LUND UNIVERSITY
ENGINEERING ACOUSTICS, LTH

Exercises week 1 – The foundations of acoustics

See these questions as: (i) "recap" for those of you who took the course "*Ljud I byggnad och samhälle (VTAF01)*" and (ii) "acoustic kick-off" for those of you who are new to the subject.

1. The pain threshold is at 130 dB. Calculate the corresponding effective value for the sound pressure.

2. Answer the following questions:
   a. What is the effective value for the sound pressure corresponding to L_p = 0 dB?
   b. What is the sound pressure level that corresponds to absolute quiet ($\tilde{p} = 0$)?

3. Calculate the effective value of the sound pressure $\tilde{p}$ from the sound field $p(x,t) = \hat{p}\cos(\omega t - kx + \varphi)$ with the amplitude $\hat{p}$ = 0.35 Pa and a fixed position ($x = x_0$).
   Hint 1: Let x and φ be 0 and sketch the oscillation of p and p^2 as a function of t in a diagram, and then take the mean of the curve over an integer number of periods.
   Hint 2: $\cos^2 x = \dfrac{1+\cos 2x}{2}$

4. Calculate the SPL for the sound field in the previous task.

5. The atmospheric pressure is p_{atm}=101300 Pa. A harmonically oscillating sound field can have this amplitude as a maximum. From this, calculate the maximal theoretical SPL.

6. Show, from $L_p = 10\log\left(\dfrac{\tilde{p}^2}{p_{ref}^{\,2}}\right)$, that $L_p = 20\log\left(\dfrac{\tilde{p}}{p_{ref}}\right)$.

7. Calculate the A-weighed SPL L_A from the following frequency spectrum

f	63	125	250	500	1000	2000	4000
L_n	75	77	82	75	67	60	55

8. Suppose that the SPL at a large road is measured and logged during an entire day. Calculate the equivalent SPL $L_{eq,24h}$ and maximum SPL L_{max} for the following situations:
   a. 60 dBA during 12 h and quiet the remaining 12 h.
   b. 60 dBA during 6 h and quiet the remaining 18 h.
   c. 60 dBA during 12 h and 50 dBA the remaining 12 h.
   d. 60 dBA during 6 h, 55 dBA during 6 h, 50 dBA during 6 h and quiet the rest.

9. How long can you have a constant SPL of 100 dBA (and quiet the rest of the time) if $L_{eq,8h}$ cannot exceed 85 dBA?

10. A sound source, e.g. a car, is producing noise with a certain SPL L_A. Answer the following:

a. How much does the SPL increase if another source is added, so you have two identical sources? (do it both analytically and proving it graphically).
b. How much does the SPL increase with three identical sources?
c. How much does the SPL increase with four identical sources?

11. Two machines placed at a certain position are, respectively, producing noise with 30 dBA and 31 dBA.
a. Calculate the total SPL at that position.
b. A third machine is to be purchased and placed next the other two. What is the maximum SPL this third machine can make if the total SPL cannot exceed 35 dBA?

12. When measuring a sound you often have the problem of dealing with background noise from different sources as well as from the instruments. How much lower SPL than the signal being measured can a background noise have so as to not have any effect on the result? The requirement for the latter to be fulfiled is that the sum of the signal and the background noise must not be more than 0.1 dB of the signal itself.

Answers:

1. $\tilde{p} = 63\,\text{Pa}$
2. a) $\tilde{p} = \tilde{p}_{ref} = 2\cdot10^{-5}\,\text{Pa}$
   b) $L_p = -\infty$
3. $\tilde{p} = 0.25\,\text{Pa}$
4. $L_p = 82\,\text{dB}$
5. $L_{p,\max,theory} = 191\,\text{dB}$
6. Theoretical
7. $L_A = 77\,\text{dBA}$
8. a) $L_{eq,24h} = 57\,\text{dBA}$
   b) $L_{eq,24h} = 54\,\text{dBA}$
   c) $L_{eq,24h} = 57.4\,\text{dBA}$
   d) $L_{eq,24h} = 55.5\,\text{dBA}$
9. $t = 15\,\text{min}$
10. a) $L_2 = L_A + 3\,\text{dB}$
    b) $L_3 = L_A + 4.8\,\text{dB}$
    c) $L_4 = L_A + 6\,\text{dB}$
11. a) $L_2 = 33.5\,\text{dBA}$
    b) $L_P = 29.6\,\text{dBA}$
12. $\Delta x = 16.3\,\text{dB}$

… and some other "extra exercises".

13. A whistle emitting a frequency of 4300 Hz produces a wave whose maximum pressure value above ambient pressure is $4\cdot10^{-2}$ Pa. This wave propagates at 344 m/s in the air.
a. Write the wave equation. Determine the wavelength.
b. What is the sound pressure level?

14. The equation of a transverse wave travelling through a string is given by $y(x,t) = 6\sin(0.02\pi x + 4\pi t)$ where x and y are given in centimetres and t in seconds. Answer:
a. Express the above equation in terms of cosines, giving its wavelength and frequency.
b. What is its amplitude? In which direction it propagates, and at which speed?
c. What are the maximum vibration acceleration and velocity of a point in the string?

15. A wave that propagates in a rope can be described by the equation $y(x,t) = 0.2\sin\left(6\pi t + \pi x + \pi/4\right)$
a. Calculate its frequency, period, wavelength and propagation speed.
b. State of vibration, velocity and acceleration of a particle located in x=0.2 m at instance t=0.3 s.

c. Give the phase difference between two points separated 0.3 m.
d. Calculate the particle's maximum velocity and acceleration.

16. A 432.9 Hz pure tone propagates in the aire at a speed of 340 m/s. The pressure wave amplitude in a point located 2 m from the source is 184 mPa. Calculate:
a. Wave equation. Plot in the before mentioned point, the pressure as function of time.
b. Wave intensity and intensity level in the point in question.
NOTE: Consider the density of air as 1.27 kg/m^3 and remember that $I_0=10^{-12}$ W/m^2

17. A spherical sound source produces, at 1 m of distance from it, an intensity level of 65 dB. Calculate, assuming spherical propagation and under the environmental conditions given in the previous exercise, the following:
a. Sound power of the source.
b. Maximum value of the pressure of the wave at 2 m distance from it. What is the corresponding RMS value at that location?

18. A semi-spherical speaker is set for an intensity level of 40 dB at 10 m distance.
a. What is the intensity in W·m^{-2} at that distance?
b. What is the intensity level at 2.5 m distance?
c. Assuming that the hemispherical speaker is an isotropic sound source, what is its power?
d. What is the RMS pressure at 20 m distance?
NOTE: Assume air density=1.29 kg/m^3; c= 344 m/s; intensity perception threshold $I_0=10^{-12}$ W/m^2

Answers:

13. a) λ=0.08 m
b) L_p=63 dB
14. a) $y = 6\sin(0.02\pi x + 4\pi t - \pi/2)$ / λ=1 m / f=2 Hz
b) c=200 cm/s in negative *x*-direction / A=6 cm
c) $v_{max}=24\pi$ cm/s / $a_{max}=96\pi^2$ cm/s^2
15. a) f=3 Hz / T=0.333 s / λ=2 m / c=6 m/s
b) v=2.666 m/s / a=-50.25 m/s^2
c) $\Delta\varphi = 0.3\pi$ rad
d) $v_{max}=0.2\cdot 6\,\pi$ / $a_{max}=0.2\cdot 36\pi^2$
16. a) $p(x,t) = 184\cos(8x - 2720t)$
b) L_I=76 dB
17. a) W=4·10^{-5} W
b) P=2.61·10^{-2} Pa / P_{RMS}=1.85·10^{-2} Pa
18. a) $I_I=10^{-8}$ Wm^{-2}
b) L_I=52 dB
c) W=6.28·10^{-2} W
d) P_{RMS}=1.05·10^{-2} Pa