Audiometry

Any of the following calculations may be asked in the midterms/exam.

1. Enter the missing data into the table using the equal-loudness contours (Lab Manual, ***Fig. 1***). Data in the same row belong to the same pure sinusoid sound.

	f	p_{eff}	J	$\log(J/J_0)$	H_{phon}	H_{sone}
a)	60 Hz			60 dB		
b)	0.2 kHz					4 sone
c)				11 B	90 phon	
d)	6 kHz		10^{-6} mW/cm^2			
e)		2 Pa				32 sone
f)	100 Hz		1 nW/m^2			
g)	8 kHz					0.1 sone

2. Answer the following questions using the equal-loudness contours (Lab Manual, ***Fig. 1***).
a) How many decibels is the intensity level of the sound of 40 Hz that has the same loudness as the 40 dB 6 kHz sound?
b) How many W/m^2 is the intensity of the 6000 Hz sound which is as loud as the 10^{-4} W/m^2 80 Hz sound?
c) At what frequency will a sound of 110 dB have the loudness level of 110 phons?
d) How many decibels is the intensity level of the 50 Hz sound which is as loud as the 110 dB 5 kHz sound?

3. Answer the following questions using the equal-loudness contours (Lab Manual, ***Fig. 1***).
a) How many times is a 40 Hz 90 dB sound louder than a 10 kHz 30 dB sound?
b) Compared to a 200 Hz 60 dB sound, how many times is a 6 kHz 80 dB sound louder?
c) Compared to a 8 kHz 10^{-9} W/m^2 sound, how many times is a 400 Hz 10^{-9} W/m^2 sound louder?
d) How many times is a 90 dB 30 Hz sound louder than a 80 dB 3 kHz sound?

4. Answer the following questions using the equal-loudness contours (Lab Manual, ***Fig. 1***).
a) How many decibels is the intensity level of the 200 Hz sound which is four times louder than the 80 dB 3 kHz sound?
b) How many decibels is the intensity level of the 60 Hz sound which is forty times louder than the 10^{-10} W/m^2 10 kHz sound?
c) How many decibels is the intensity level of the 3 kHz sound which has the eighth of the loudness of the 130 dB 50 Hz sound?
d) How many watts per square meter is the intensity of the 6 kHz sound which is 160 times louder than the 400 Hz 30 dB sound?

5. Answer the following questions using the equal-loudness contours (Lab Manual, ***Fig. 1***).
How many decibels was the auditory threshold sixty years ago ...
a) ... at 50 Hz,
b) ... at 200 Hz,
c) ... at 1 kHz, and
d) ... at 7.5 kHz?

6. How does
a) the sound pressure,
b) the intensity,
c) the intensity level, and
d) the loudness level of a 1 kHz sound change if its loudness is doubled?

7. We increase the intensity of a 1 kHz sound hundredfold. Supposing a greater than 10^{-8} W/m^2 initial intensity, how does its
a) intensity level,
b) loudness level, and
c) loudness change?

8. The loudness of a sound is 2 sones. How does its loudness level change, if its loudness changes to
a) 4 sones,
b) 8 sones,
c) 64 sones, as well as
d) 1 sone?

9. The intensity of the sound of a motorbike at idle speed is $6 \cdot 10^{-6}$ W/m^2 while at 8000 rpm it is $3.5 \cdot 10^{-1}$ W/m^2. How many decibels greater intensity level belongs to the latter?

10. We increase the volume of a speaker by 25 dB. How many times greater will the sound intensity be?

11. The hearing loss of a patient at a certain frequency is 40 dB.
a) What is the least intensity he can just notice if the auditory threshold at this frequency is $5 \cdot 10^{-12}$ W/m^2?
b) If out of this sound intensity a wall transmits $5 \cdot 10^{-12}$ W/m^2 then we say that the sound reduction index of this wall is 40 dB. How many half value layers is the thickness of this wall?
c) If the wall's thickness is 12 cm, what is the half value layer and the attenuation coefficient of the wall for this sound?

12. Mr. Deaf, who has 30 dB hearing loss, is disturbed by the next-door house party despite the 15 half value layer thick wall. He can only manage not to hear it if he uses earplugs of at least 45 dB noise reduction. Find the sound intensity incident on the other side of the wall. (For simplicity's sake, consider a 1 kHz pure sinusoid sound.)

13. What is the least intensity of a 300 Hz sound that a person with 25 dB hearing loss can hear? The average auditory threshold at this frequency is $3 \cdot 10^{-11}$ W/m^2.

14. The 45 dB hearing loss of a person is compensated by a hearing aid containing a microphone with 5% and a speaker with 8% conversion efficiency. How many decibels is the electric amplification?

15. Laci is sitting 2 meters away from a speaker, which takes up 40 W electric power and can be considered a point-like isotropic sound source. The conversion efficiency of the speaker is 8% and it produces a 1000 Hz sound. How many phons is the sound heared by Laci?

16. Equal temperament of musical instruments in Western music means that an octave is divided into 12 equal intervals called semitones (or minor seconds), that is, each semitone corresponds to equal pitch difference. What is the frequency ratio of two notes a semitone apart in case of this temperament?

17. What is the decibel value of the auditory threshold of a person at 1000 Hz frequency if the corresponding output voltage of the sound generator is 14 mV? Is it better or worse than the average? $A = 10^{-8}$ W/(m^{2}V^2)

Formulæ

$p = p_1 \cdot \sin(\omega_0 \cdot t + \phi)$ (pressure variation during propagation of sound)

$J = \frac{P}{A}$ (definition of intensity)

$J = \frac{p_{eff}^2}{Z}$ (sound intensity calculated from sound pressure and acoustic impedance)

$Z = c \cdot \rho$ (acoustic impedance)

$R = \frac{J_{reflected}}{J_0} = \left(\frac{Z_2 - Z_1}{Z_2 + Z_1}\right)^2$ (sound reflectance)

$c = \frac{\lambda}{T} = \lambda \cdot f$ (speed of wave propagation)

$A_{sphere} = 4r^2\pi$ (surface area of a sphere)

$n_{octave} = \log_2\left(\frac{f_2}{f_1}\right)$ (pitch)

$J_{dB} = 10\log\left(\frac{J}{J_0}\right)$ (intensity level, dB)

$H_{phon} = 10\log\left(\frac{J}{J_0}\right)_{1000Hz}$ (phon scale)

$H_{sone} = \frac{1}{16}\left(\frac{J}{J_0}\right)_{1000Hz}^{0.3}$ (sone scale)

$H_{phon} + 10phon = H_{sone} \cdot 2$ (relationship between the phon and sone scales)

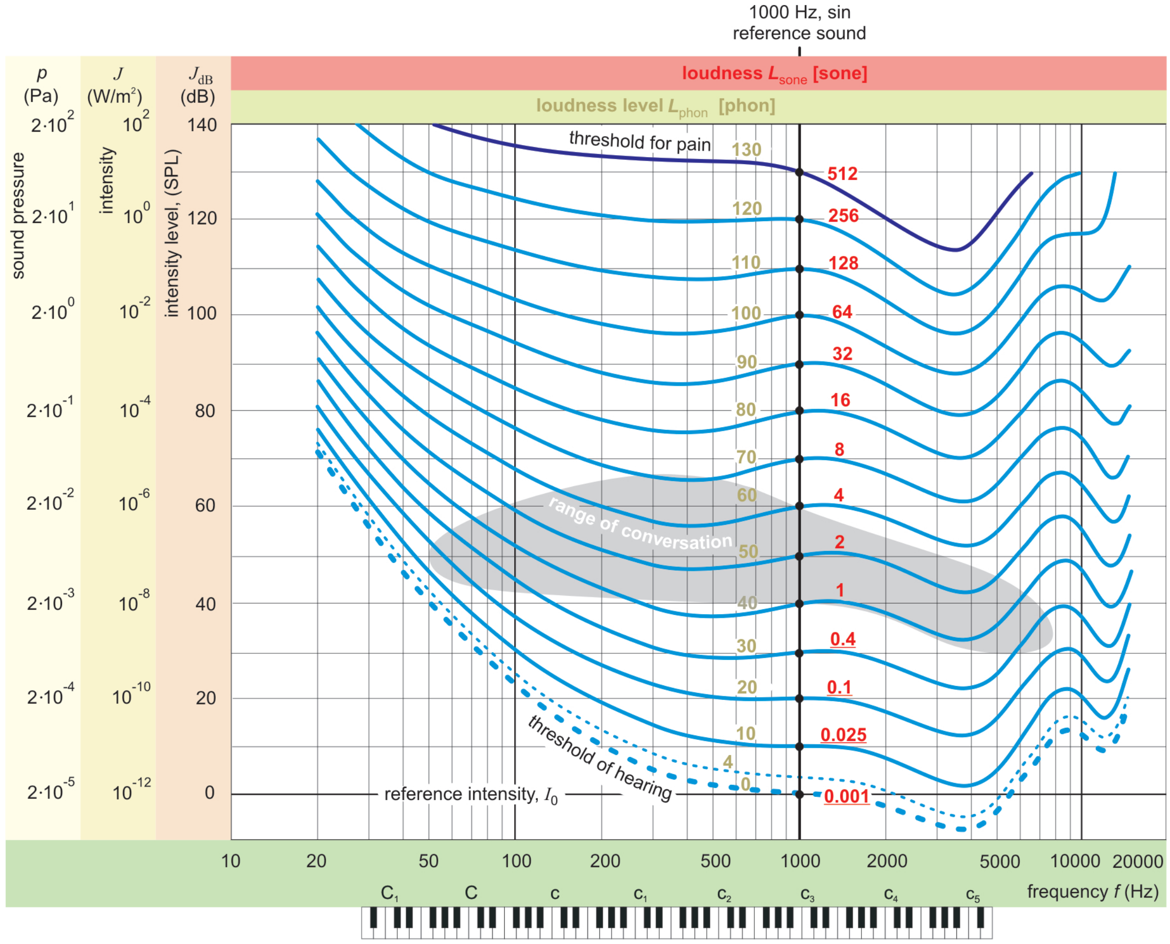
$J_0 = 10^{-12}\frac{W}{m^2}$ (intensity of reference sound)

$f_0 = 1000Hz$ (frequency of reference sound)

$D_{sound} = J_{sound} \cdot t$ (sound dose)

$J = A \cdot U^2$ (voltage-to-sound intensity conversion in a speaker)

$HL = J_{dB,meas} - J_{dB,norm}$ (hearing loss)



1000 Hz, sin
reference sound
loudness L_{sone} [sone]
loudness level L_{phon} [phon]
p (Pa)
J (W/m²)
J_{dB} (dB)
sound pressure
intensity
intensity level, (SPL)
2·10^2 10^2 140
2·10^1 10^0 120
2·10^0 10^-2 100
2·10^-1 10^-4 80
2·10^-2 10^-6 60
2·10^-3 10^-8 40
2·10^-4 10^-10 20
2·10^-5 10^-12 0
threshold for pain
130 120 110 100 90 80 70 60 50 40 30 20 10 4 0
512 256 128 64 32 16 8 4 2 1 0.4 0.1 0.025 0.001
range of conversation
threshold of hearing
reference intensity, I_0
discotheque
120 phon
very
noisy factory
100 phon
busy street
70-90 phon
quiet street
50 phon
whisper
30 phon
10 20 50 100 200 500 1000 2000 5000 10000 20000
frequency f (Hz)
C1 C c c1 c2 c3 c4 c5

Solutions

1.

	f	p_{eff}	J	$\log(J/J_0)$	H_{phon}	H_{sone}
a)	60 Hz	**0.02 Pa**	**10^{-6} W/m²**	60 dB	**40 phon**	**1 sone**
b)	0.2 kHz	**0.02 Pa**	**10^{-6} W/m²**	**60 dB**	**60 phon**	4 sone
c)	**30 Hz**	**6.32 Pa**	**0.1 W/m²**	11 B	90 phon	**32 sone**
d)	6 kHz	**0.0632 Pa**	10^{-6} mW/cm²	**70 dB**	**70 phon**	**8 sone**
e)	**60 Hz**	2 Pa	**0.02 W/m²**	**100 dB**	**90 phon**	32 sone
f)	100 Hz	**$6.32\cdot10^{-4}$ Pa**	1 nW/m²	**30 dB**	**20 phon**	**0.1 sone**
g)	8 kHz	**$6.32\cdot10^{-4}$ Pa**	**10^{-9} W/m²**	**30 dB**	**20 phon**	0.1 sone

2. Look for the contour belonging to the given sound then find the sound in question along this contour.
a) [40 dB;6 kHz] → 40 phon (1 sone) → 40 Hz → 70 dB.
b) 10^{-5} W/m².
c) At 200 Hz, at 1000 Hz, and at 6000 Hz.
d) 130 dB.

3. Relative loudness can be found by comparing sone-values.
a) [40 Hz;90 dB] → 8 sone; [10 kHz;30 dB] → 0.1 sone; 8 sone/0.1 sone, i.e., 80 times.
b) 16 sone/4 sone, i.e., 4 times.
c) 0.4 sone/0.1 sone, i.e., 4 times.
d) 4 sone/32 sone, i.e., 1/8.

4. a) [80 dB;3 kHz] → 32 sone → 128 sone → 200 Hz → 110 dB
b) 60 dB.
c) 80 dB.
d) 10^{-2} W/m².

5. These can be read from the lowest contour, i.e. the auditory threshold:
a) 40 dB.
b) 10 dB.
c) 0 dB (reference sound)
d) 10 dB.

6. a) $\sqrt{10} = 3.16$ -fold increase.
b) 10-fold increase.
c) Increases by 10 dB.
d) Increases by 10 phons.

7. a) Increases by 20 dB.
b) Increases by 20 phons.
c) 4-fold increase.

8. a) Increases by 10 phons.
b) Increases by 20 phons.
c) Increases by 50 phons.
d) Decreases by 10 phons.

9. $J_{dB} = 10\log\left(\frac{J}{J_0}\right) = 10\log\left(\frac{3.5\cdot 10^{-1}\frac{W}{m^2}}{6\cdot 10^{-6}\frac{W}{m^2}}\right) = \underline{\underline{47.66dB}}$

10. $J_{dB} = 10\log\left(\frac{J}{J_0}\right) \Rightarrow \frac{J}{J_0} = 10^{\frac{J_{dB}}{10}} = 10^{\frac{25}{10}} = \underline{\underline{316}}$ -times greater.

11. a) $J_{dB} = 10\log\left(\frac{J}{J_0}\right) \Rightarrow J = J_0\cdot 10^{\frac{J_{dB}}{10}} = 5\cdot 10^{-12}\frac{W}{m^2}\cdot 10^{\frac{40}{10}} = \underline{\underline{5\cdot 10^{-8}\frac{W}{m^2}}}$

b) $J_{dB} = 10\log\left(\frac{J}{J_0}\right) \Rightarrow \frac{J}{J_0} = 10^{\frac{J_{dB}}{10}} = 10^{\frac{40}{10}} = 10000$

$2^n = 10000$

$n = \frac{\log 10000}{\log 2} = \underline{\underline{13.3}}$

c) $13.3D = 12cm$

$D = \frac{12cm}{13.3} = \underline{\underline{0.9cm}}$ is the half value layer.

$\mu = \frac{\ln 2}{D} = \frac{\ln 2}{0.9cm} = \underline{\underline{0.77cm^{-1}}}$ is the linear attenuation coefficient.

12. $J_{dB} = 10\log\left(\frac{J}{J_0}\right) \Rightarrow J = J_0\cdot 10^{\frac{J_{dB}}{10}}$

$J = 10^{-12}\frac{W}{m^2}\cdot 10^{\frac{30}{10}}\cdot 2^{15}\cdot 10^{\frac{45}{10}} = \underline{\underline{1.036\frac{W}{m^2}}}$

13. $J_{dB} = 10\log\left(\frac{J}{J_0}\right) \Rightarrow J = J_0\cdot 10^{\frac{J_{dB}}{10}}$

$J = 3\cdot 10^{-11}\frac{W}{m^2}\cdot 10^{\frac{25}{10}} = \underline{\underline{9.5\cdot 10^{-11}\frac{W}{m^2}}}$

14. $J_{dB} = 10\log\left(\frac{J}{J_0}\right) \Rightarrow \frac{J}{J_0} = 10^{\frac{J_{dB}}{10}} = 10^{\frac{45}{10}} = 31623$

$\frac{31623}{5\%\cdot 8\%} = 7905694$

$J_{dB} = 10\log\left(\frac{J}{J_0}\right) = 10\log(7905694) = \underline{\underline{69dB}}$

15. $P = 40W\cdot 8\% = 3.2W$

$A_{sphere} = 4r^2\pi = 4\cdot(2m)^2\cdot\pi = 50.27m^2$

$$J = \frac{P}{A} = \frac{3.2W}{50.27m^2} = 0.0637\frac{W}{m^2}$$

$$H_{phon} = 10\log\left(\frac{J}{J_0}\right)_{1000Hz} = 10\log\left(\frac{0.0637\frac{W}{m^2}}{10^{-12}\frac{W}{m^2}}\right) = \underline{\underline{108 phon}}$$

16. Equal tone interval means equal frequency ratio; in case of an octave this ratio is 2. The 12 consecutive equal intervals correspond to multiplying frequency by the same number (a) 12 times, i.e.:

$$f \cdot a^{12} = 2 \cdot f$$

$$a^{12} = 2$$

$$a = \sqrt[12]{2} \approx \underline{\underline{1.06}}$$

17. The sound intensity produced by the speaker:

$$J_{own} = A \cdot U^2 = 10^{-8}\frac{W}{m^2 \cdot V^2} \cdot (0.014V)^2 = 1.96 \cdot 10^{-12}\frac{W}{m^2}$$

Convert this to decibels:

$$J_{dB,own} = 10\log\left(\frac{J}{J_0}\right) = 10\log\left(\frac{1.96 \cdot 10^{-12}\frac{W}{m^2}}{10^{-12}\frac{W}{m^2}}\right) = 10\log(1.96) = \underline{\underline{2.92dB}}$$

Nowadays, the average auditory threshold at 1 kHz is 4 dB, i.e. the hearing of the patient is better than the average. However, the average auditory threshold determined decades ago was 0 dB; compared to this the hearing of the patient is worse.