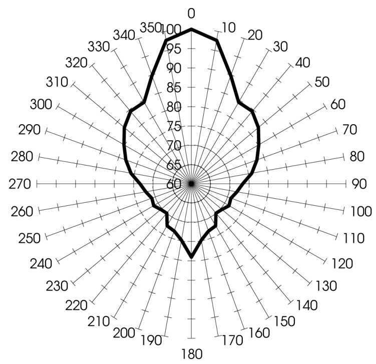
Pitch and Loudness

Basic Problems

1. How many octaves are spanned by the audible frequency range of the human ear?
2. What interval can be heard when a major third is followed by a minor third?
3. Calculate the frequency ratios for consecutive keys in the major and the minor scale (just temperament). How many different whole and half-tone steps are there?
4. Calculate the frequency of the tone one equally tempered halftone above a^1 (standard pitch 440 Hz).
5. Estimate the power arriving at the ear drum when the intensity level at its position is 100 dB.
6. By how many decibels does the intensity level decrease when the distance to a loudspeaker with conical radiation characteristic is increased by 10 %?
7. Ear protectors of a certain type reduce the intensity level at 1 kHz by 25 dB. What fraction of the sound intensity can pass them?
8. Calculate the increase in intensity level when the sound intensity gets five times greater, and the change in sound intensity when the intensity level is decreased by 5 dB.
9. The absorption of sound waves in air causes a decrease of the sound intensity level of 3 dB/km. Calculate the total change in sound intensity if the distance to the sound source is increased from 1.5 km to 4.5 km.
10. Two machines produce noises with intensity levels of 78 dB and 81 dB respectively. What is the intensity level when they are running at the same time?
11. The polar diagram below displays the directional characteristic of a typical loudspeaker facing to 0°. The thick black line shows the intensity level for the corresponding angle (loudspeaker facing to 0°).
    Use the diagram to answer the following questions:
    - What is the intensity level measured at 40°?
    - What are the angles with minimum intensity level? Give a reason why this is not at 180°
    - In what angular range is the sound intensity at least 10 % of the maximum?

    In the same diagram, sketch the polar graphs for loudspeakers with a) isotropic directional characteristic; b) emitting sound waves to the front only; c) emitting sound waves to a cone with cone angle 30°.



Additional Problems

12. What is the maximum pitch of the fundamental oscillation on a 1.2 m long steel string before it breaks?
13. A siren has an isotropic radiation characteristic. At a distance of 150 m from the siren the intensity level is measured to be 85 dB.
    a) What is the minimum power of the emitted sound waves?
    b) Taking into account the absorption in air (- 3 dB/km) calculate the minimum distance between the siren and a person for whom the sound intensity is below the hearing threshold.
14. A SUVA regulation demands that for a weekly working time of 40 hours the average intensity level must not surpass 87 dB. Increasing the level by 3 dB leads to a reduction of the allowed exposure time by 50 %.
    a) Show that this rule of thumb corresponds to a constant total energy arriving at the ear-drums.
    b) Is a weekly exposure to 90 dB during 10 hours and to 92 dB during 8 hours still acceptable?
15. The maximum intensity level at rock concerts is 100 dB (measured at the centre of the venue). At an open air concert the intensity level at 3.2 km from the stage is 56 dB. The sound absorption in air is some 3 dB/km. Calculate the intensity level at 10 m from the stage.

Solutions to Basic Problems: 1. 10 octaves; 2. fifth; 3. whole steps: 9 : 8 and 10 : 9, half-tone step: 16 : 15; 4. 466 Hz; 5. 1 μW; 6. -0.8 dB; 7. 3 ‰; 8. + 7 dB, - 67 %; 9. - 98.6 %; 10. 82.8 dB; 11. 85 dB, 140°/220°, 340° – 360°° and 0° – 20°; 12. 210 Hz; 13. 89 W, 15 km; 14. not acceptable; 15. 116 dB

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12. maximum stress for steel: $\sigma_B = 196 \cdot 10^7 \, N/m^2$ (FoTa 169

$$\rightarrow f_{max} = \frac{v_S}{2 \cdot l} = \sqrt{\frac{\sigma_B}{\rho}} \cdot \frac{1}{2 \cdot l} = \sqrt{\frac{196 \cdot 10^7 \, N/m^2}{7900 \, kg/m^3}} \cdot \frac{1}{2 \cdot 1{,}2m}$$

$$= \underline{210 \, Hz}$$

13. a) without absorption: $P = I \cdot A = I_0 \cdot 10^{\beta/10} \cdot 4\pi r^2$

$$= 10^{-12} \, N/m^2 \cdot 10^{8{,}5} \cdot 4\pi \cdot (150m)^2 = \underline{89 \, W}$$

b) with absorption: $\Delta\beta = k \cdot (r' - r) + 10 \cdot \log\left(\left(\frac{r}{r'}\right)^2\right)$

SOLVE with $\Delta\beta = -85 \, dB$, $k = -3 \cdot 10^{-3} \, dB/m$, $r = 150 m$

$$\Rightarrow r' = \underline{15 \, km}$$

14. a) $E = P \cdot \Delta t = I \cdot A \cdot \Delta t = I_0 \cdot 10^{\beta/10} \cdot A \cdot \Delta t$

$\beta \rightarrow \beta' = \beta + 3 dB \rightarrow I' = 2 \cdot I \rightarrow \Delta t = \frac{\Delta t}{2}$ for constant energy

b) reference value: $E_0 = I_0 \cdot 10^{\beta_0/10} \cdot A \cdot \Delta t_0$ with $\beta_0 = 87 dB$, $\Delta t_0 = 40 h$

for $\beta_1 = 90 dB$, $\Delta t_1 = 10 h$, $\beta_2 = 92 dB$, $\Delta t_2 = 8 h$:

$$E' = I_0 \cdot A \cdot (10^{\beta_1/10} \cdot \Delta t_1 + 10^{\beta_2/10} \cdot \Delta t_2)$$

$$\frac{E'}{E_0} = \frac{10^{\beta_1/10} \cdot \Delta t_1 + 10^{\beta_2/10} \cdot \Delta t_2}{10^{\beta_0/10} \cdot \Delta t_0} = \frac{10^9 \cdot 10 + 10^{9{,}2} \cdot 8}{10^{8{,}7} \cdot 40} = 1{,}1$$

$\rightarrow E' > E_0$ (not acceptable)

15. $\Delta\beta = k(r' - r) + 10 \cdot \log\left((r/r')^2\right)$ (see 13. b))

$$\Rightarrow \beta' = \beta + k(r' - r) + 10 \log\left((r/r')^2\right)$$

$$= 56 \, dB - 3 \, dB/km \cdot (0{,}01 - 3{,}2) \, km + 10 \cdot \log\left(\left(\frac{3200}{10}\right)^2\right) = \underline{116 \, dB}$$