PY 231
THE PHYSICS IN MUSIC
Professor B. Lee Roberts

Spring

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http://physics.bu.edu/py231/

Prof. Roberts' Office: PRB 373, (3 Cummington Street)
Office phone number: 617-353-2187 The PY231 Lab in PRB is room 156.

Office Hours: By appointment. I am willing to answer questions just after class. You are welcome to phone 617-353-2187, or send email (preferred) to see if I am available at some other time if just after class doesn't work. More detailed discussions can be scheduled by appointment. During the course of the term, you will have at least two and probably three conferences with Prof. Roberts to discuss your project.

Text: Musical Acoustics, D.H. Hall, 3rd edition.

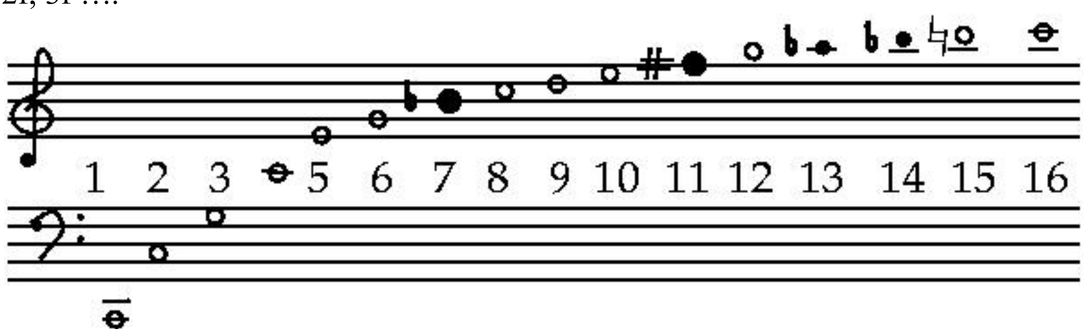
PY231 and the HUB

PY231 satisfies the following HUB areas: Scientific Inquiry, Quantitative Reasoning, and Aesthetic Exploration.

Scientific Inquiry I – Acoustics is the science of sound, which began in the late 19th century with the seminal books on acoustics by Hermann Helmholtz and Lord Rayleigh. Helmholtz's *On the Sensations of Tone* laid out the foundations of musical acoustics. In order to understand musical acoustics one must learn the basics of systems that vibrate (oscillate), understand how nonlinear systems generate harmonics when presented with a single frequency sound, understand how sound waves propagate through the air, and how the human auditory system processes a complex sound *viz*. the psychoacoustics of hearing. In class, we constantly study systems that vibrate and make quantitative measurements of these oscillations, and elucidate the underlying physical processes that are at work in the production and propagation of musical sounds. The acoustical musical instruments consist of a medium that vibrates: either strings, an air column, a stretched membrane, or a solid object that is struck with a mallet. The different ways that each of these systems can vibrate are called the "normal (natural) modes" of the system. These normal modes determine the frequencies present in the sound, and give each instrument it's characteristic timbre. The students learn to identify the basic physical principles at work in the production of musical sounds from each of the instruments, and learn the difference between impulsively excited (percussion) instruments, and those driven by a steady frequency, which include bowed strings, brass and woodwind instruments.

In their term projects, the students make quantitative measurements on the musical system of their choosing, and then write a detailed paper presenting their method and results. In addition to brass, woodwind and string instruments, students have also studied percussion instruments, including the bells in the belfry of the Arlington Street Church in Boston. The term paper takes the form of a journal article, covering the physics of the project, the methodology used to make the measurements, presentation of the results graphically and numerically, along with a summary and conclusions section. The last several days of class time are devoted to students making a brief presentation of their projects to the class.

Quantitative Reasoning I – Central to the entire course is the harmonic series, which is the set of frequencies that are integer multiples of the lowest (fundamental) frequency, f, 2f, 3f ….



The members of the harmonic series based on the note C2. The number below each note is the harmonic number. The frequency ratio of each of the just intervals is the ratio of the harmonic numbers, e.g. the octave P8 has a frequency ratio of 2:1, and the P5 a ratio of 3:2, etc.

The harmonic series defines beat free musical intervals. The generation of harmonics by non-linear systems in response to a single driving frequency (harmonic distortion), manifests itself in many areas of acoustics, giving each instrument its characteristic timbre, as well as giving us the ability to make vowel sounds. Jimi Hendrix was a pioneer in using electronic harmonic distortion, which quickly became an important tool in rock music. The harmonic series also gives rise to tuning and temperament, which is central to music theory. We constantly use the harmonic series in our discussions in a quantitative manner, especially in the construction of musical scales.

Students must learn to quantitatively describe data, and to understand and interpret graphs of the data. Because the response of our auditory system is logarithmic, which permits us to sense stimuli over many orders of magnitude, the students must become familiar with logarithmic as well as with linear scales on graphs. All of the psychoacoustic data is displayed on log-log, or semi-log scales. The homework on psychoacoustics, as well as on homework and tests require a careful understanding of data presented this way, in order to interpret these data. Similarly, the term projects require the presentation of data on logarithmic scales. The homework exercises stress quantitative calculations, and the interpretation of data, both from graphs and from a simple analysis of data. The project requires a much more sophisticated interpretation of data.

Aesthetic Exploration – I make many connections between the physics of sound and hearing and how that affects the way composers use the various instruments to create aesthetic effects. One example is the opening of Richard Wagner's *Das Rheingold* which opens with the horns playing a harmonic series in $E\flat$. In over four minutes of some of the most beautiful music ever written for the beginning of an opera, this harmonic series evolves into the opening chorus of the Rheinmaidens (*Rheintöchter*) . One can argue that this beginning and its slow evolution to the opening Rheinmaiden chorus, foreshadows the compositional aesthetics later developed in the minimalist music of Philip Glass and other 20th century composers. The second movement of Bartok's Concerto for Orchestra "Game of pairs" has an excellent demonstration of a composer using different parallel intervals for each of the five sections: m6, m3, m7, p5, M2. Because of the constant parallel intervals between the two instruments, and the harmonics present in the two individual sounds, the two sounds merge into a unique new sound that can be both beautiful, and sometimes grating, depending on the musical interval. This passage presents a wonderful example of physics, psychoacoustics and art working together to create a very special effect.

Grade Your grade will be determined from the three tests (total 40 %), the homework/discussion 10%, the project 25% and the final exam 25%.

Tests and the Exam There will be three tests during the term, February xx, March xx, April xx. The final examination is scheduled on Tuesday May x from X:00 to Y:00 am. The project is due by 5:00 pm Friday, May xth, and may be submitted electronically.

Goal of the Course: This course is for students who are musicians (at any level) and want to learn about the physics that is involved in producing musical sounds. We will also study some of the psychophysical phenomena associated with the perception of musical sound. Room acoustics will also be discussed.

No previous knowledge of physics is assumed, but a working knowledge of musical terms will be assumed. In addition to the three hours of class and demonstrations, we have a 25 minutes discussion section on both Tuesday and Thursday. In the discussion section we will have worksheets, or a simple lab task.

We will try to discuss a significant fraction of the material in Halls's book, so please keep up in the reading. You are expected to read all the "Exercises and Projects" at the end of each chapter. You will be asked to hand in some of these. You should think about all of them.

Reserve Books: A number of books will be on reserve for this course in the Science and Engineering Library, or in Mugar depending on the Class preference.

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Project

In addition to tests and a final exam, each student is required to do a project on some aspect of musical acoustics. This project should be on a topic of special interest to you and should help you to focus all the course material onto one area and give you deeper insight into musical acoustics.

We have a MacIntosh-based analysis programs (Electroacoustics Toolbox, Audacity) at our disposal, as well as a number of other standard laboratory instruments. We can measure the resonant frequencies of wind instruments, analyze sounds in the laboratory, or we can analyze music (wav) files which you have recorded elsewhere.

Some project topics from previous years have been: “A Research and Analysis of the Clarinet’s Harmonics,” “The Acoustics of Melodic Percussion Instruments,” “The Effect of Striking Point on the Partials Produced by a String,” “Trombones: Red Brass vs. Yellow Brass,” “Just Noticeable Difference for Frequency Change,” “The Spectrum of French Horn Tones,” “Measurement of Critical Band and Limit of Discrimination,” “The Harmonica”. “The bells in Arlington St. Church”. The projects combine acoustical measurements with a paper. The point is to make acoustical measurements with the intent to explain or discover some effect, e.g. the difference in tone produced by a trombone of red brass with one of yellow brass, etc. It is crucial that your results are carefully presented. You should first define the problem or issue to be studied, tell what measurements were done, giving any background on what has been done before. Your results should then be presented along with a discussion of how they agree/disagree with any measurements in the literature, and then you should summarize your conclusions.

Needless to say, standard rules of term paper writing apply to the write-up. It should include an introduction which motivates what is to follow and which states the underlying thesis, a central body and a conclusion. Sources must be properly referenced with footnotes and/or a bibliography at the end. It is assumed that in addition to the lab work that the topic will be carefully researched.

The PY231 Course Schedule for Spring 2017

http://physics.bu.edu/py231/index.html

PY231 Course Schedule, Spring 2017

Last modified 21 January

Week	Date	Topic	Chapter		
1	Jan. 19 .	Introduction, The harmonic series, introduction to waves	Oscillator handout		
2	Jan. 24 Jan. 26	Work-Energy Simple oscillations, Damped oscillations Resonance, Steady State Oscillations, Transients	Oscillator handout		
3	Jan. 31 Feb. 2	Nonlinear oscillators, harmonic generation., Wave propagation, interference, diffraction	Oscillator handout Benade P. 254--278 Hall 4		
4	Feb. 7 Feb. 9	Normal modes, standing waves strings, Wave Impedance Normal modes, bars, membranes, driving multimode systems	Oscillation Handout section 9		
5	Feb. 14 Feb. 16	SW of strings and air columns, Wave Impedance **Test 1 (Through Oscillators sections 1-4)**			
6	Feb. 21 Feb. 23	*Monday Schedule, No class* Finish SW, Periodic Waves			
7	Feb. 28 Mar. 2	Periodic Waves Sound Intensity Level, the decibel scale			
8	Mar. 7 Mar. 9	*Spring Break, No Class* *Spring Break, No Class*			
9	Mar. 14 Mar. 16	Class cancelled snow SIL,			
10	Mar. 21 Mar. 23	No Class **Test 2 Normal Modes and Periodic Waves**			
11	Mar. 28 Mar. 30	SIL, intro to Psychoacoustics Psychoacoustics			
12	Apr. 4 Apr. 6	Finish Psychoacoustics, Musical Scales. Finish Scales,			
13	Apr. 11 Apr. 13	Plucked and struck strings Piano/Guitar Bowed strings, steady sounds, regime of oscillation			
14	Apr. 18 Apr. 20	Woodwinds and Brasswinds **Test 3 SIL, Psychoacoustics, Scales**			
15	Apr. 25 Apr. 27	The Voice Room acoustics			
16	May 1 May 2	**Term papers due** Discussion of the Projects (Last Class)			
16	May 9	**Final Exam 9:00 - 11:00 Covers all the material**			