Seminary 10
SOUND WAVES-2

Intensity and sound intensity level: The intensity I of a sound wave is the time average rate at which energy is transported by the wave, per unit area. For a sinusoidal wave, the intensity can be expressed in terms of the displacement amplitude A or the pressure amplitude p_{max}. (See Examples 16.5–16.7.)

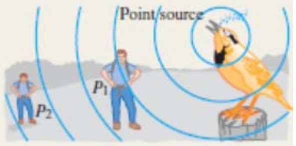
The sound intensity level β of a sound wave is a logarithmic measure of its intensity. It is measured relative to I_0, an arbitrary intensity defined to be $10^{-12}\ \mathrm{W/m^2}$. Sound intensity levels are expressed in decibels (dB). (See Examples 16.8 and 16.9.)

$$I = \tfrac{1}{2}\sqrt{\rho B}\,\omega^2 A^2 = \frac{p_{max}{}^2}{2\rho v} = \frac{p_{max}{}^2}{2\sqrt{\rho B}} \qquad (16.12),\ (16.14)$$

(intensity of a sinusoidal sound wave)

$$\beta = (10\ \mathrm{dB}) \log \frac{I}{I_0} \qquad (16.15)$$

(definition of sound intensity level)



Standing sound waves: Standing sound waves can be set up in a pipe or tube. A closed end is a displacement node and a pressure antinode; an open end is a displacement antinode and a pressure node. For a pipe of length L open at both ends, the normal-mode frequencies are integer multiples of the sound speed divided by $2L$. For a stopped pipe (one that is open at only one end), the normal-mode frequencies are the odd multiples of the sound speed divided by $4L$. (See Examples 16.10 and 16.11.)

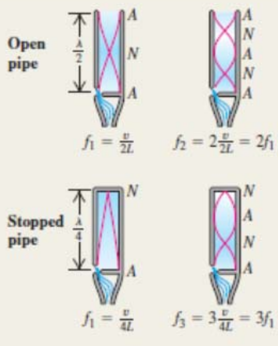
A pipe or other system with normal-mode frequencies can be driven to oscillate at any frequency. A maximum response, or resonance, occurs if the driving frequency is close to one of the normal-mode frequencies of the system. (See Example 16.12.)

$$f_n = \frac{nv}{2L} \qquad (n = 1, 2, 3, \ldots) \qquad (16.18)$$

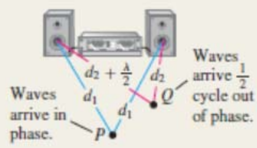
(open pipe)

$$f_n = \frac{nv}{4L} \qquad (n = 1, 3, 5, \ldots) \qquad (16.22)$$

(stopped pipe)



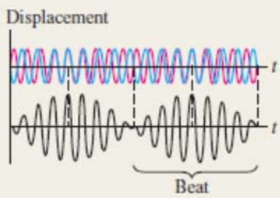
Interference: When two or more waves overlap in the same region of space, the resulting effects are called interference. The resulting amplitude can be either larger or smaller than the amplitude of each individual wave, depending on whether the waves are in phase (constructive interference) or out of phase (destructive interference). (See Example 16.13.)



Beats: Beats are heard when two tones with slightly different frequencies f_a and f_b are sounded together. The beat frequency f_{beat} is the difference between f_a and f_b.

$$f_{beat} = f_a - f_b \qquad (16.24)$$

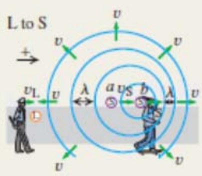
(beat frequency)



Doppler effect: The Doppler effect for sound is the frequency shift that occurs when there is motion of a source of sound, a listener, or both, relative to the medium. The source and listener frequencies f_S and f_L are related by the source and listener velocities v_S and v_L relative to the medium and to the speed of sound v. (See Examples 16.14–16.18.)

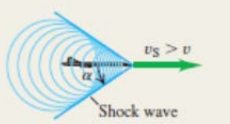
$$f_L = \frac{v + v_L}{v + v_S} f_S \qquad (16.29)$$

(Doppler effect, moving source and moving listener)

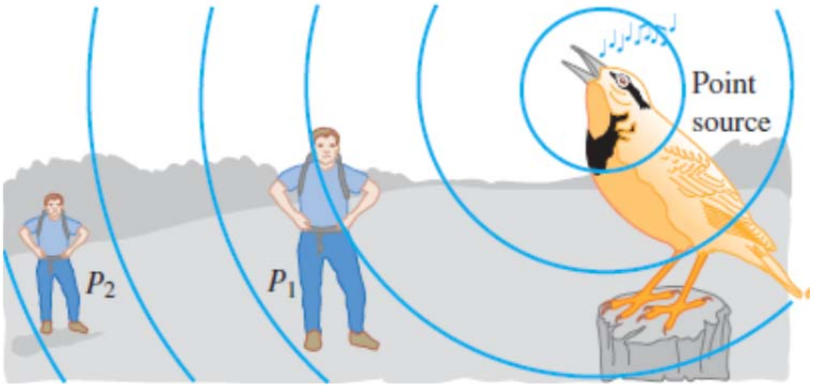


Shock waves: A sound source moving with a speed v_S greater than the speed of sound v creates a shock wave. The wave front is a cone with angle α. (See Example 16.19.)

$$\sin\alpha = \frac{v}{v_S} \qquad \text{(shock wave)} \qquad (16.31)$$



1/ Bird sings in a meadow
Consider an idealized bird (treated as a point source) that emits constant sound power, with intensity obeying the inverse-square law.



If you move twice the distance from the bird, by how many decibels does the sound intensity level drop?

Answer:

The difference $\beta_2 - \beta_1$ *between any two sound intensity levels is related to the corresponding intensities by:*

$$\beta_2 - \beta_1 = (10\text{ dB})\left(\log\frac{I_2}{I_0} - \log\frac{I_1}{I_0}\right)$$
$$= (10\text{ dB})[(\log I_2 - \log I_0) - (\log I_1 - \log I_0)]$$
$$= (10\text{ dB})\log\frac{I_2}{I_1}$$

For an inverse square-law source, if the power output of the source is P, then the average intensity through a sphere with radius r_1 and surface area $4\pi r_1{}^2$ is:

$$I_1 = \frac{P}{4\pi r_1^2}$$

The average intensity I_2 through a sphere with a different radius r_2 is given by a similar expression. If no energy is absorbed between the two spheres, the power P must be the same for both, and:

$$4\pi r_1^2 I_1 = 4\pi r_2^2 I_2$$

$$\frac{I_1}{I_2} = \frac{r_2^2}{r_1^2} \qquad \text{(inverse-square law for intensity)}$$

For this inverse square-law source, $\frac{I_2}{I_1} = \frac{r_1^2}{r_2^2} = \frac{1}{4}$ *, so:*

$$\beta_2 - \beta_1 = (10\text{ dB})\log\frac{I_1}{I_2} = (10\text{ dB})\log\tfrac{1}{4} = -6.0\text{ dB}$$

Discussion:
The result is negative, which tells us that the sound intensity level is less at P2 than at P1. The 6-dB difference doesn't depend on the sound intensity level at P1 any doubling of the distance from an inverse-square-law source reduces the sound intensity level by 6 dB.

Note that the perceived loudness of a sound is not directly proportional to its intensity. For example, most people interpret an increase of 8 dB to 10 dB in sound intensity level (corresponding to increasing intensity by a factor of 6 to 10) as a doubling of loudness.

2/ Flying bat
In patrolling mode, a bat, emits a sound with a frequency of 40 kHz. When attacking an insect the bat changes the frequency of the emitted sound to 85 kHz.
a) Does a human being hear these sounds?
b) What are the wavelengths of the emitted sounds?
c) Why in attacking mode the bat is increasing the frequency of the emitted sound? (Take the speed of sound in air to be v = 340 m/s.)

3/ Doppler effect
One way to tell if a mosquito is about to sting is to listen for the Doppler shift as the mosquito is flying. The buzzing sound of a mosquito's wings is emitted at a frequency of 1050 Hz. a) If you hear a frequency of 1034 Hz, does this mean that the mosquito is coming in for a landing or that it has just bitten you and is flying away? b) At what velocity is the mosquito flying?

Use the following equation: $f_L = \frac{v + v_L}{v + v_s} f_S$ (*Doppler effect, moving source and moving listener*), where: v is the sound velocity in air, v_L is the listener velocity, v_S is the source velocity, f_s is the frequency of the sound emitted by the source and f_L the frequency heard by the listener. When the source moves towards listener $v_s<0$, when the source moves away from the listener $v_s>0$.

4/ **Beats**
The A string of a violin is a little too tightly stretched. Beats at 4.00 per second are heard when the string is sounded together with a tuning fork that is oscillating accurately at concert A (440 Hz).What is the period of the violin string oscillation?

Questions/discussions

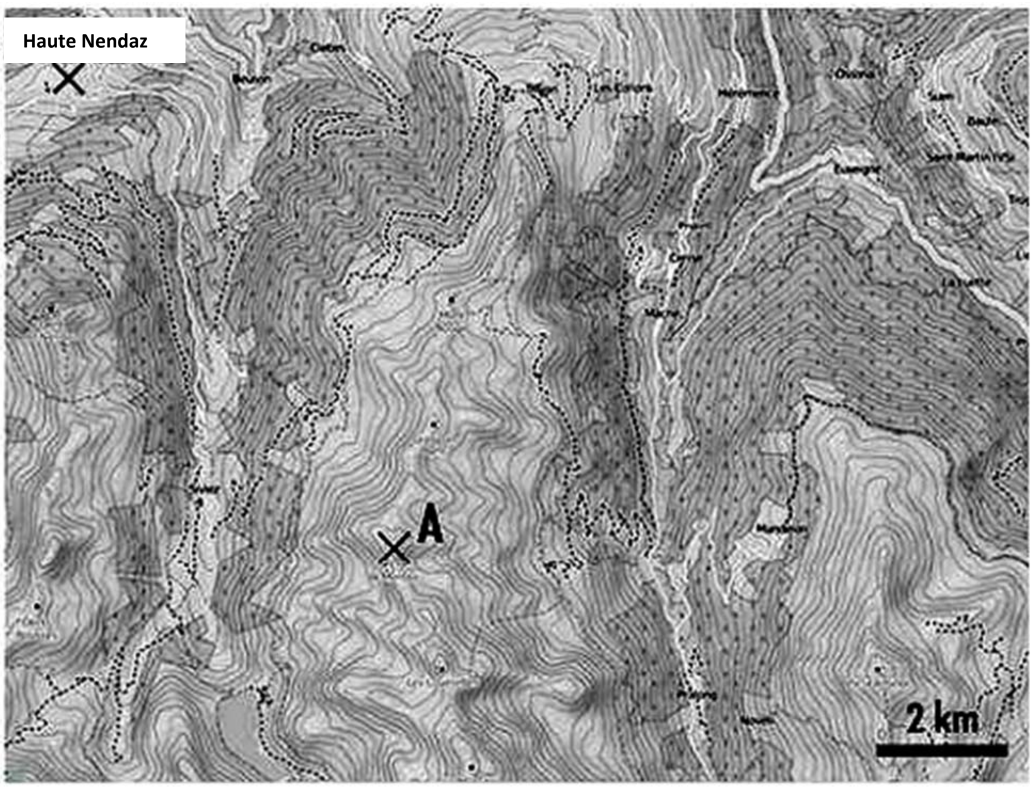
1/ In a popular and amusing science demonstration, a person inhales helium and then his voice becomes high and squeaky. Why does this happen? (*Warning:* Inhaling too much helium can cause unconsciousness or death.)

2/Does the sound intensity level obey the inverse-square law? Why?

3/ A small fraction of the energy in a sound wave is absorbed by the air through which the sound passes. How does this modify the inverse-square relationship between intensity and distance from the source? Explain your reasoning.

4/ A large church has part of the organ in the front of the church and part in the back. A person walking rapidly down the aisle while both segments are playing at once reports that the two segments sound out of tune. Why?

Homework: individual study BAC – Physics- FRANCE 2014
Problem: Every year, in July, the International Alphorn Festival takes place in *Haute Nendaz*, Switzerland. This folk instrument was once used by shepherds to communicate with each other.



A shepherd at the top of a hill (point A on the map) plays the lowest note of his Alpine horn. His instrument has a length of 3.4 m. **Can we hear it in Haute Nendaz if the level of sound intensity is 100 dB at one meter from the instrument?**

Working hypotheses:
- The damping of the wave is not taken into account: the dissipation of energy during the propagation is negligible.
- The radiation of the source is supposed to be isotropic.

The analysis of the data as well as the approach followed will be evaluated and need to be correctly presented. Numerical calculations will be carried out with rigor. It is also necessary to take a critical look at the result and discuss the validity of the assumptions made.

Given :

- Reference acoustic intensity: $I_0 = 1{,}0 \times 10^{-12}$ W.m^{-2}

Document 1. Values of the speed of sound in the air according to the temperature

Temperature °C	10	20	30	40
Sound velocity m.s^{-1}	337	343	349	355

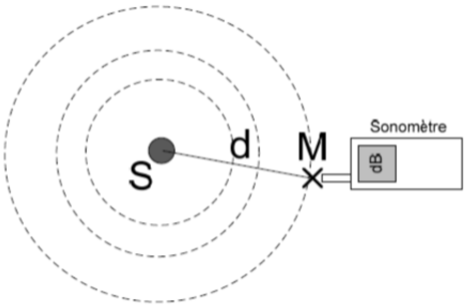
Document 2. A blowing instrument: the horn of the Alps

When you blow air in an Alpine horn for the first time, it seems impossible to get a single harmonious sound. But with a little practice, we can learn to produce up to twenty-two notes, without using a valve or button. The range of notes achievable on this instrument depends first of all on its geometry, then on the talent of the one who plays it. The first horns of the Alps date from the 14th century, they were traditionally used by the herdsmen to communicate with each other over distances of about ten kilometers. This instrument of the brass family is made of a single piece of wood, a tube curved at its end and generally measuring two to four meters long. To play, the musician blows in a mouth. The most serious note is reached when the wavelength of the sound wave associated with the note is twice the length of the horn.

Document 3. The loudness of an isotropic source

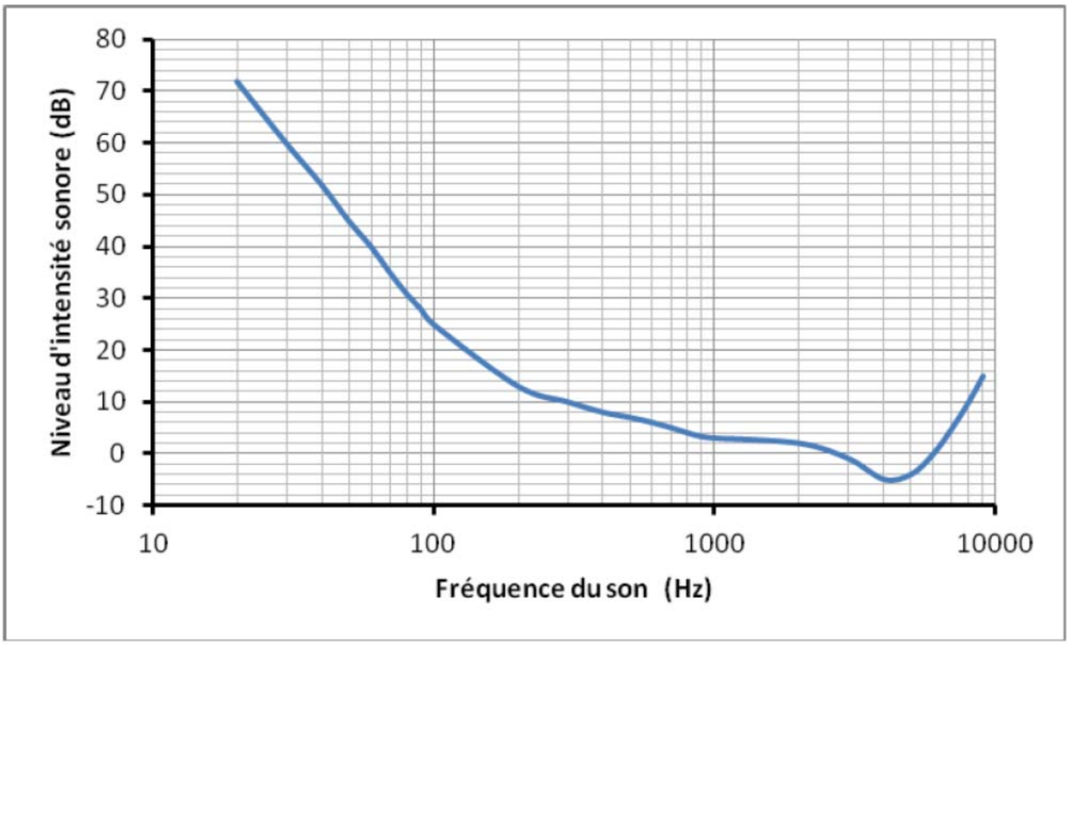
For an isotropic source (emitting the same energy in all directions) of power P, the sound intensity I at the point M depends on the distance d at the source and is expressed as follows:

$$I = \frac{P}{4\pi d^2} \qquad \text{with } I \text{ en W.m}^{-2} \text{ ; } P \text{ in W ; } d \text{ in m}$$



Document 4. Threshold of human audibility as a function of frequency

The following graph shows the minimum values of audible loudness level as a function of frequency.



Solution:

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EXERCICE III spécialité – LE COR DES ALPES (5 points)	

Pourra-ton entendre le cor à Haute Nendaz si le niveau d'intensité sonore est de 100 dB à un mètre de l'instrument ?

- Déterminons la distance entre la source sonore (le cor) et Haute Nendaz :

D'après la carte, 17 mm → 2 km
On mesure sur la carte entre le point A et Haute Nendaz 75 mm → d_2 km

$$d_2 = \frac{75\times2}{17} = \mathbf{8{,}8\ km}$$

- Déterminons le niveau d'intensité sonore L_2 à Haute-Nendaz :

$$L_2 = 10\log\left(\frac{I_2}{I_0}\right)$$

Or $I_2 = \dfrac{P}{4\pi d_2^2}$ et à une distance d_1 = 1 m, on a $I_1 = \dfrac{P}{4\pi d_1^2}$

$$\text{donc } \frac{I_2}{I_1} = \frac{\dfrac{P}{4\pi d_2^2}}{\dfrac{P}{4\pi d_1^2}} = \frac{P}{4\pi.d_2^2}.\frac{4\pi.d_1^2}{P} = \frac{d_1^2}{d_2^2}$$

$$\text{Ainsi } I_2 = \frac{d_1^2}{d_2^2}.I_1$$

$$L_2 = 10\log\left(\frac{\dfrac{d_1^2}{d_2^2}.I_1}{I_0}\right) = 10\log\left(\frac{d_1^2}{d_2^2}.\frac{I_1}{I_0}\right) = 10\log\left(\frac{d_1^2}{d_2^2}\right) + 10\log\left(\frac{I_1}{I_0}\right)$$

$$L_2 = 10\log\left(\frac{d_1^2}{d_2^2}\right) + L_1$$

$$L_2 = 10\log\left(\frac{1}{(8{,}8\times10^3)^2}\right) + 100 = \mathbf{21\ dB}$$

- Déterminons la fréquence f de la note émise par le cor :

D'après le document 2, longueur d'onde de la note la plus grave possède une longueur d'onde λ égale à deux fois la longueur L du cor.

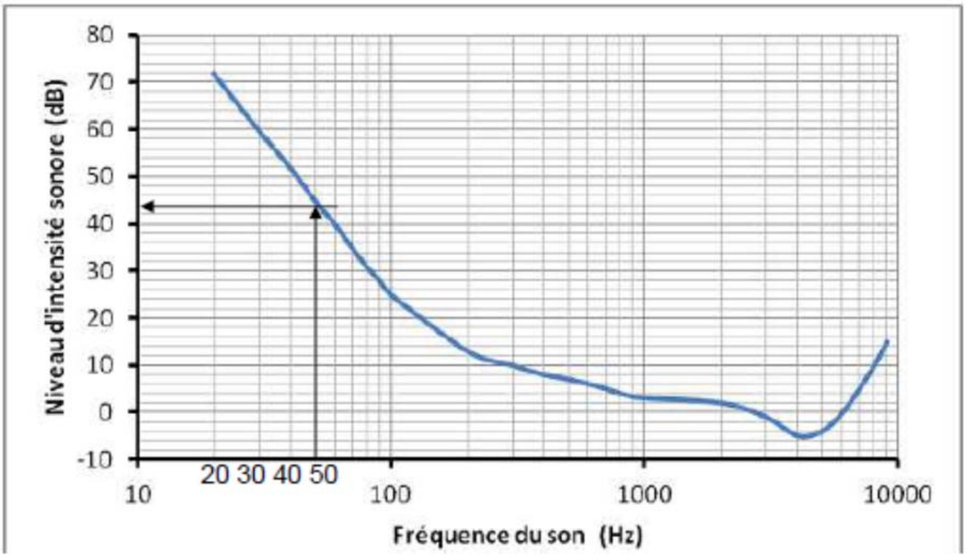
$\lambda = 2L$

De plus $\lambda = \dfrac{v}{f}$, soit $f = \dfrac{v}{\lambda}$ donc $f = \dfrac{v}{2L}$

En considérant que la température est de 20°C, $v = 343\ m.s^{-1}$.

$$f = \frac{343}{2\times3{,}4} = \mathbf{50\ Hz}$$

- Utilisons le document 4 pour déterminer si le cor sera audible :



À la fréquence de 50 Hz, le son est audible si son niveau d'intensité sonore est supérieur à 44 dB.
Or le son du cor n'est perçu qu'avec un niveau d'intensité sonore de 21 dB, **il n'est pas audible** à Haute Nendaz.

<u>Regard critique sur le résultat :</u>
Le son du cor est sans doute un son complexe qui contient des harmoniques de fréquences $f_n = n.f_0$, donc de fréquences plus élevées.
Or sur la courbe du document 4, on remarque que les sons de plus hautes fréquences sont perçus avec des niveaux d'intensité sonore plus faibles.
Par exemple, l'harmonique de rang n = 3, de fréquence f_3 = 150 Hz serait perçu.
Cependant avec un niveau d'intensité sonore de seulement 21 dB, il est probable qu'il soit masqué par le bruit ambiant.

<u>Validité des hypothèses formulées :</u>
Le rayonnement du cor n'est peut-être pas parfaitement isotrope.