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**UIUC Physics 498: Physics of Music/Musical Instruments**  
**Course Syllabus**  
**Spring Semester, 2009**

**Introduction to Course, Course Structure, Organization:**

- This course meets 3x/week:
  - \* Lecture Tu & Th 1:00-2:30 pm in 6105 ESB, and:
  - \* 3 hr Lab Fri 11am-2pm or 2:00-5:00 pm in 6105 ESB
- Lecture/demo/lab/hands-on interactive/investigative-type format
- ~ 1 HW assignment/week (typical, short), lecture related
- Midterm & Final Exams
- Lecturer: Steve Errede 435 Loomis, email: [serrede@uiuc.edu](mailto:serrede@uiuc.edu) 333-0074 (office); 333-4225 (lab), 333-4452 (sec'y)
- TA: TBA xxx Loomis-MRL Interpass (xxx-yyyy) [yyyyy@uiuc.edu](mailto:yyyyy@uiuc.edu)
- Course Project - of own choice (must be relevant to course), can be wide-ranging
  - \* Brief oral presentations/written report @ midterm
  - \* Final oral presentations/written report @ end of semester, substantive effort.
  - \* Put final written reports on P199POM web page.
- Web page for course, URL: <http://online.physics.uiuc.edu/courses/phys498pom/>
- Final grade: mix of HW, midterm, final exams, active participation in class & labs, project midterm & final oral presentation(s) and final report(s) on project(s).

**Course Content:**

- Essentially acoustical physics, with emphasis on music and musical instruments.
- What is music? For humans? For other animals?
- Why does music exist? Why is it important? For humans? For other animals?
- Why/how did music evolve? History of music/musical instruments.
- Human music, music associated with other living creatures...
- Importance of music today in our societies. In future? Evolution of music?
- Music in Nature/Music of the Cosmos.
- Scientific study of music/musical instruments (history):
  - \* Ancient Greeks - Pythagoras (~ 500 BC) at least. Earlier endeavors?
  - \* Since then: Aristotle, Ptolemy. Huygens, Euler, Ohm, Young, Helmholtz
- How is music made?
  - \* (Collective) vibrations of atoms of matter
  - \* Matter vibrations coupling to air - collective vibrations of air molecules
  - \* Propagation of sound waves in air, other media, fluids & solids.
- How/why is music heard/perceived? Human & animal hearing/sound perception
  - \* Evolution - why is it beneficial to perceive sound?
  - \* Psychoacoustics - study of human hearing
  - \* How human ear(s) + brain work
  - \* Hearing in other animals

- Simple Vibrating Systems
  - \* Simple harmonic motion - e.g. mass on a spring, tuning fork
    - + Frequency, period, wavelength, amplitude, phase, energy, energy loss/damping/dissipation, power
  - \* Travelling waves and wave propagation in a medium
    - + One-dimensional medium - bead-spring system
    - + One-dimensional transverse and longitudinal waves
    - + Wave propagation in two and three dimensions
  - \* One-dimensional standing waves
    - + Sum/superposition of two counter-propagating travelling waves
    - + Boundary conditions for standing waves
      - o Reflection, refraction, diffraction of travelling waves
      - o Interference effects
      - o Resonance effects
    - + Transverse standing waves, e.g. on a guitar/violin/piano string
    - + Longitudinal standing waves, e.g. in air - organ pipes/flutes
  - \* Standing waves in two and three dimensions
    - + Vibrating membranes - drums, musical saw
  - \* Doppler effect - source/observer motional effects on sound waves in air.
  - \* Beats - interference between two frequencies
  - \* Distortion - non-linear response & generation of harmonics of fundamental
  - \* Intermodulation distortion - non-linear response with 2 or more frequencies.
  - \* The Human Ear/Human Hearing
    - + Structure of the outer & inner human ear, and its response to sound
    - + Why two ears? Phase sensitivity, source location determination.
    - + Sound Intensity,  $I$  ( $\text{Watts/m}^2$ )
    - + Sound Intensity Level,  $L$  (decibels)
      - o Threshold of hearing, threshold of pain
    - + Sound Pressure Level,  $L_p$  (decibels)
    - + Loudness Level (phons)
    - + Loudness (sones)
  - \* Musical Tone Quality/Timbre
    - + Pure tones/simple tones - sine/cosine waves
      - o have well-defined frequencies/wavelengths, amplitudes & phases
    - + Partial tones (= partials) - assembly of pure tones
      - o = a mix of different frequencies & amplitudes
    - + Complex tone - superposition of simple tones - complex waveform
    - + Periodic complex waveform - has fundamental + harmonics/overtones
      - o harmonics/overtones = integer multiples of fundamental frequency
      - o phase sensitivity of human ear to complex tone/tone quality/timbre
      - o harmonic (Fourier) analysis of musical instrument tones
    - + Formants - resonances
    - + Sound Envelope - attack time/decay time
  - \* Sound Effects
    - + Vibrato, tremelo, chorus, phase shift/flanging, reverberation/echo, etc.
    - + Noise
    - + Subjective tones - (non-linear response/distortion in the ear)

- + Auditory sensation “tricks”
- \* Musical intervals, musical scales, tuning and temperament
  - + Consonance/dissonance
  - + Discrete frequencies = scale
  - + Frequency ratios: unison, octave, fifth, fourth, third, etc.
  - + Interval = separation of two notes on a scale
- \* Musical Scales - Pentatonic, Pythagorean, Meantone Tuning, Just, Just Diatonic, Tempered Scales
  - + whole tones, semi-tones, cents
  - + pitch standard(s)
  - + octave notation
  - + frequencies of musical notes, e.g. in tempered scale
- \* Acoustics
  - + Acoustics of rooms and auditoriums
    - o Interference, sound absorption
    - o Reverberation & echo
  - + Acoustics of loudspeaker enclosures
- \* Production of musical sounds by musical instruments
  - + Stringed Instruments
    - o Physics of plucked & bowed vibrating strings
    - o Plucked: acoustic/classical and electric guitar(s), mandolin, ukelele, etc
    - o Bowed: violin, viola, cello, bass
    - o Hammered: piano, hammered dulcimer
  - + Woodwind Instruments
    - o Physics of whistles, reeds & organ pipes
    - o Whistles: Whistle, recorder, flute
    - o Reed: Clarinet, oboe, bassoon, saxophone
    - o Pipe: Pipe organ, bagpipes
  - + Brass Instruments
    - o Physics of mouthpiece, bell
    - o Trumpet, trombone, French horn
  - + Percussion Instruments
    - o Physics of vibrating bars, plates, membranes
    - o Xylophone, glockenspiel, Fender-Rhodes piano
    - o Drums (all kinds), cymbals (all kinds)
    - o Musical saw
  - + Electronic Musical Instruments
    - o Electro-mechanical organs - e.g. Hammond B3
    - o Electronic organs/keyboard instruments
    - o Analog and Digital Sound Synthesizers,
    - o MIDI & MIDI instruments
    - o Computer-generated music
    - o Electronic Stringed Instruments – guitars, bass guitar, cello, mandolin..
  - + Analog & Digital Recording of Music & Sound
    - o Edison phonograph - cylinder & disk records (analog)
    - o Magnetic wire and tape recorders (analog & digital)
    - o Digital recording (e.g. to CD, DVD, etc.)

- o Analog input transducers - condenser and dynamic microphones
- o Analog output transducers - loudspeakers
- + Music in the near-term and distant future
  - o Human music - culture & society. New kinds?
  - o Development of new kinds of musical instruments & technology.
  - o Evolution of music in animals? Human - animal music interactions?
- + Sound Analysis Methodology & Analysis of Musical Sounds
  - o Harmonic/Fourier Analysis – complex waveforms
  - o Digital Signal Processing/Digital Filtering
  - o Wavelet Analysis