Physics of Sound Review

I) Basic nature of physical science
   A) Interaction of theory and experiment in constructing descriptions of structure.
   B) Measurements and units. Variables and constants.
   C) Equations and graphs as descriptions of relations. (linear, nonlinear, etc.)

II) Simple Harmonic Motion (chapter 1).
   A) Ingredients: inertia and linear restoring force.
   B) Analogy to circular motion.
   C) Damped and driven motion: resonance.
   D) Force and motion: impedance, Newton's laws.

III) Waves and Sound (chapter 2 also supplementary material).
   A) Frequency, wavelength and speed. The spectrum.
      1) The speed of sound on strings, in solids, liquids, and in air.
   B) Basic phenomena
      1) Linearity and "superposition".
         a) Huygen's principle.
         b) Interference: constructive and destructive.
         c) Diffraction.
      2) Reflection.
         a) Role of impedance.
         b) "fixed" vs "free" end.
      3) Refraction
         a) mirage
      4) Inverse square law (conservation of energy).
      5) Polarization
      6) Doppler shift (moving source, moving receiver).
      7) Shock wave.
   C) Relation between velocity and pressure in sound– wave impedance.

IV) Standing waves and overtones (Chapter 3).
   A) Waves trapped by reflections: standing waves as the sum of two traveling waves.
   B) Mersenne's Laws
   C) Frequencies in the overtone series of strings and pipes.
   D) "Intervals" and frequency ratios of overtones.
   E) Modes and the analogy to simple harmonic motion. Resonance of modes.
   F) Modes in higher dimension.

V) Analysis and synthesis of complex waves (Chapter 4).
   A) Representations of sound.
      1) Time domain p(t).
      2) Frequency domain. p(f)
      3) Spectrogram p(f,t); the compromise of resolving both.
   B) Analysis of a complex sound in terms of the overtones.
   C) Measures of tone quality
      1) Attack-decay transients.
      2) Inharmonicities.

        3) Formants (filtering).
        4) Vibrato.
        5) Tremolo.
        6) Chorus effect.
    D) Resonance curves
    E) Helmholtz oscillators.

VI) Electronic music synthesis (chapter 5).
    A) Addition of waveforms.
    B) Voltage controlled oscillators. Frequency Modulation (FM).
    C) Voltage controlled amplifiers.
        1) Envelope generator
        2) Ring modulation (balanced modulation).
        3) Amplitude modulation (AM).
    D) Voltage controlled filters (formants).
    E) Noise generation.
    F) Digital representation of sound.

VII) The human ear and voice (chapter 6).
    A) Basic parts of the ear and vocal tract and their function.
    B) Sound detection and the cochlea (place theory of hearing).
        1) Critical band.
        2) JND
    C) Peculiarities of the ear.
        1) Ohm's law of hearing – little sensitivity to phase.
        2) Periodicity pitch and fundamental tracking.
        3) Masking.
        4) binaural effects (directionality)
        5) Combination tones.
        6) Amplitude and frequency response of the ear.
    D) Linear (watts/m^2) and log (decibel) scales of Sound Intensity Level (SIL).

VIII) Sound recording and reproduction (chapter 7 sections 1,3,4,and 10)
    A) The electro-mechanical analogy. Electrical force, motion, and impedance.
        1) Ohm's law of electricity V=IR.
        2) Electrical power. P=VI
    B) Transducers
        1) Microphones of various types.
        2) Loudspeakers. and effects of the enclosure.
    C) Digital representation.

IX) Room and Auditorium Acoustics (chapter 8)
    A) Reverberation time (definition).
        1) How it is calculated.
    B) Other terms: liveness, intimacy, fullness, clarity, warmth, brilliance, texture, blend, and ensemble.
    C) The ray theory of sound.
    D) Problems: focusing, echoes, shadows, resonances.
        1) Calculating room resonances.

X) Basic acoustic components of musical instruments how: energy gets into sound.
   A) Free energy->instability->/<-modes->filtering->radiation.
   B) Types of instability.

XI) Intervals, linear and log frequency axis. Circle of fifths.

XII) Types of dynamics – linear vs nonlinear.

Some useful equations and numbers:
Typical speed of sound in air: 340m/s

Vibration and waves in general: $T=1/f$ $\omega=2\pi f$

Waves in general: $f \cdot \lambda = S$

Power: $P=Zv^2$

Sound in air: $S=\sqrt{\frac{\gamma RT}{M}} \approx (331.3 + 0.6 * T_{celcius})\,\frac{m}{s}$.

Waves on strings: $S = \sqrt{\frac{F}{W}}$ $Z = \sqrt{F \cdot W}$ $W = \frac{M}{L}$

Simple harmonic oscillator: $\omega_{res} = 2\pi f_{res} = \sqrt{\frac{k}{m}}$

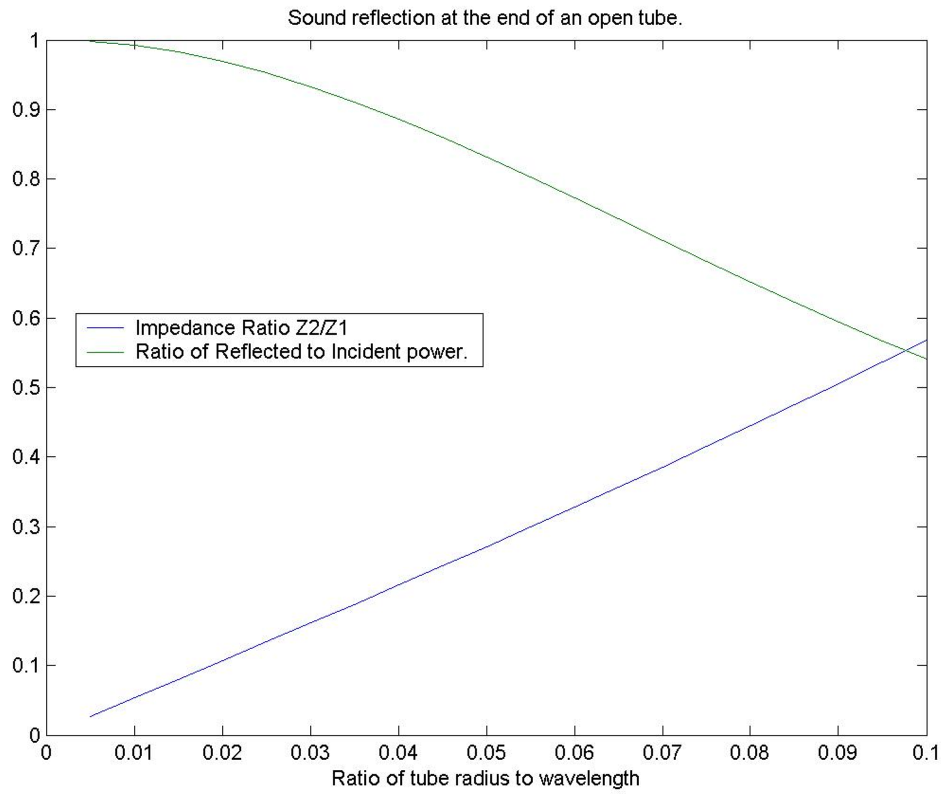
Doppler effect (moving source): $\frac{f_{source}}{f_{air}} = 1 - \frac{v_s}{v}$

Doppler effect (moving receiver): $\frac{f_{receiver}}{f_{air}} = 1 + \frac{v_o}{v}$

Amplitude ratio of reflection from an impedance change: $\frac{A_r}{A_i} = \frac{1 - Z_2/Z_1}{1 + Z_2/Z_1}$

Power ratio from an impedance change is the square of the amplitude ratio: $\frac{P_r}{P_i} = \left(\frac{A_r}{A_i}\right)^2$

$$\frac{r}{\lambda} = \frac{r}{S} \cdot f$$



Impedance of a tube.

$$Z_{tube} = \frac{Z_s}{A} = \frac{\sqrt{\gamma pnm}}{A} = \frac{n\sqrt{\gamma RTm}}{A}$$ The units are Kg/(m^4s)

Modes in strings and tubes with both ends the same.

$$f_1 = \frac{S}{2L}$$

$$f_n = n \bullet f_1 = n \cdot \frac{S}{2L}$$

$$\lambda_n = \frac{2L}{n}$$

$$L = n\frac{\lambda_n}{2}$$

$$T_1 = \frac{2L}{v}$$

$$f_1 = \frac{v}{2L} = \frac{1}{2L}\sqrt{\frac{F}{W}}$$

$$f_n = n \cdot f_1 = n \cdot \frac{v}{2L} = \frac{n}{2L}\sqrt{\frac{F}{W}} = \frac{1}{T_n}$$

Modes in tubes with one end open and one end closed.

$$f_1 = \frac{S}{4L}$$

$$f_n = n \bullet f_1 ; n = 1,3,5,7,9,\ldots$$

$$\lambda_n = \frac{4L}{n} ; n = 1,3,5,7,9,\ldots$$

$$L = n\frac{\lambda_n}{4} ; n = 1,3,5,7,9,\ldots$$

Reverberation time

$$T_r = 55.2\frac{V}{S \cdot A}$$

Electrical Ohm's law

$$V = I \cdot R \qquad P = V \cdot I = I^2 R = \frac{V^2}{R}$$

Log scale of sound intensity level.

$$SIL(db) = 10 \cdot Log_{10}\left(\frac{Intensity}{10^{-12} W / m^2}\right) \qquad I = 10^{-12}\,\frac{watts}{meter^2} * 10^{\left(\frac{SIL(db)}{10}\right)}$$

$$SIL(db) = 20 \cdot Log_{10}\left(\frac{p_{RMS}}{2 \cdot 10^{-5}(Pascal)}\right).$$

Modes in 3 dimensions (for modes in 2-d just set N_z=0)

$$f_{N_x, N_y, N_z} = \frac{S}{2}\sqrt{\left(\frac{N_x}{x}\right)^2 + \left(\frac{N_y}{y}\right)^2 + \left(\frac{N_z}{z}\right)^2}$$