Problem 13.

Sound

The problem

Measure the speed of sound in liquids using light.

Overview

- Basic explanation and measurement principle
- Advanced theory
- Apparatus
- Measurements and comparison

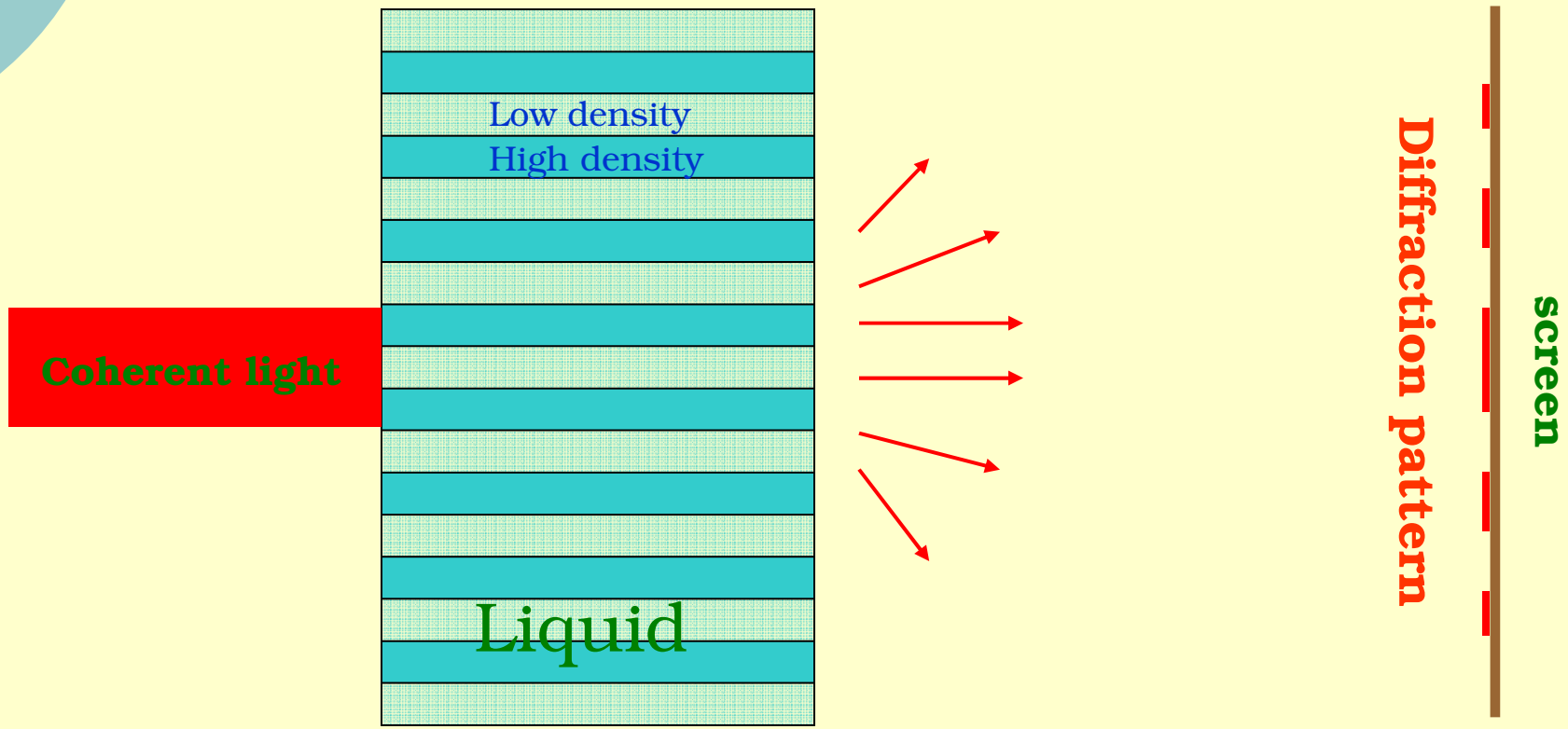
Basic explanation

- Small wavelength compressional standing waves in liquid
- Variation in density – variation of refraction index
- Diffraction of light on waves
- Diffraction pattern – acoustic wavelength measurement
- If frequency is known, sound velocity obtained

Basic explanation cont.

- **Simplest model:**

wave system = diffraction grating



Basic explanation cont.

- **Acoustical wavelength – grating spacing**
- **On a far screen:**

$$\Lambda \frac{z}{L} = m\lambda$$

Λ – acoustic wavelength
z – vertical coordinate on screen
L – distance liquid – screen
m – diffraction order
λ – light wavelength

- **Sound velocity if frequency is known:**

$$c = \Lambda \nu$$

Λ – acoustic wavelength
ν – frequency

Basic explanation cont.

⇒ **If light wavelength, sound frequency and interference peaks are known, sound velocity follows!**

$$c = \frac{L}{z} m \nu \lambda$$

z – vertical coordinate on screen
L – distance liquid – screen
m – diffraction order
λ – light wavelength
ν – frequency

- measurement principle

Advanced modeling

- **True explanation – sinusoidal refraction index diffraction pattern**
- **Phase shift of ray passing through liquid:**

$$\Delta\phi_0 = kDn(\varsigma)$$

k – wavenumber
D – length of path through liquid
n – refraction index
ζ – vertical coordinate in liquid

- **To first approximation – refraction index linear to liquid density**

Advanced modeling

⇒ **refraction index at amplitude moment:**

$$n(\varsigma) = n_0 + A_n \cos\frac{2\pi}{\Lambda}\varsigma$$

n_0 – equilibrium index
A_n – index amplitude
Λ – acoustic wavelength

- **Pattern on screen:**

$$I(z) = I_0\left[\int_{-R}^{+R} \sin(\omega t - \Delta\phi_0(r) - kr)dr\right]^2$$

I – intensity on screen
I_0 – initial light intensity
ω – light circular frequency

$\Delta\varphi_0$ – phase shift after passing through liquid
r – distance to screen point
R – snop radius

Advanced modeling

- **Numerical integration:**

Measuring

- Two liquids:
  - Xylene (C_8H_{10})
  - Carbon sulphide (CS_2)
- Patterns for several laser amplitudes
- Peaks distance measurement
- Repeated measurements – error calculation
- Time – average intensity distributions

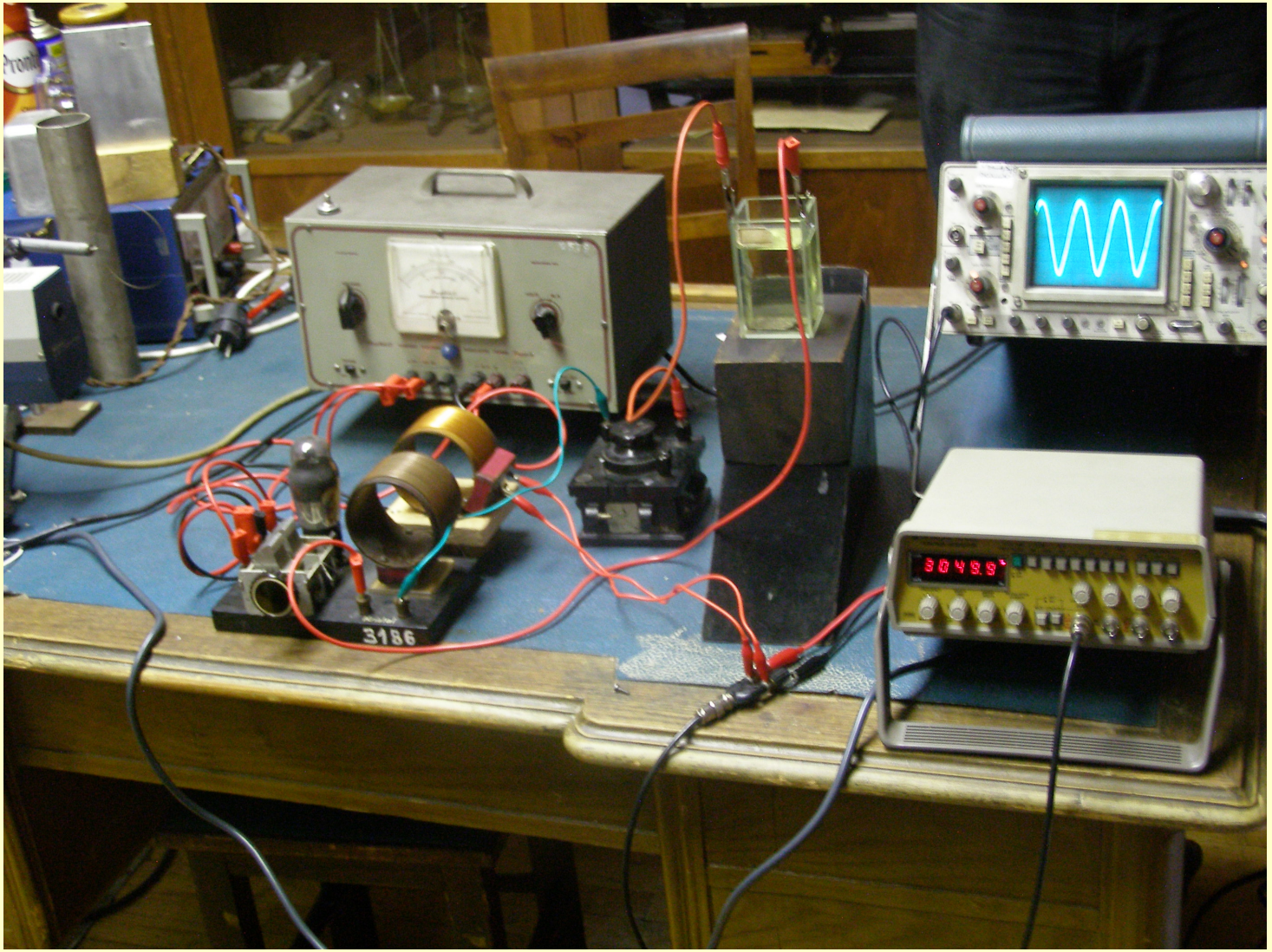
Apparatus

- **Laser (red, 633 nm)**
- **Liquid vessel with wave source (silicon piezoplate):**

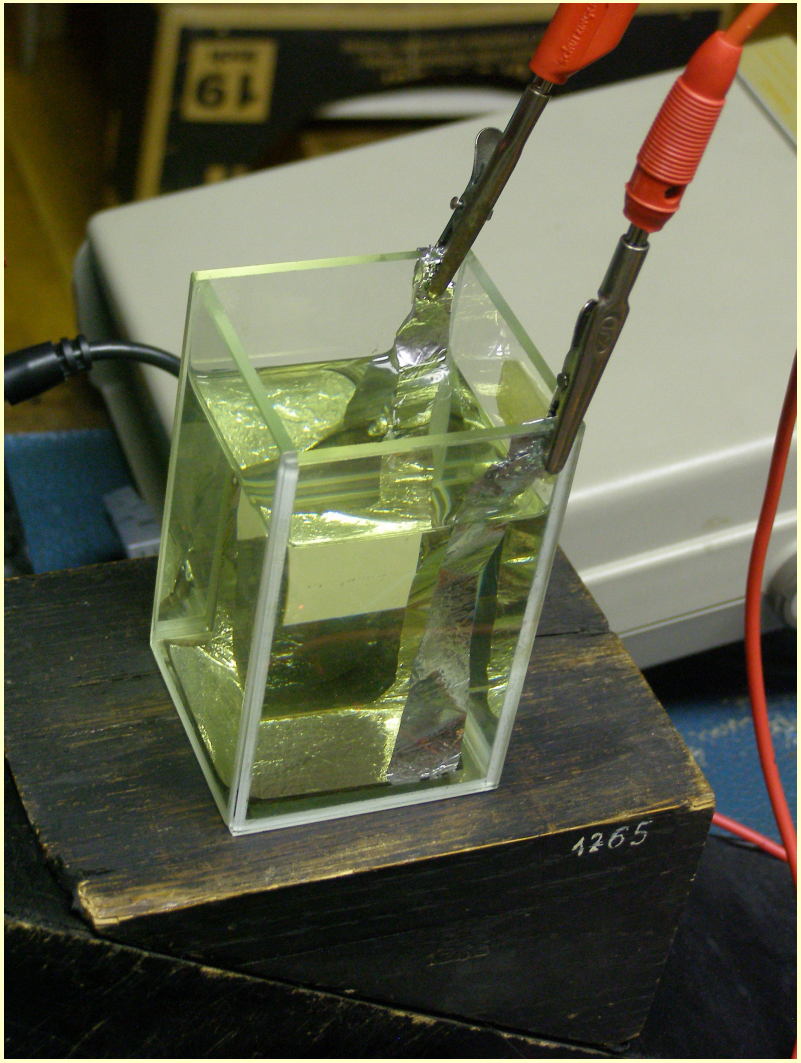
Plate length/width	5 cm
Plate thickness	0.13 cm
Vessel length/width	6.2 cm
Vessel height	10.3 cm

- **Screen (distance from vessel 3.85 m)**
- **Oscillator – Hartley circuit**
- **Frequency counter, oscilloscope**

Apparatus cont.



Apparatus cont.



Vessel



Piezoplate

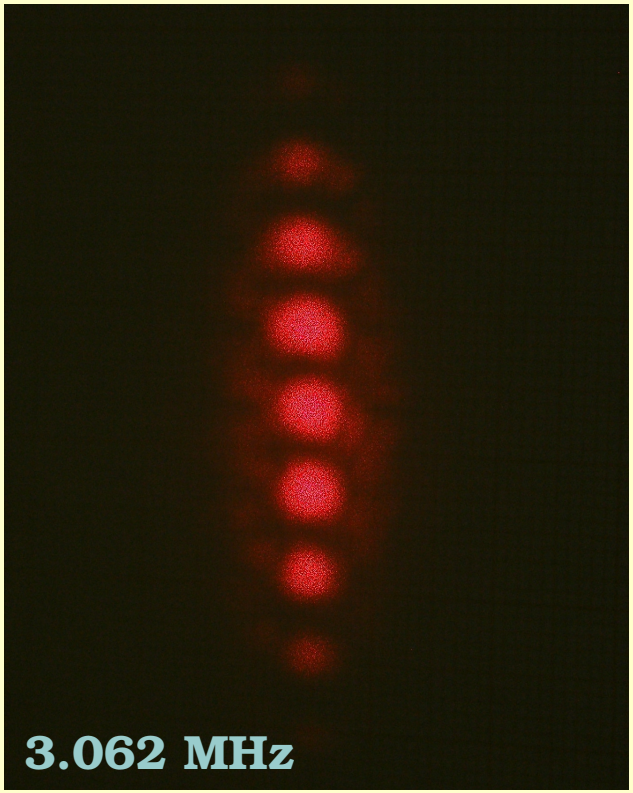
Apparatus cont.

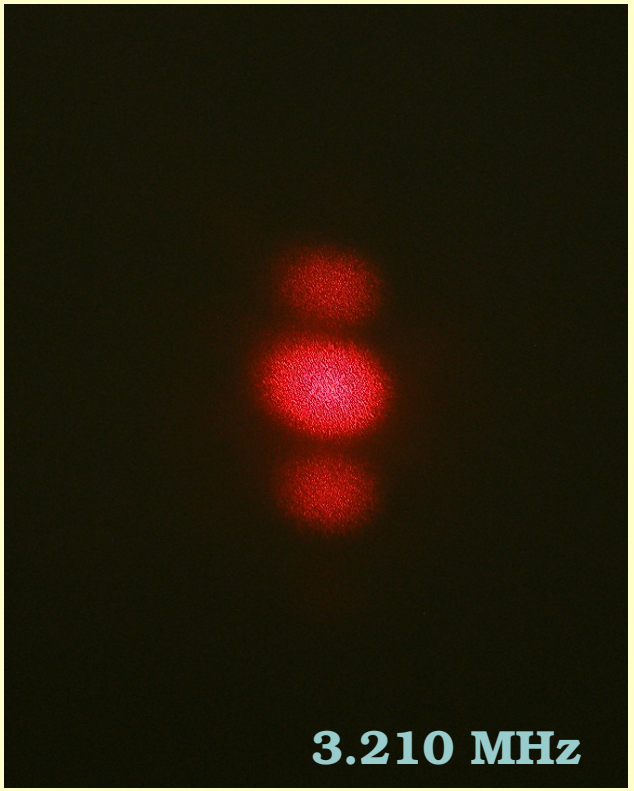
(oscilator)

Results and comparison

- **Obtained pattern samples:**

Xylene **CS_2**





Results and comparison cont.

- **Measured sound velocities (at 20°C):**

Xylene

Measured value [m/s]	1300±50
Literature value [m/s]	1330

CS_2

Measured value [m/s]	1170±60
Literature value [m/s]	1158

Results and comparison cont.

- **Intensity distribution (twodimensional):**

Conclusion

- Base of measurement technique – diffraction of light on ultrasound
- Diffraction pattern – furnishes acoustical wavelength
- Sound velocities obtained with 5% precision – relatively accurate method
- Sinusoidal grating model reliable theory