Hearing light

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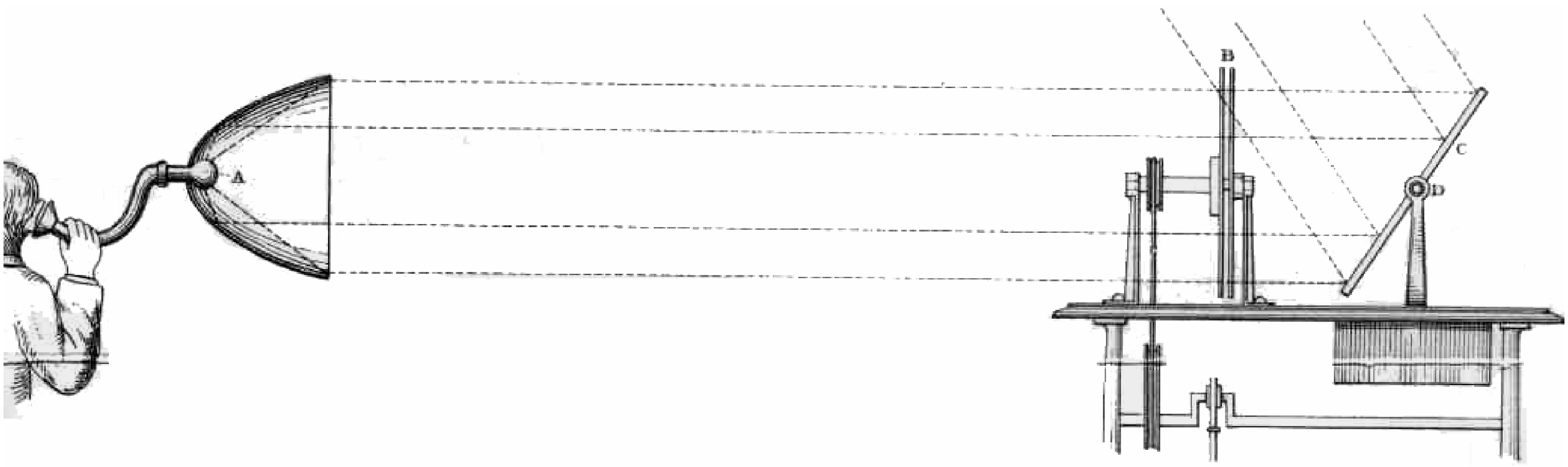
The problem

Coat one half of the inside of a jar with a layer of soot and drill a hole in its cover. When light from a light bulb connected to AC hits the jar’s black wall, a distinct sound can be heard. Explain and investigate the phenomenon.

Discovery of the photoacoustic effect

The photoacoustic effect was discovered independently by Bell, Tyndall and Röntgen in 1880–1881.

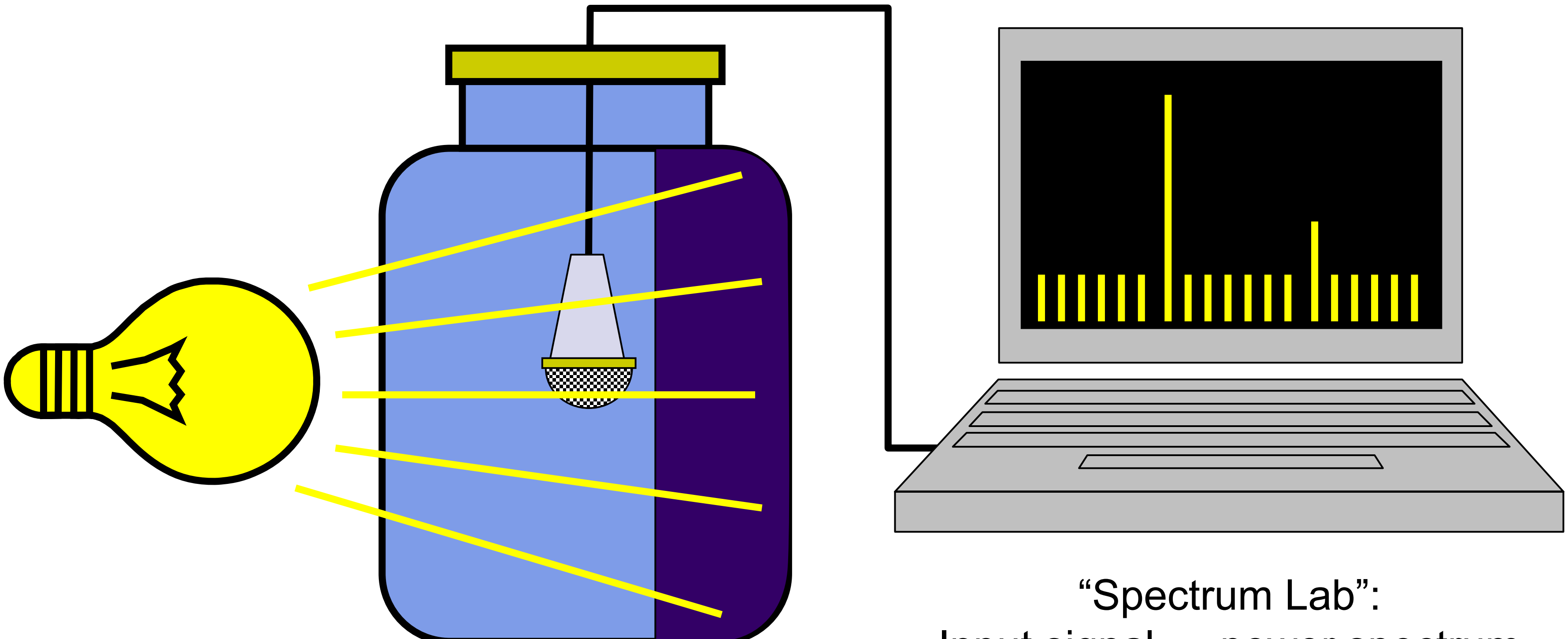


Bell A. G. (1880) “On the production and reproduction of sound by light”. *Am. J. Sci*. **20**, 305.
Tyndall J. (1881) “Action of an intermittent beam of radiant heat upon gaseous matter”. *Proc. R. Soc. London* **31**, 307-317.
Röntgen W. C. (1881) “On tones produced by the intermittent irradiation of a gas”. *Philos. Mag.* **11**, 308.

First observations

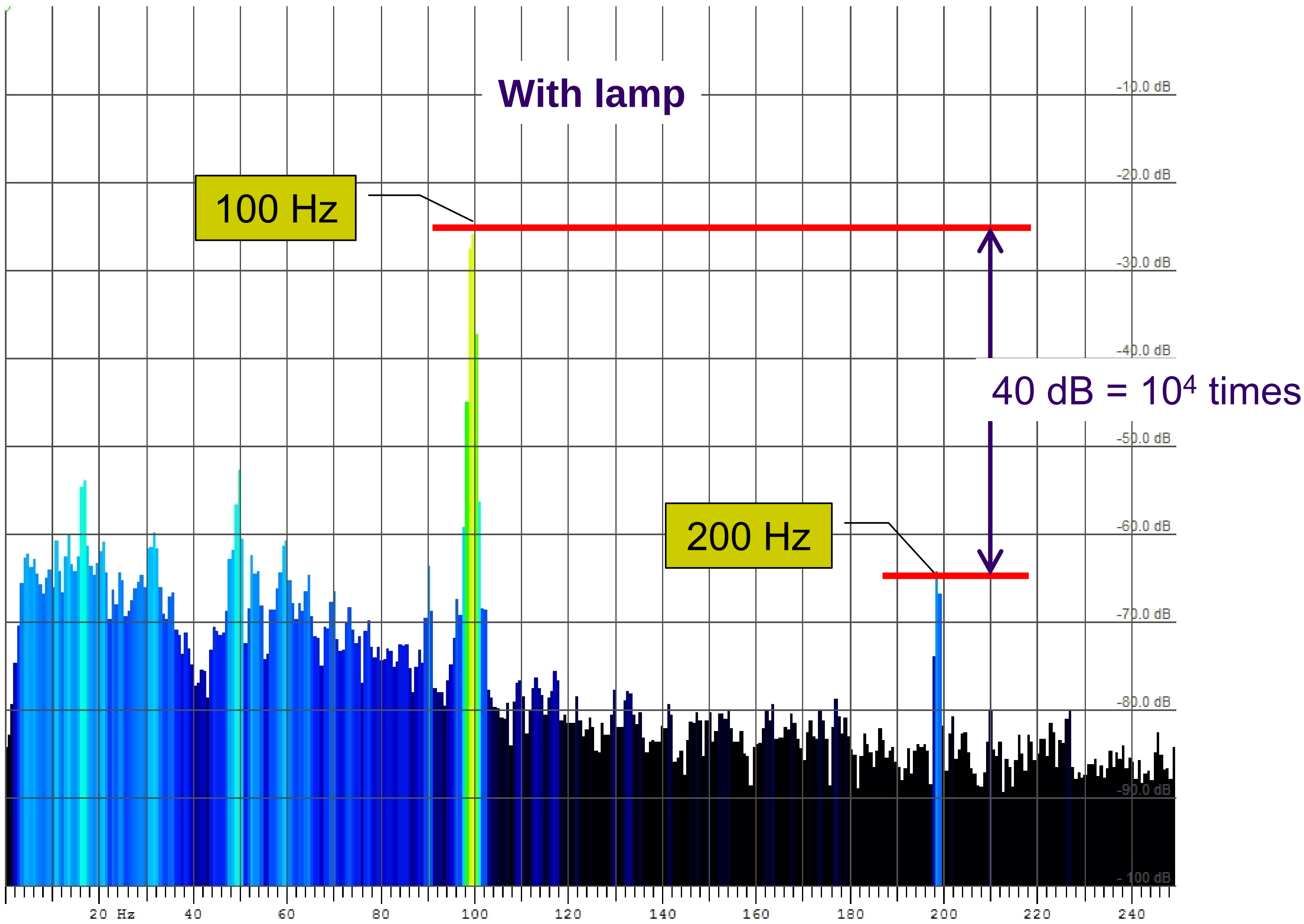
Experimental setup

Registration of the sound



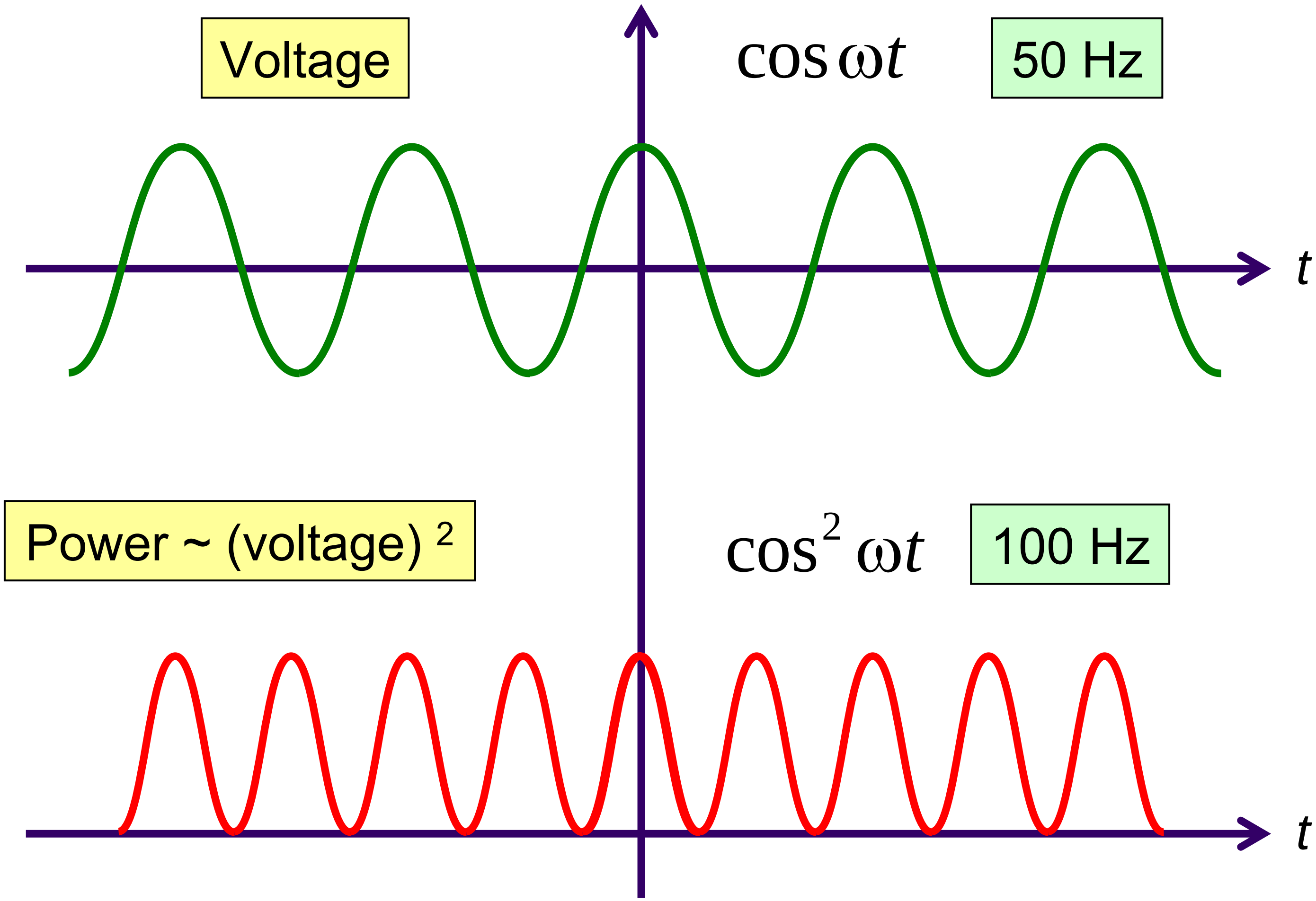
“Spectrum Lab”:
Input signal → power spectrum
(Fourier transformation)

Sound spectrum



Explanation of the phenomenon

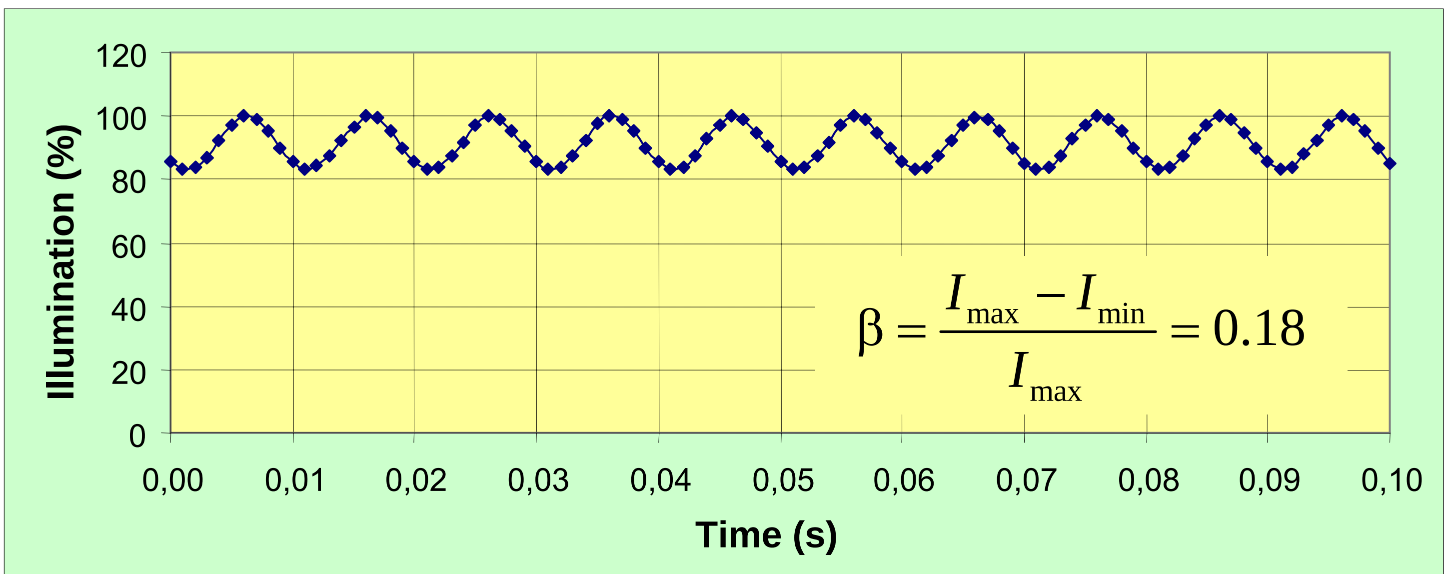
Why is the frequency 100 Hz?



Lamp blinking

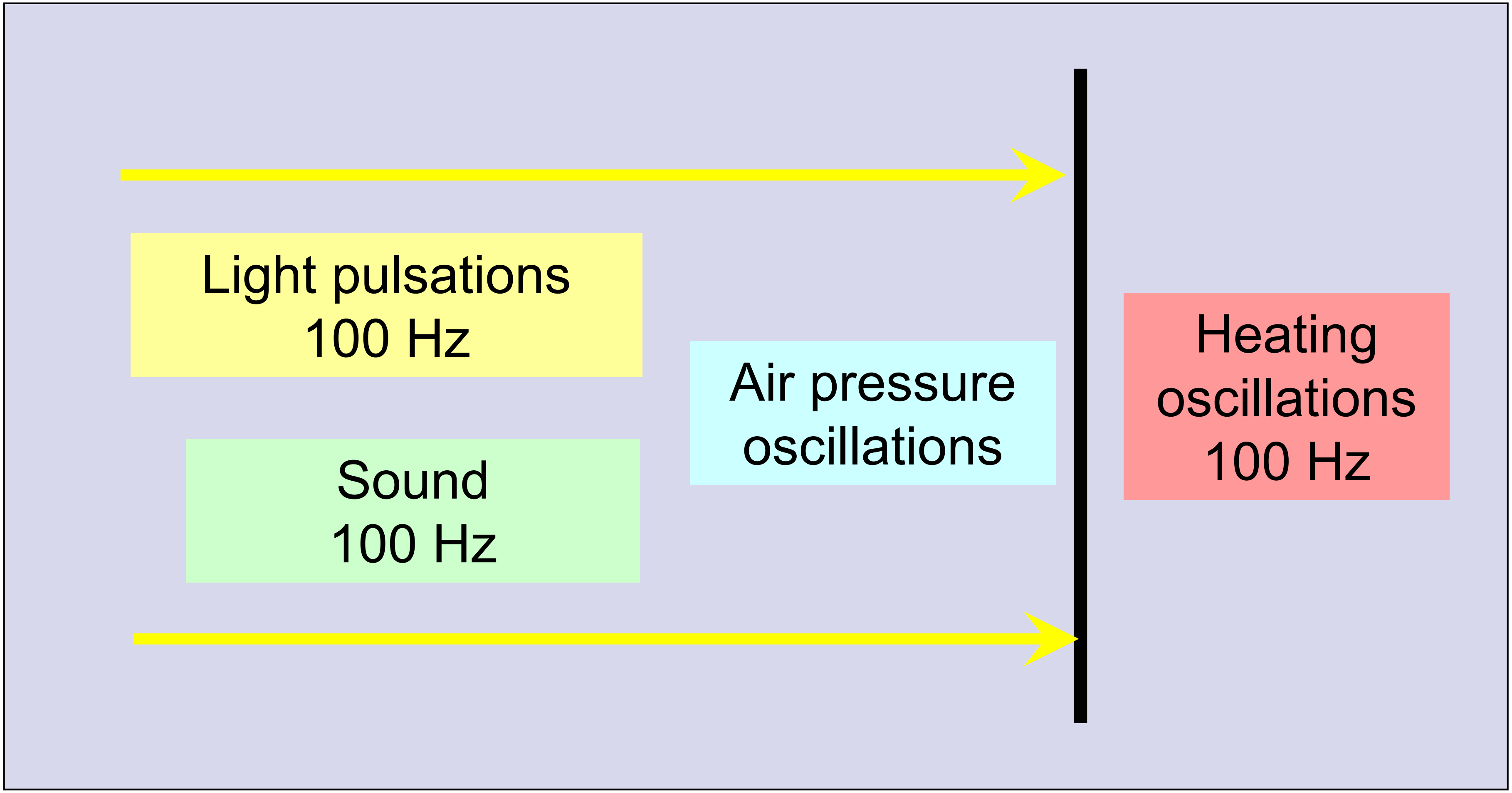
Video 1000 fps

Illumination sensor

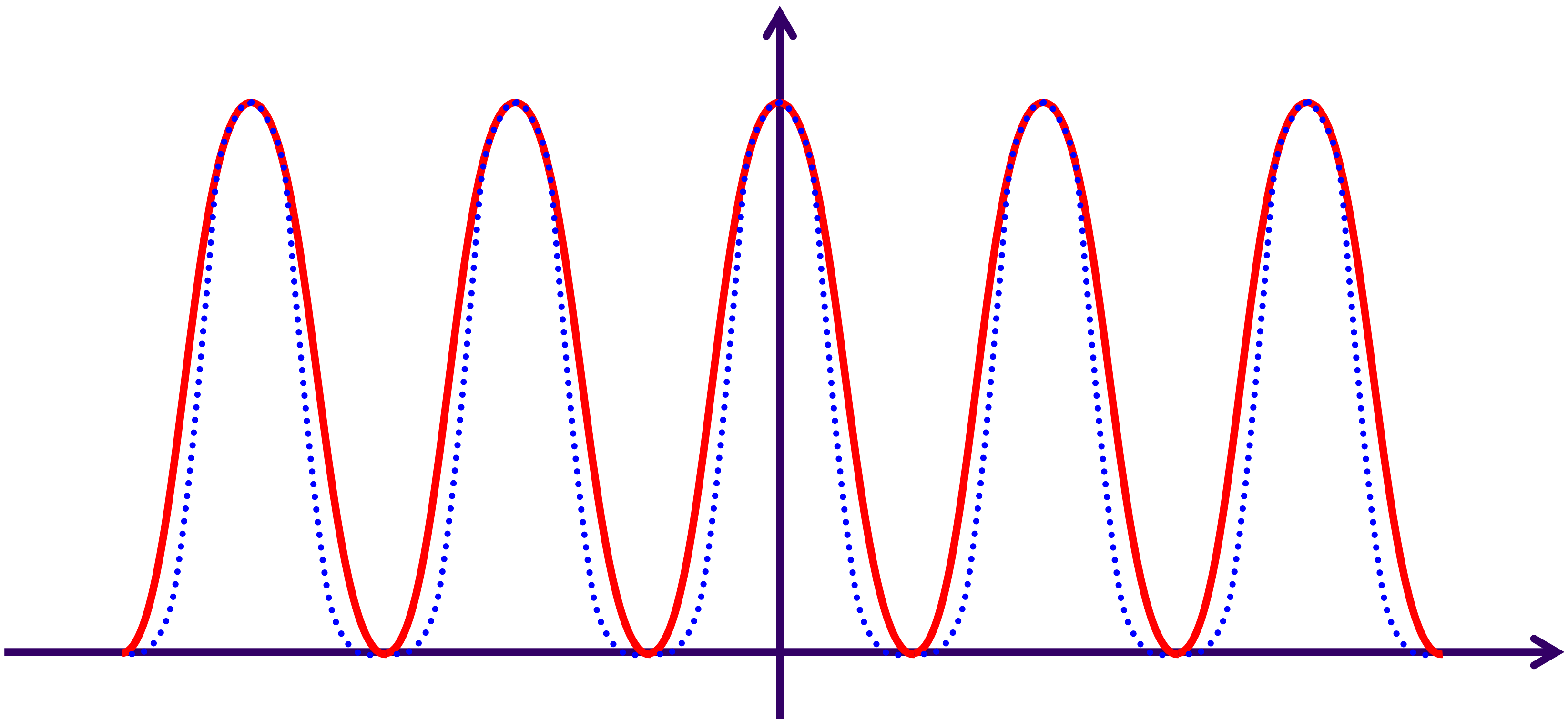


$$\beta = \frac{I_{max} - I_{min}}{I_{max}} = 0.18$$

Photo-thermo-acoustic conversion



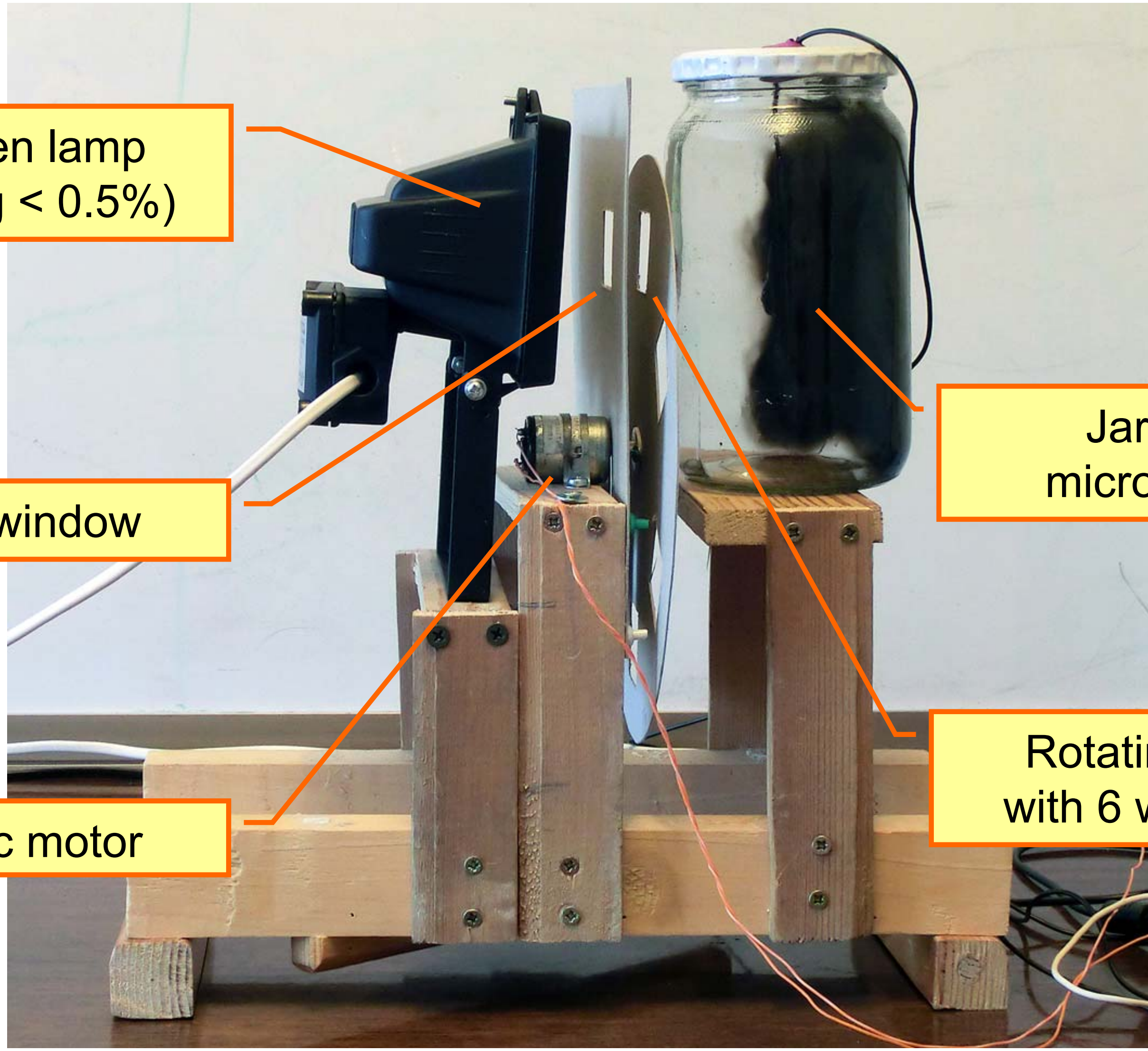
The secondary harmonic



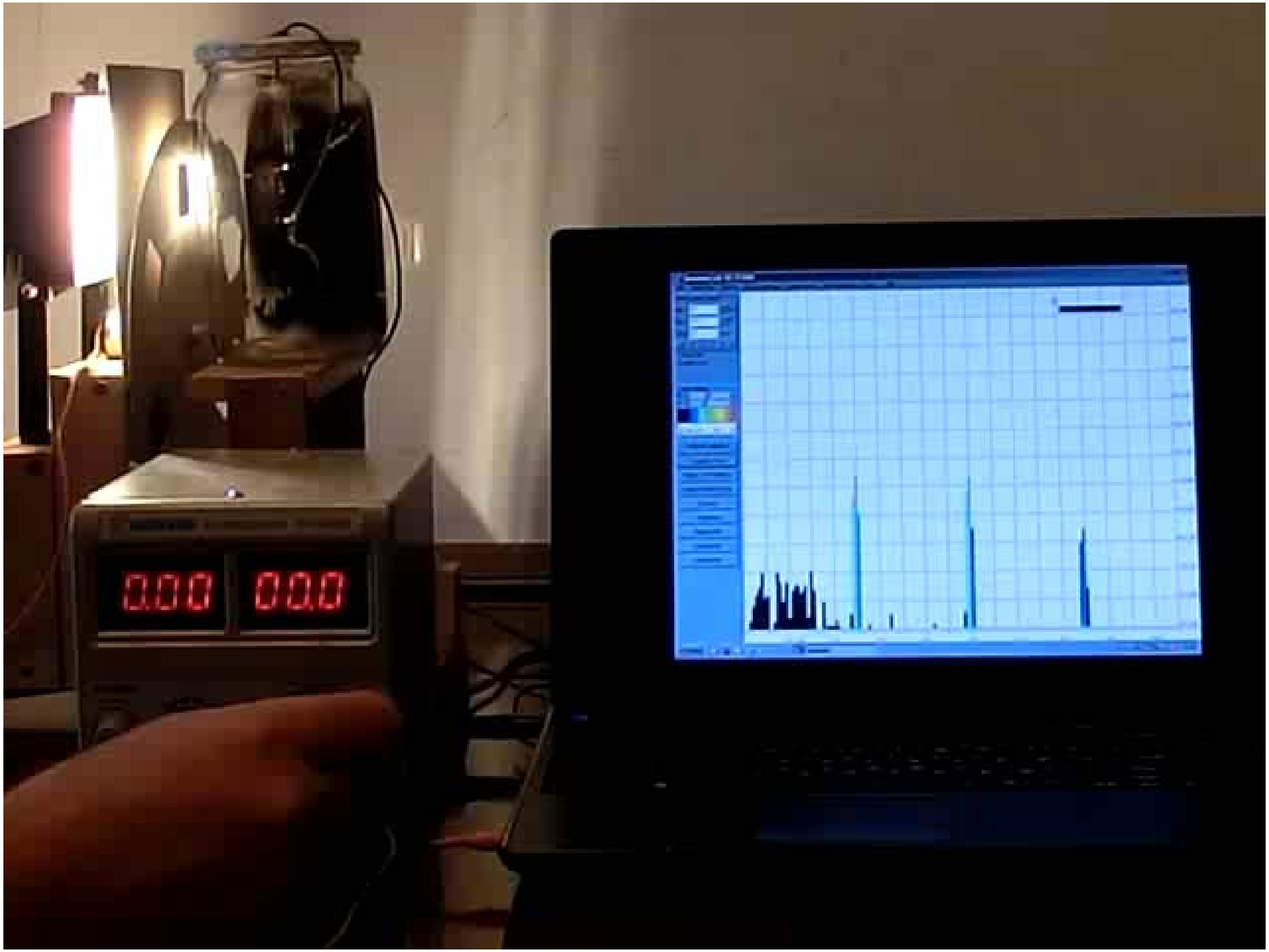
The secondary harmonic appears
because of weak nonlinear effects

Experiment with a mechanical obturator

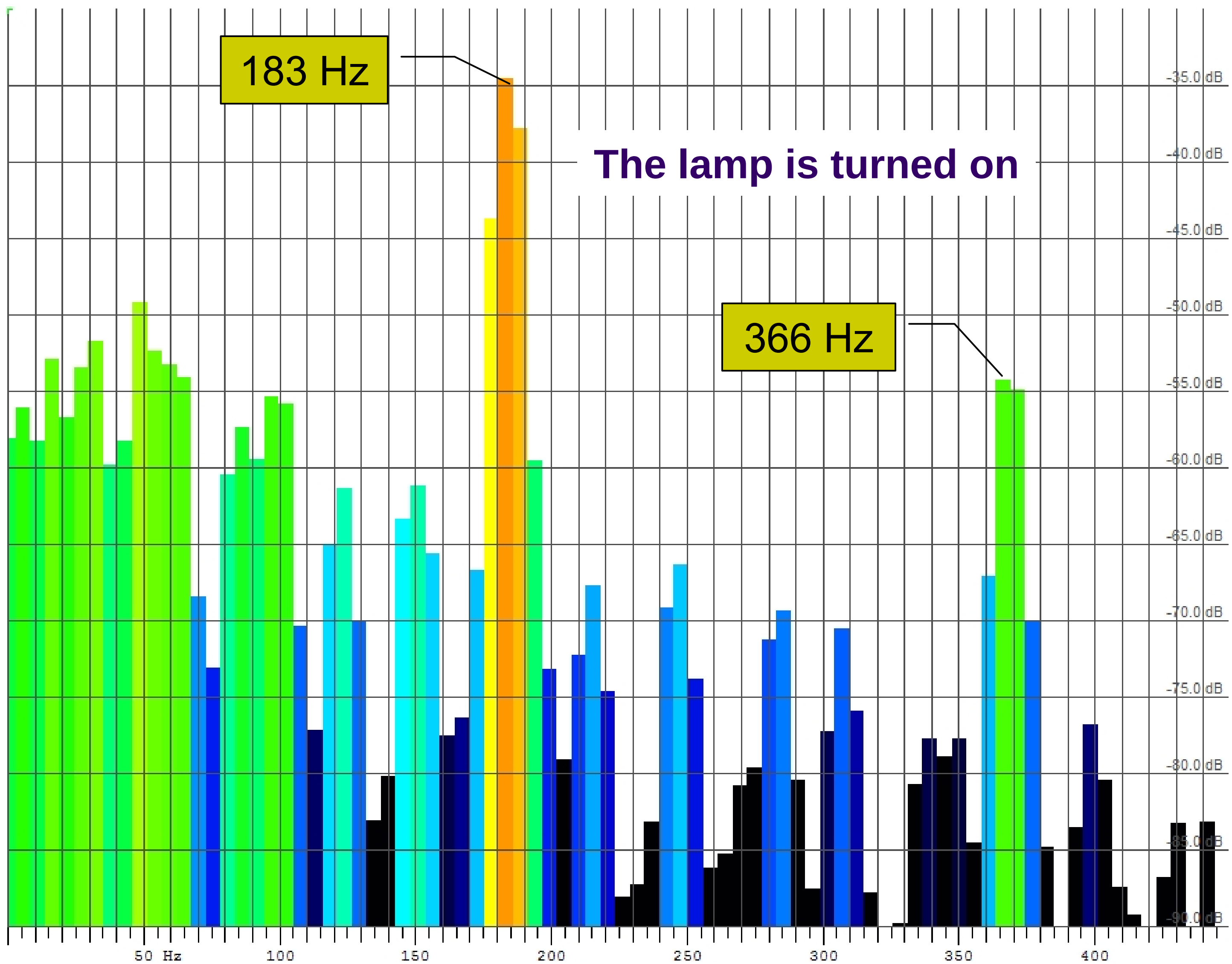
Experimental setup



Experiment (video)



Sound spectrum



Resonant amplification

Helmholtz resonator

Resonant frequency:

$$f = \frac{c}{2\pi}\sqrt{\frac{S}{V \cdot L}}$$

Speed of sound (c)

Cross-section of a pipe (S)

Volume of a jar (V)

Length of a pipe (L)

Calculation of the pipe length

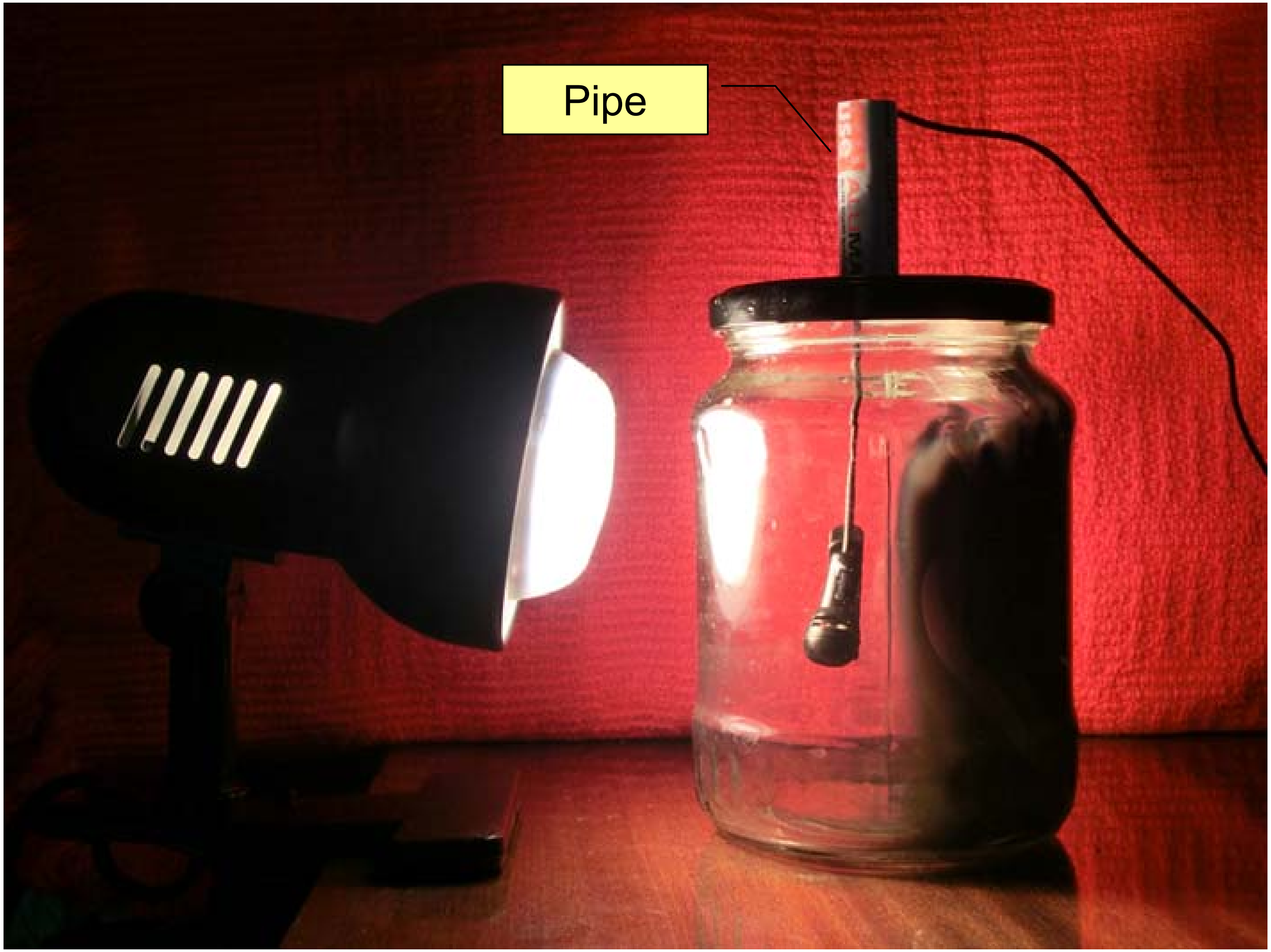
$$L = \frac{S}{V}\left(\frac{c}{2\pi f}\right)^2$$

$$c = 330 \text{ m/s} \quad f = 100 \text{ Hz}$$

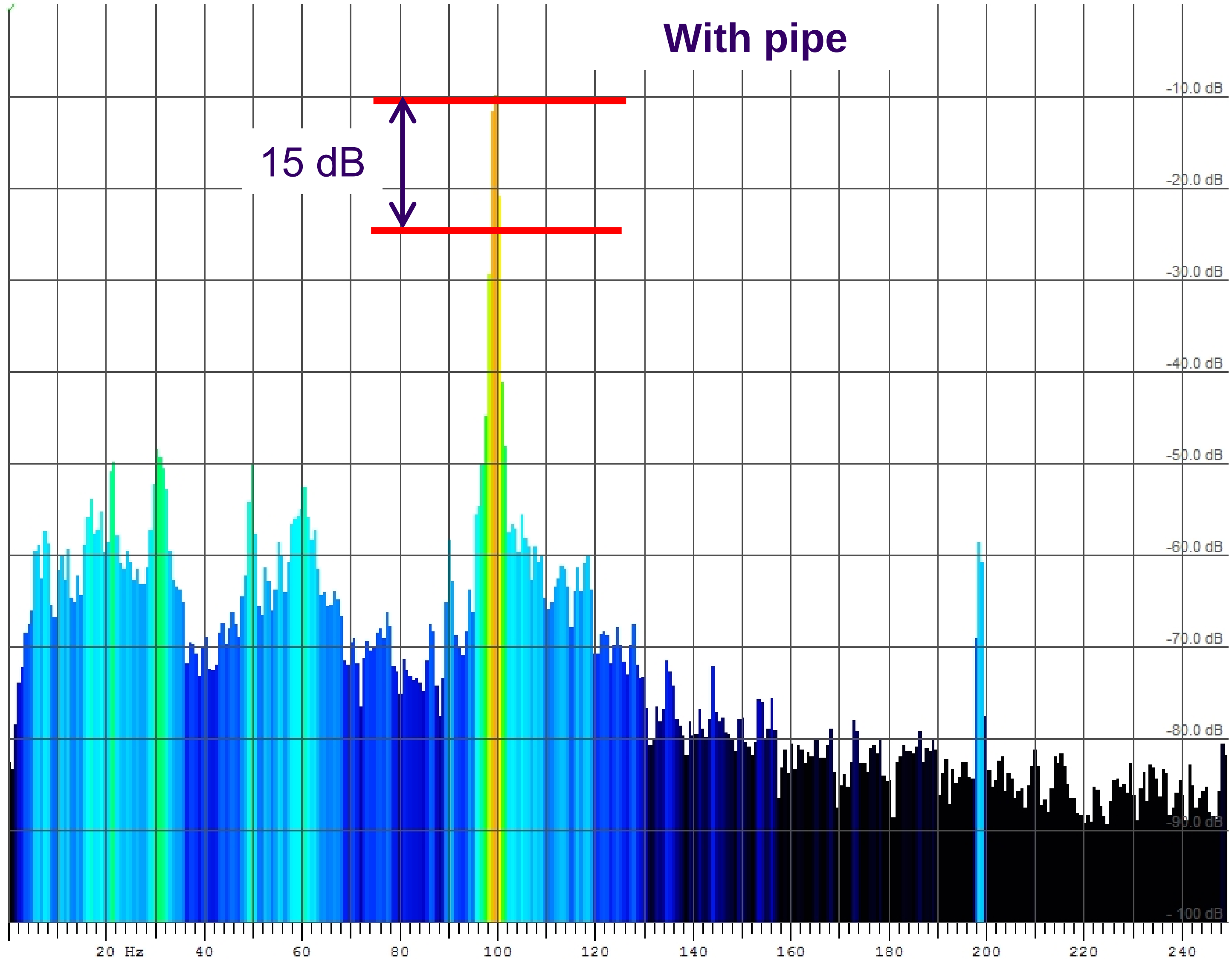
$$V = 750 \text{ cm}^3 \quad S = 1.5 \text{ cm}^2$$

$$L = 5.5 \text{ cm}$$

Jar as a Helmholtz resonator

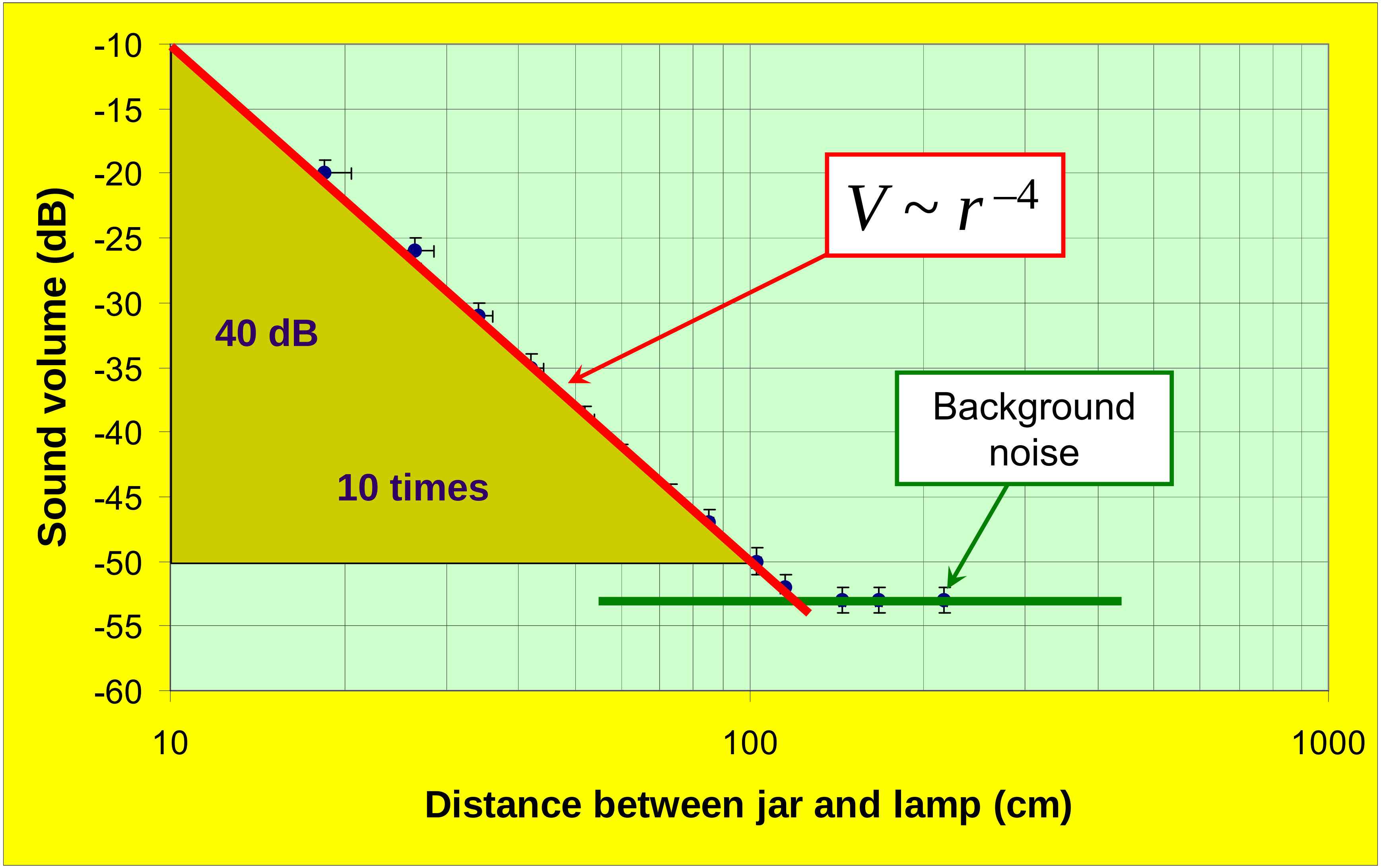


Sound spectrum



How does sound volume depend on the distance?

Sound volume vs. distance



Explanation of the dependence

$$P \sim I$$

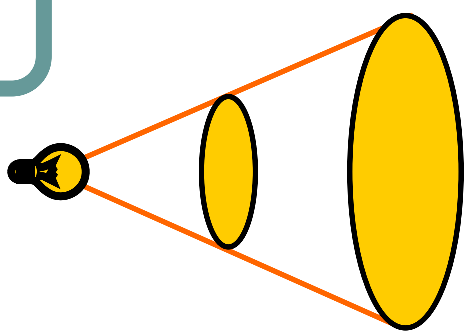
Amplitude of air pressure oscillations

Amplitude of light intensity oscillations

$$V \sim P^2 \sim I^2$$

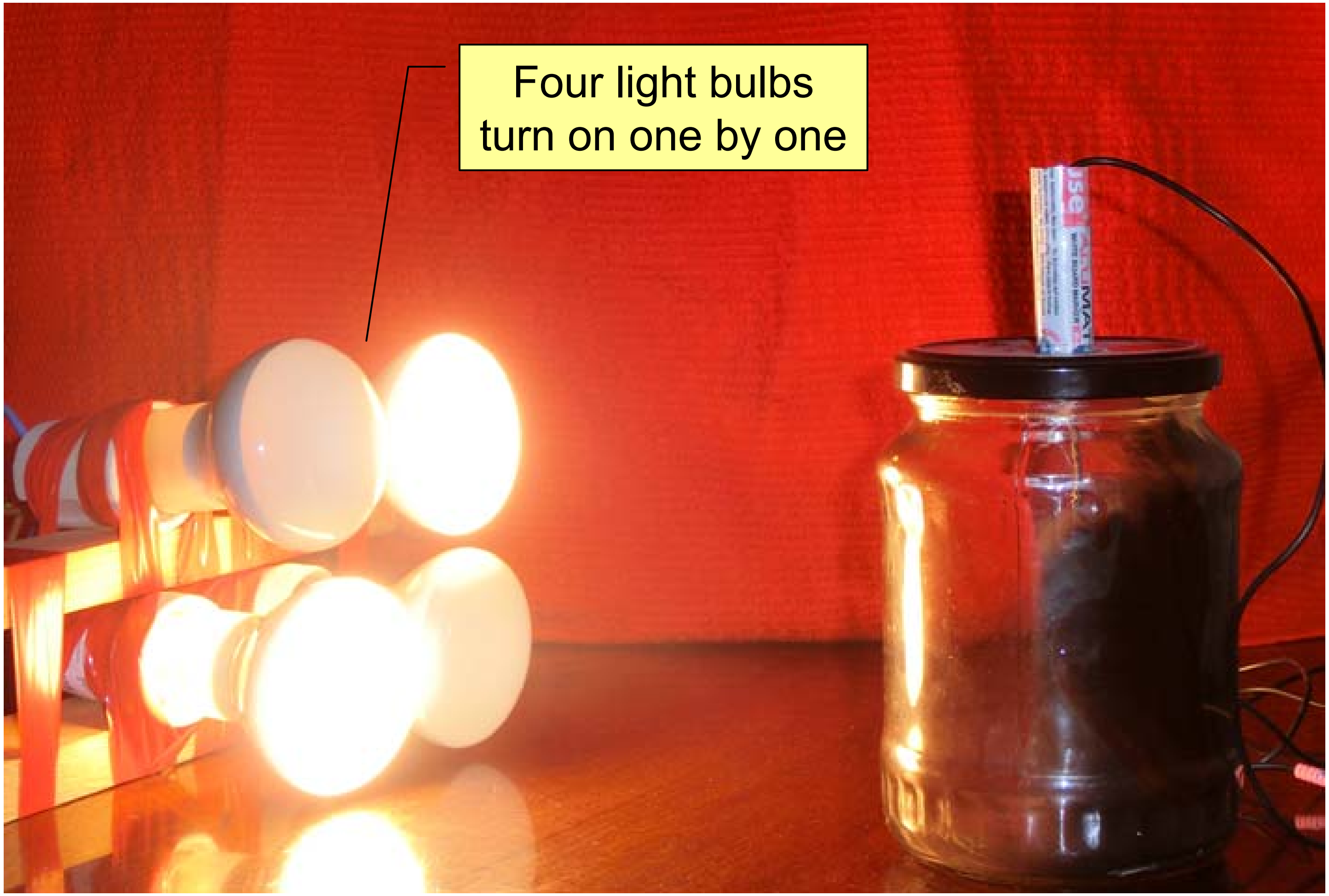
Sound volume

$$I \sim r^{-2}$$

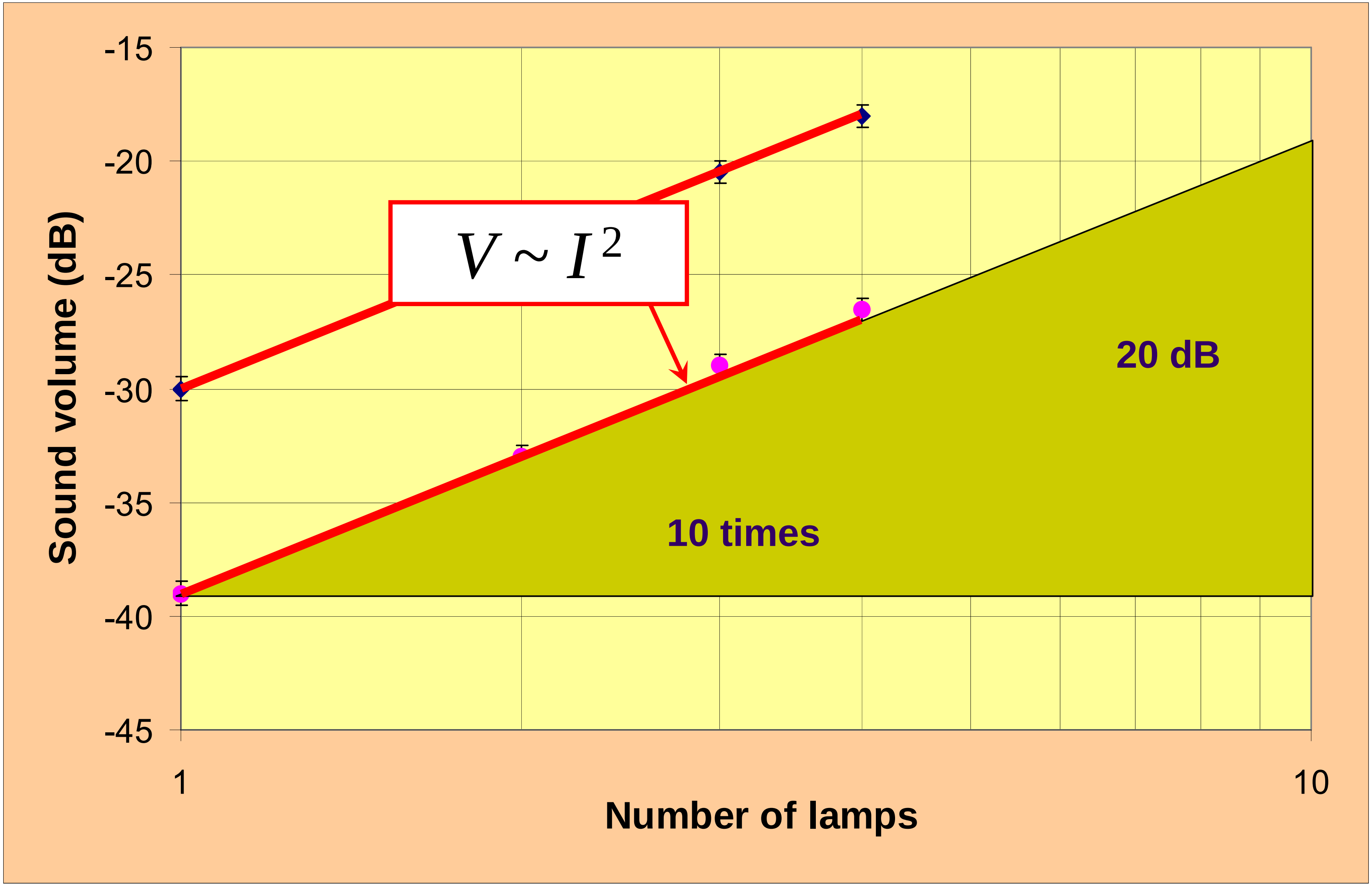


$$V \sim r^{-4}$$

Experimental confirmation

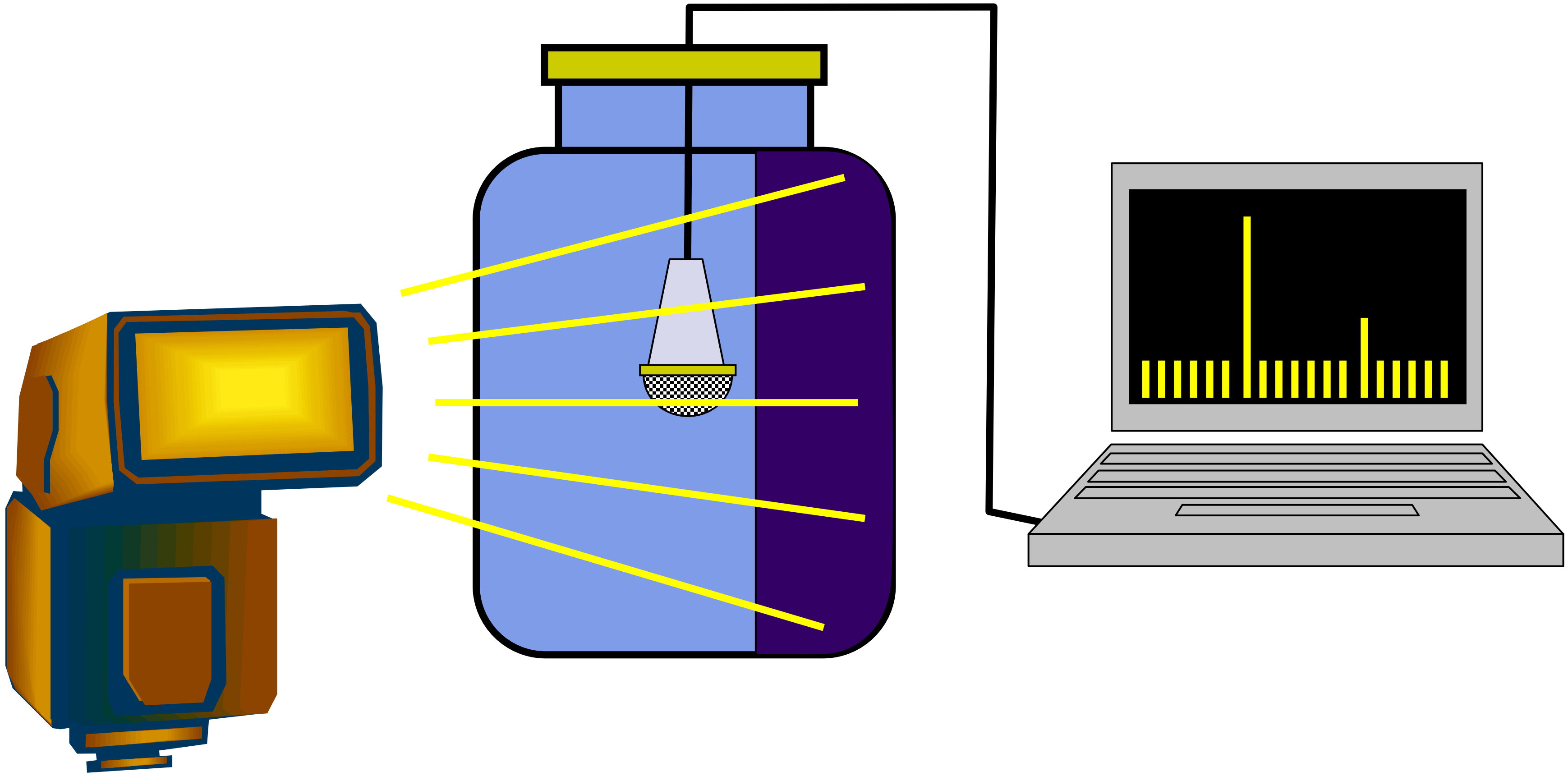


Experimental confirmation

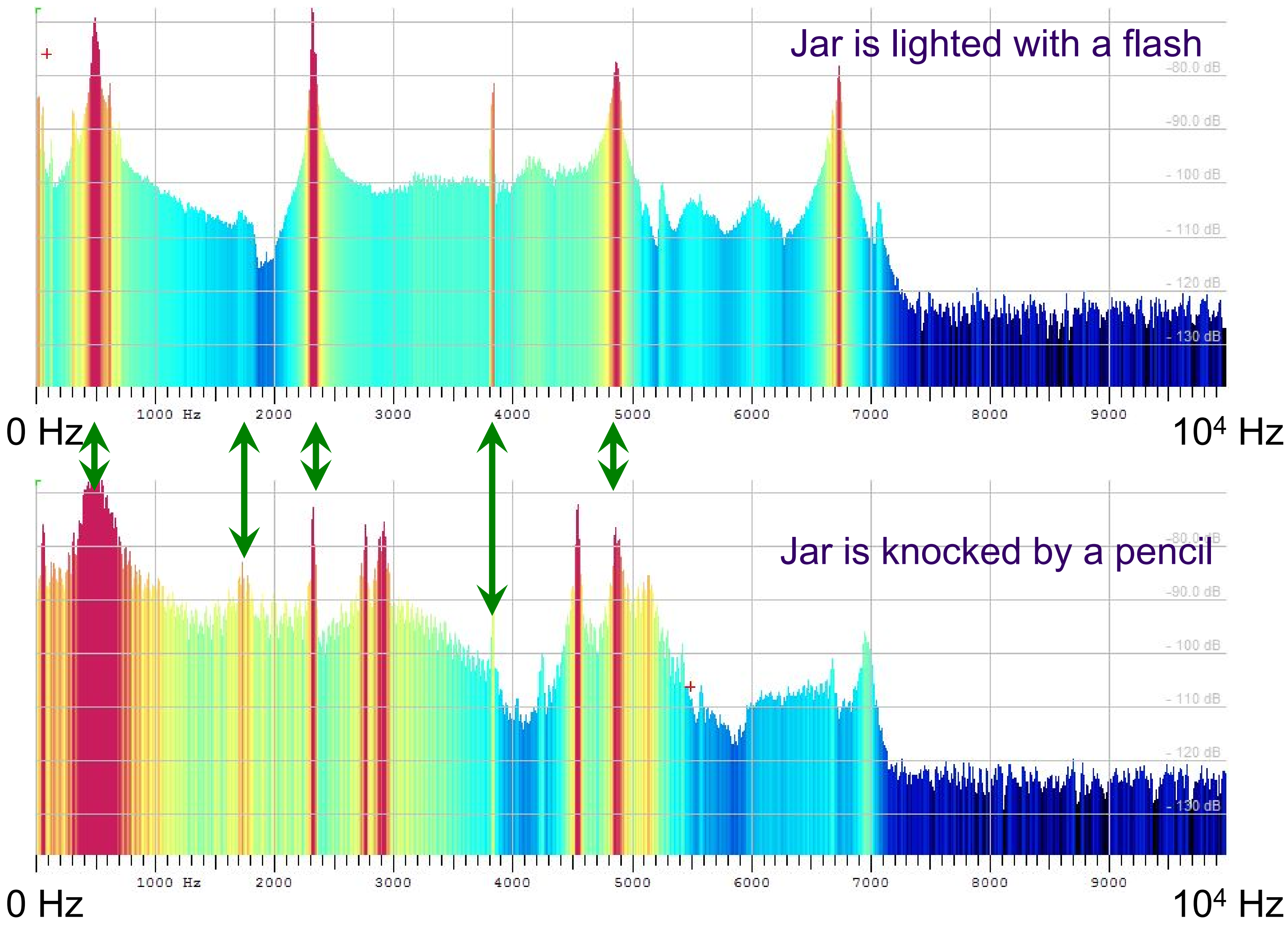


Experiment with a flash

Experiment with a flash



Experiment with a flash



Explanation of the phenomenon

- The flash produces a short impulse of light.
- Absorption of this light leads to a short sharp heatstroke.
- The result of this heatstroke is a sound with a wide-band spectrum.
- The jar responds to this sound on its resonant frequencies, so we heard “a glassy sound”.

Summary

Conclusions

- Illumination with periodic intensity leads to periodic changes in the temperature of a sooty wall and of the air inside the jar. This leads to periodic modulation of air pressure and thereby to appearance of the sound.
- The volume of sound is inversely proportional to the 4-th power of the distance between the light source and the photoacoustic converter.
- Single flash of light, illuminating the jar, creates sound with a wide range of frequencies similar to the sound caused by a blow to the jar.

References

- Euler M., Niemann K., Müller A. (2000) “Hearing light”. *Phys. Teach*. **38**, 356–358.
- Haisch C., Niessner R. (2002) “Light and sound — photoacoustic spectroscopy”. *Spectrposc. Eur.* **14**(5), 10–15.

Thank you for your attention!