Then, the combined knowledge of music and physics allows the student to tune wine glasses to the desired pitches. The project involves modern equipment available on a smart phone, a frequency counter. Such apps include both the pitch in musical terms such as $A_4$ and physics terminology such as 440 Hz.

A natural scientific question arises. How does the volume of water in the glass affect the frequency? This question leads to a scientific investigation finding as many semitones as possible for a wine glass. Of course, one can even find more data points by considering pitches in between the semitones of the equal-tempered scale. The resulting empirical plot with a modern spreadsheet gives a nice result in either case.

The interdisciplinary lab activity is rich in both physics and music. Students will have fun playing tones with the singing glasses and taking the data for the science experiment. Finally, students can watch our video which includes the choir and physics data [15], as well as listen to our full performance of *Stars* by Ešenvalds in a second video [16].

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**Authors**

**Christine Boone** received her BM in vocal performance at Indiana University and both her MM and PhD in music theory at the University of Texas, USA. She is Assistant Professor of Music at the University of North Carolina at Asheville, USA. Boone, a soprano, is an active performer in both choral ensembles and solo work. She has also put her musical knowledge to work on National Public Radio's classical music game show, 'Piano Puzzler'.

**Melodie Galloway** is Associate Professor and Chair of the Department of Music at the University of North Carolina at Asheville, USA. She received her MA in Vocal Performance from Florida State University, USA and her DMA in conducting from the University of North Carolina at Greensboro, USA. She was invited in 2012 to lead 200 singers and orchestra at Carnegie Hall. She has also led choir performances in Vienna, Prague, Salzburg, and directed the UNC Asheville Singers at the White House from 2006 to 2016, including open house and private performances for President and Mrs Obama.

**Michael J Ruiz** is professor of physics at the University of North Carolina at Asheville, USA. He received his PhD in theoretical physics from the University of Maryland, USA. His innovative courses with a strong online component aimed at general students have been featured on CNN. He also composed three piano concertos, performed by each of his three children as soloists with the Winston-Salem Symphony in the 1990s.