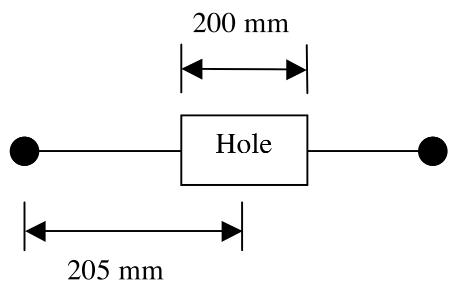
Acoustics Ph.D. Qualifying Examination
Fall 2010
Closed book

Answer **three** of the following **four** questions.

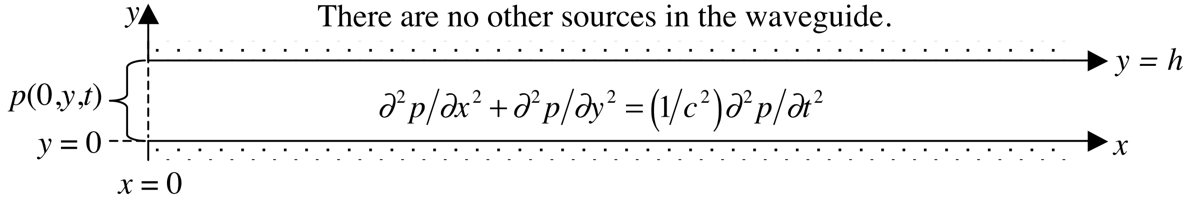
1. A square opening of 200 mm on a side is required for access into an enclosure containing a source of low frequency noise. Suppose you mount two loudspeakers on either side of the opening with centers 205 mm from the center of the opening as shown below. The speakers are driven in phase with each other and in antiphase and at half the amplitude of the sound issuing from the opening. The medium is air with c = 343 m/s, ρ_0 = 1.206 kg/m^3, and p_{ref} = 20 μPa.

    a. Assume that with the speakers turned off, the sound power issuing from the opening is W and all wavelengths of interest are long compared to the dimensions of the opening. By how many decibels will the sound power be reduced at 63 Hz when the speakers are turned on?
    b. When the speakers are turned on what will be the expected changes in sound pressure level at θ = 0, π/4, and π /2 radians at 63 Hz? Describe the sound field.



(drawing not to scale)

2. A long two-dimensional (x,y) waveguide is formed by a gas with density ρ and sound speed c that is trapped between **hard** surfaces located at y = 0 and y = h. Sound is launched into this waveguide at x = 0, via a time-varying pressure distribution at x = 0: $p(0, y,t) = S(t)F(y)$. There are no other sources in the waveguide.



Using a modal expansion, the pressure field in the waveguide can be written as: $p(x, y,t) = \int_{-\infty}^{+\infty} \sum_{m=0}^{\infty} A_m \cos(k_m y) \exp\{ik_{x,m}x - i\omega t\} d\omega$.

a) (6 pts) Find the first two propagating normal modes (m=0 and m=1). What is the mode shape, phase velocity $(\omega / k_{x,m})$, group velocity $(d\omega / dk_{x,m})$ and cutoff frequency for these two first modes?

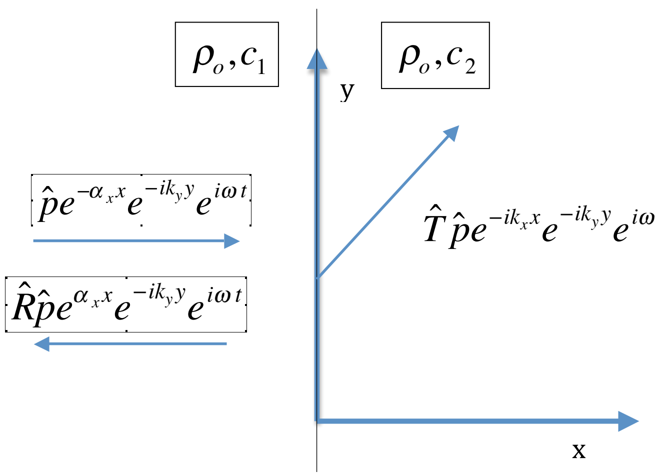
b) (3 pts) Explain physically the behavior of the group velocity and phase velocity of the second mode as the frequency approaches cutoff

c) (1pt) What are the spatial forcing functions $F(y)$ needed to excite mode one or mode two ?

d) (4pts) Assume a broadband impulse *S(t)* (e.g. having either a flat or "Gaussian" frequency spectrum) is transmitted via mode one. Sketch what the signal will look like (in time and frequency) at a recording location x located far from the source.

e) (4pts)Assume the same pulse *S(t)* is transmitted via mode 2 instead. Sketch what the signal will look like (in time and frequency) at the same location x far from the source.

3. Consider two fluids separated by the plane $x = 0$ as shown below. Fluid 1 has sound speed c_1 and fluid 2 has sound speed c_2 with $c_2 < c_1$. Both fluids have density ρ. An evanescent wave originating somewhere to the left in fluid 1 impinges on the $x = 0$ interface producing a reflected evanescent wave and a transmitted propagating wave.



The incident evanescent wave is given by

$$p_{inc} = \hat{p}e^{-\alpha_x x}e^{-ik_y y}e^{i\omega t}$$

the reflected evanescent wave by

$$p_{refl} = \hat{R}\hat{p}e^{\alpha_x x}e^{-ik_y y}e^{i\omega t}$$

and the propagating transmitted wave by

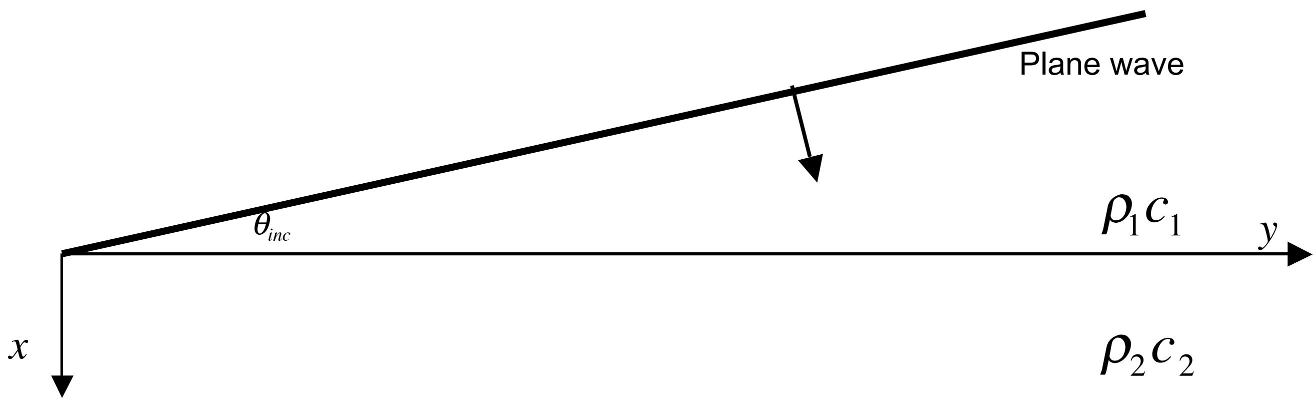
$$p_{trans} = \hat{T}\hat{p}e^{-ik_x x}e^{-ik_y y}e^{i\omega t}$$

where α_x and k_x are real, positive numbers given by

$$\alpha_x^2 = k_y^2 - (\omega/c_2)^2$$
$$k_x^2 = (\omega/c_1)^2 - k_y^2$$

a. Find the reflection coefficient $\hat{R}$. What is its magnitude?
b. Find the transmission coefficient $\hat{T}$. What is its magnitude?
c. Find the x-component of the acoustic intensity vector in fluid 1. Show that it is independent of position x.

4. Consider 2 liquids in contact with each other. The contact plane is called the interface. We place a transducer in liquid 1 which is emitting ultrasonic waves onto the interface between liquid 1 and liquid 2 (see figure). The configuration is such that the transducer is at an angle with the interface therefore emitting waves at an angle θ^{inc} from the direction perpendicular to the interface.



For simplicity we assume that the transducer is emitting (infinite) harmonic plane waves. The emitted waves can therefore be described as

$$p = A\exp\left(j\omega t - j\mathbf{k} \bullet \mathbf{r}\right)$$

in which $j = \sqrt{-1}$

Liquid 2 is non-viscous (e.g. water). Liquid 1 is viscous (e.g. glycerin).
For non-viscous liquids we assume that sound waves are determined by the classical linear wave equation. For viscous liquids we assume that sound waves are determined by the lossy wave equation being reduced for harmonic waves to the lossy Helmholtz equation:

$$\nabla^2 p + \mathbf{k}^2 p = 0$$

with $\mathbf{k} = k - j\alpha_s = \dfrac{\omega / c}{\sqrt{1 + j\omega\tau_S}}$ in which c is the speed of sound and c_p is the phase speed. α_S is the spatial absorption coefficient and τ_S is a relaxation time.

You are asked to describe the transmission of sound from liquid 1 (e.g. glycerin) to liquid 2 (e.g. water)

QUESTIONS:

a) Give the amplitude and phase of the incident wave when it reaches the interface.
b) describe qualitatively (in words) your result obtained in a).
c) Explain briefly what ingredients (or physical laws) are necessary to determine the transmitted sound field in amplitude and phase.
d) Derive an expression for the transmitted wave. You do not need to evaluate the transmission coefficient, just call it T in your answer.
e) What kind of wave is the transmitted sound field? describe (wave)function describing the transmitted wave with detailed description of each parameter used