Master Marine Physics (M1)
Fluides II

Homework#3:
Acoustic waves
Written answers are due for Wednesday March 6 (mailbox O.Arzel).

1. History tells that Newton determined a value of the speed of sound by stamping his foot regularly at one end of the cloister of Trinity College and using the echo reflected at the other end (63 m). Can you think of an **accurate** way to do so? Find out if he could detect the variation of sound speed between winter (-10º C) and summer (25º C).

2. Acoustic intensity I [W m^{-2}] is the averaged power transmitted per unit area in the direction of wave propagation.

(i) Show from first principles (i.e. kinetic energy equation) that it is the average over a period of the product of pressure times velocity.

(ii) Take a wave propagating in the positive x direction and sketch the pressure and velocity over a period (or wavelength). Show that $I= p^2_{rms}/\rho c$

3. The human ear is able to hear frequencies between 20 Hz and 20 Khz and acoustic pressures between 2 10^{-5} and 200 Pa. Auditive sensation depends more of the log of sound intensity. Sound intensity level IL [decibel] is defined as $IL=10.\log(I/I_0)$ where I is acoustic intensity and $I_0=10^{-12}$ W m^{-2} is a reference which corresponds to the weakest sound detected by the human ear. Hence one decibel corresponds to the smallest sound difference detected by the human ear. The same definition occurs for the sound power level $PWL=10.\log(P/P_0)$ with P and P_0 in [W], $P_0=10^{-12}$ W.

(i) Suppose a sinusoidal progressive wave which has a IL=100 decibel and a frequency of 1000 Hz.
Compute the amplitude of the pressure wave and the amplitude of the particle displacement.

(ii) Find out the sound intensity levels corresponding to the limits that the ear can detect 2 10^{-5} Pa or stand(!) 200 Pa.

4. In practice acoustic waves travel in 3D space. The pressure of such a wave obeys the wave equation :

$$\partial_{tt}^2 p = c^2 \nabla^2 p$$

(i) Find out a sinusoidal solution for a diverging spherical wave (the wave fronts are spheres).

(ii) Show that there is now a geometric attenuation of the radiated power power from a source (say at r=0) which goes like $1/r^2$. Find out how the sound intensity level varies with increasing distance.

5. Temperature also varies during the propagation of an acoustic wave because the propagation is adiabatic and not isothermal.

(i) Take the wave of ex 3 (i) to find out the amplitude of the temperature variations.

(ii) Any fluid has some molecular heat conductivity. For air it is k=2.4 10^{-2} J $m^{-1}s^{-1}deg^{-1}$. Find out the distance over which heat has diffused during a wave period and compare this to the wavelength. No detailed calculations are asked here just a scaling. What do you conclude? You will also need C_P=1004 J Kg^{-1} deg^{-1}.