Part 1

Point 1-1

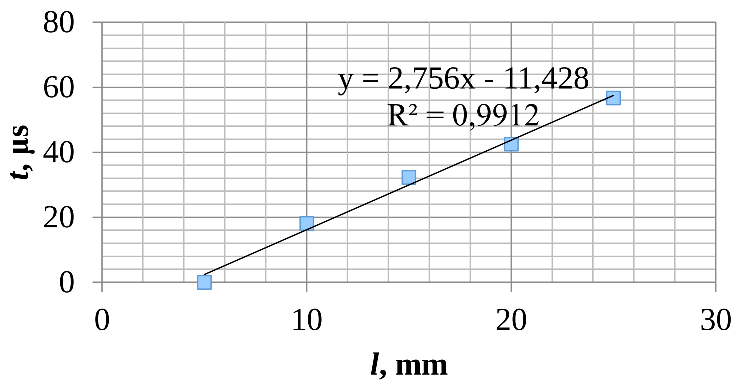
Frequency:	**Total: 2,5**
$$\nu = 25{,}2\ kHz$$	**0,5** – dimensions **0,5** – correct number of significant figures **1,5** – result ±0,1 –0,5, if ±0,2

Point 1-2

Measurements and processing:

L, mm	*T*, μs
5	0
10	18,10
15	32,26
20	42,50
25	56,70

Gradient of the line $k = 2{,}8 \pm 0{,}2\,\frac{\mu s}{mm}$, whence $\lambda = \frac{T}{k} = \frac{1}{k\nu}$.



Wavelength:
1,42 ± 0,08 cm

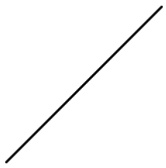
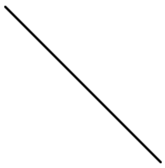
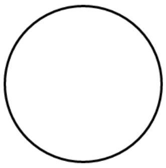
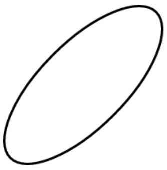
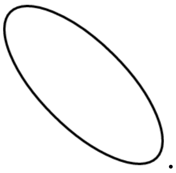
Total: 7,0
Measurements:
2,5 – 5 and more points
If the graph is used:
0,5 –scale
0,5 – labeled axis
1,5 – points are plotted
0,5 – error bars
Otherwise 5,5 marks for a method using 5+ points.

1,0 – the correct formula for the wavelength
0,5 – the answer

Point 1-3

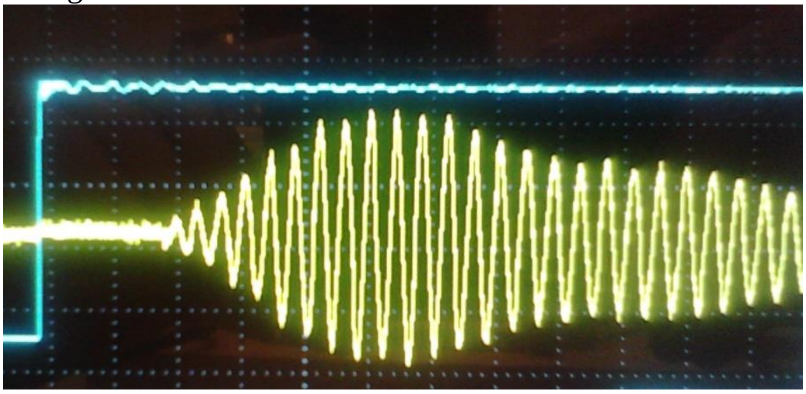
Formula for calculation: $$\nu = \frac{c}{\lambda} = \frac{1}{k}$$	**Total: 3,0** **1,0** – Formula for calculation **0,5** – dimensions **1,0** – the answer in the range [330; 390] m/s 0,5 for the answer in the range [320; 400] m/s **0,5** – the error of the answer is calculated
The velocity of the sound in air: 357 ± 25 m/s	

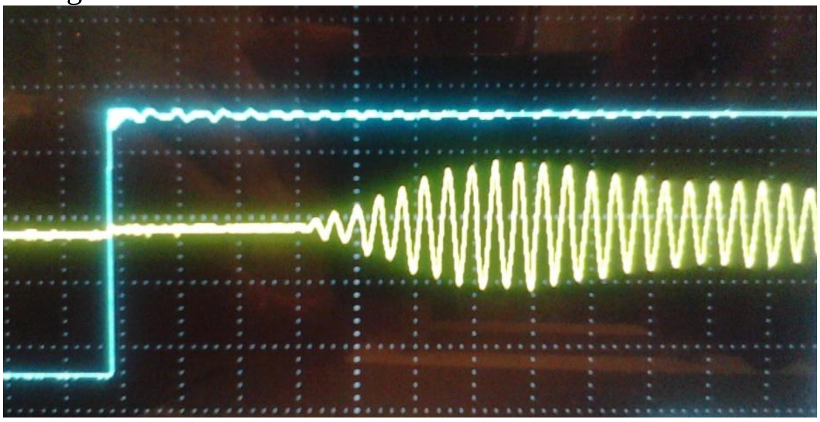
Point 1-5

The type of the oscillogram					**Total: 5,0** **0,5(*5)** for each correct diagram **0,5(*5)** for a correct phase difference (even if only one is given)
1. 	2. 	3. 	4. 	5 	
Phase difference					
1. 0	2. π	3. $\frac{\pi}{2}, \frac{3\pi}{2}$	4. $0 < \varphi < \frac{\pi}{2}$ $\frac{3\pi}{2} < \varphi < 2\pi$	5. $\frac{\pi}{2} < \varphi < \pi,$ $\pi < \varphi < \frac{3\pi}{2}$	

Part 2

Point 2-1

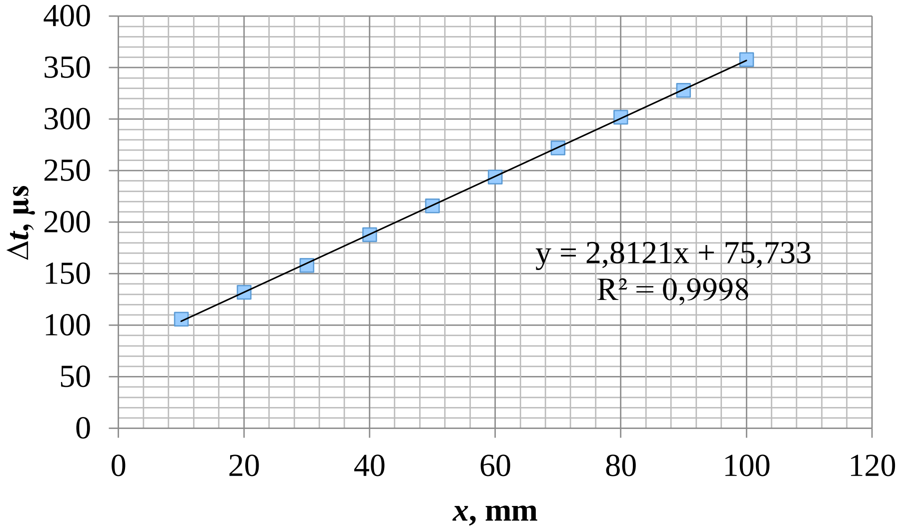
<table>
<tr><td>Oscillogram of the receiver at the distance of 5 cm from the source
</td><td rowspan="2">Total: 2,0

0,5 (*2) for each oscillogram
0,5 if can be seen that the delay has grown
0,5 if can be seen that the amplitude has decreased</td></tr>
<tr><td>Oscillogram of the receiver at the distance of 10 cm from the source
</td></tr>
</table>

Point 2-2

Measurements:

x, mm	Δt, µs
100	358
90	328
80	302
70	272
60	244
50	216
40	188
30	158
20	132
10	106



The value of the sound velocity:

$$333 \pm 27\ \frac{m}{s}$$

The value of the proper time delay:

$$75 \pm 5\ \mu s$$

Total: 9,0

2,5 – for measurements at 7+ points

0,5 – scale

0,5 – labeled axis

1,5 – points are plotted

0,5 – error bars

0,5 – dimension of the velocity

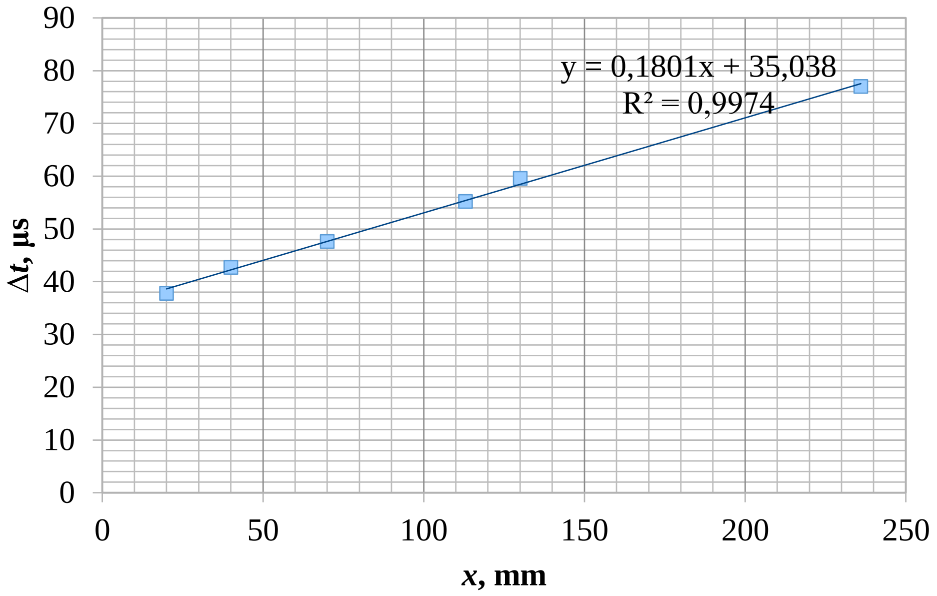
1,0 – if in the range of [310; 350] m/s

0,5 – if in the range of [290; 370] m/s

1,0 – determination of the delay time [70; 80] µs

0,5*2 – the error of each answer is calculated (v and ΔT)

Point 2-3

<table>
<tr>
<td>
Measurements:
<table>
<tr><th>l, mm</th><th>t, μs</th></tr>
<tr><td>236</td><td>77,2</td></tr>
<tr><td>130</td><td>61,8</td></tr>
<tr><td>113</td><td>55,4</td></tr>
<tr><td>70</td><td>47,6</td></tr>
<tr><td>40</td><td>42,2</td></tr>
</table>


</td>
<td>
Total: 8,0
0,5 for each point (no more than 2,5 marks)

0,5 – scale
0,5 – labeled axis
1,5 – points are plotted
0,5 – error bars
</td>
</tr>
<tr>
<td>
The value of the sound velocity:

$$5500 \pm 380\ \frac{m}{s}$$
</td>
<td>
0,5 – dimensions
0,5 – the answer in the range of [5100; 5900] m/s
0,5 – the error of the answer is calculated
</td>
</tr>
<tr>
<td>
The value of the proper time delay:

$$34 \pm 2\ \mu s$$
</td>
<td>
0,5 – determination of the delay time [30; 38] μs

0,5 – the error of the answer is calculated
</td>
</tr>
</table>

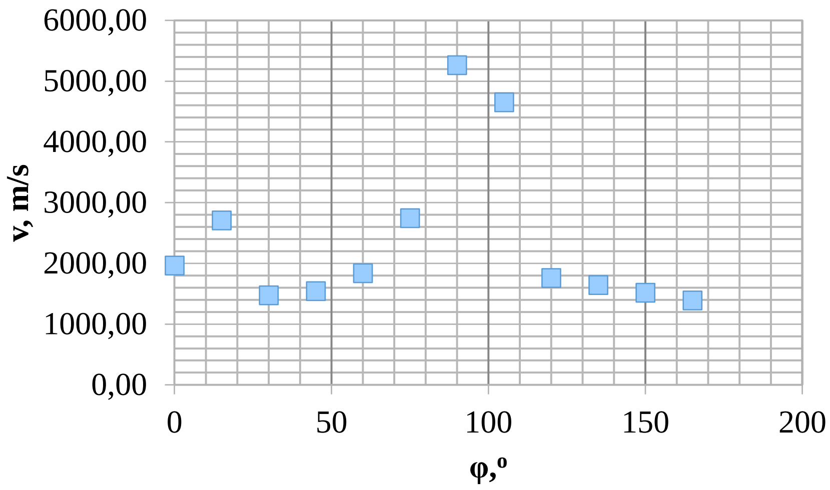
Point 2-4

The diameter of the sample:

$$100 \pm 1\ mm$$

Measurements:

φ,°	Δt, μs	v, m/s
0	86,0	1961
15	72,0	2703
30	103,0	1471
45	100,0	1538
60	89,5	1835
75	71,5	2740
90	54,0	5263
105	56,5	4651
120	92,0	1754
135	96,0	1639
150	101,0	1515
165	107,0	1389



Formula for calculation of the sound velocity:

$$v = \frac{D}{\Delta t - \Delta t_0}$$

Maximum sound velocity
5300 m/s

Minimum sound velocity
1200 m/s

The direction (select the correct answer):

- along the wood fibers

across the wood fibers

The direction (select the correct answer):

- along the wood fibers
- across the wood fibers

Total: 13,5

0,5 for the diameter in the range of [98; 102] mm

0,5 mark for each point but no more than **5**

1,0 for correct formula

1,0 for using the delay time for rules
(0,5 for each of two last points if the delay time wasn't considered)

0,5 – scale
0,5 – labeled axis
1,5 – points are plotted

0,5 – correct characteristic behavior (the presence of a peak at 75-105°, allow 1-2 «missing» points)

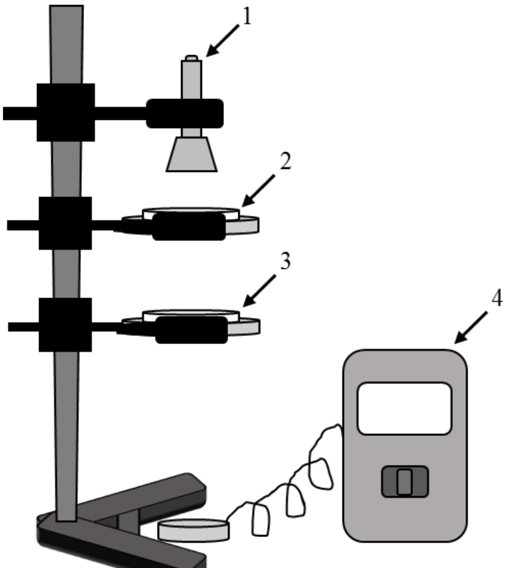
1,0 for v_{max} in the range of [4600; 5800] m/s

1,0 for v_{max} in the range of [1000; 1400] m/s

1,0 for correct directions

Part 3

Point 3-1

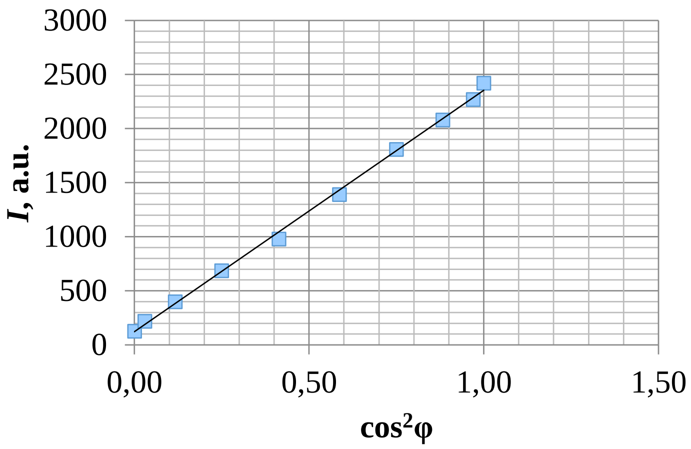


setup scheme:
1 – flashlight,
2 – linear polarizer,
3 – linear polarizer,
4 – luxmeter.

Total: 8,0
1,5 for correct experimental setup scheme

Measurements and processing:

φ,°	$\cos^2\varphi$	*I*, a.u.
0	1,00	2420
30	0,75	1810
60	0,25	687
90	0,00	129
110	0,12	399
140	0,59	1390
170	0,97	2270
200	0,88	2080
260	0,03	218
310	0,41	980



I_0 = 124 a.u.

2,5 for point
1,0 – correct linearization

0,5 -scale
0,5 – labeled axis
1,5 – points are plotted

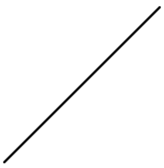
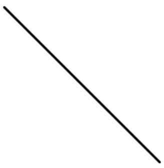
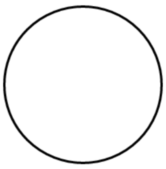
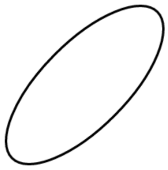
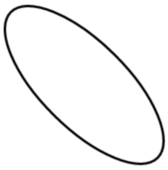
0,5 – the graph is linear

Point 3-2

I_{min} = 18 ± 3 a.u. I_{max} = 632 ± 3 a.u. $$P = \frac{I_{max} - I_{min}}{I_{max} + I_{min}} = 94{,}4 \pm 0{,}6$$	**Total: 2,0** **0,5** for each value of *I* **0,5** for determined P > 90% **0,5** – errors

Part 4

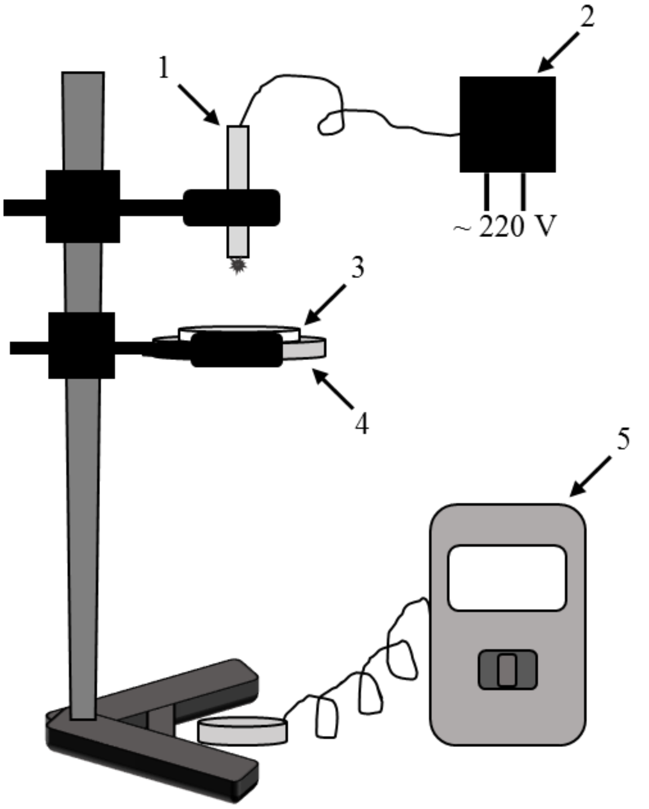
Point 4-1

The type of the oscillogram					**Total: 2,5**
1. 	2. 	3. 	4. 	5. 	**0,5(*5) 0,5(*5)** for each correct diagram+ corresponding correct phase difference (even if only one is given)
Phase difference					
1. 0	2. π	3. $\frac{\pi}{2}$, $\frac{3\pi}{2}$	4. $0 < \varphi < \frac{\pi}{2}$ $\frac{3\pi}{2} < \varphi < 2\pi$	5. $\frac{\pi}{2} < \varphi < \pi$, $\pi < \varphi < \frac{3\pi}{2}$	

Point 4-2

<table>
<tr>
<td>
The scheme of the experiment and a short text comment:

Experimental setup:
1 – laser
2 – power supply
3 – circular polarizer
4 – stand
5 – luxmeter



If the Linear polarizer (LP) is closer to the laser, then there exists an angle for which you get very small value of the intensity when the polarization of the laser beam and LP polarization plane (PP) are perpendicular. If the circular polarizer (CP) is closer to the laser, then such an angle doesn’t exist
</td>
<td rowspan="2">
Total: 5,0

3,5 – correct method (if an alternative method is proposed total mark is given)

0,5 for determination of the angle

1,0 for values in the range 40 ± 5
0,5 if the answer in the range 40 ± 10
</td>
</tr>
<tr>
<td>
The position of the polarization plane (PP) of the LP (in degrees on the scale of the CP holder) 40 ± 5. (Can be found by crossing LP and LP in CP: ((crystall–LP)–LP).
</td>
</tr>
</table>

Point 4-3

Minimum and maximum intensities (a.u.)				Total: 13,0
	Red	Green	Violet	(0,5*2)*3=**3,0** For finding maxima and minima
Maximum	1026	56	92	
Minimum	410	45	39	Dependence for the red laser:

Measurements for the red laser:

φ,°	$(I - I_0)$, a.u.	I/I_{max}
0	960	0,936
10	909	0,886
20	799	0,779
30	734	0,715
40	616	0,600
50	520	0,507
60	463	0,451
70	425	0,414
80	410	0,400
90	440	0,423
100	476	0,464
110	568	0,554
120	660	0,643
130	741	0,722
140	822	0,801
150	905	0,882
160	969	0,944
170	980	0,955
180	962	0,938

2,5 – 20+ points
1,5 – 15+ points
0,5 – 5+ points
(if measured for n points and is mentioned, the values for the symmetrical points are the same, marks are given for 2n points)

1,0 – normalized to I_{max}

1,0 – points are plotted on the graph

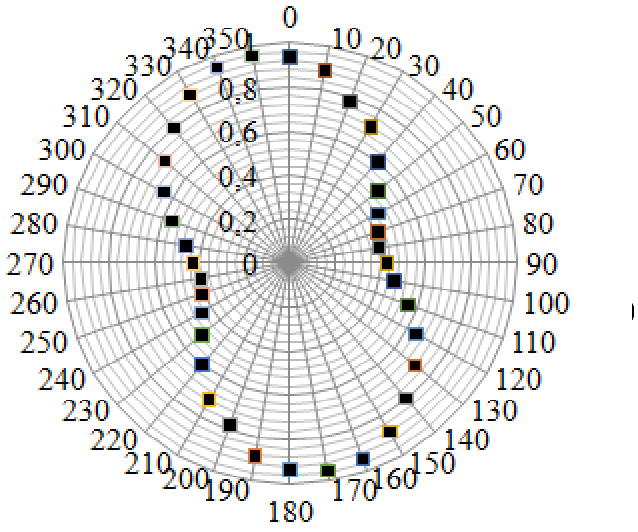
0,5 – the correct characteristic shape of the graph («bob»)

The dependence for the violet laser is marked similar to the criteria of the red laser

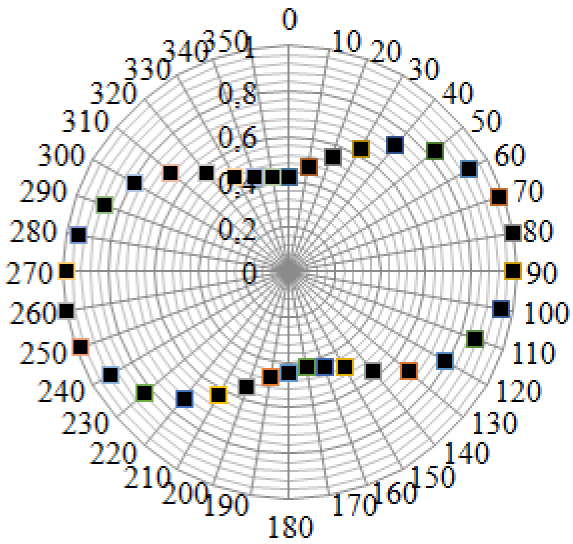
Measurements for violet laser:

φ,°	$(I - I_0)$, a.u.	I/I_{max}
0	39	0,424
10	43	0,467
20	50	0,543
30	58	0,630
40	67	0,728
50	77	0,837
60	84	0,913
70	90	0,978
80	92	1,000
90	91	0,989
100	87	0,946
110	80	0,870
120	73	0,793
130	63	0,685
140	53	0,576
150	45	0,489
160	41	0,446
170	39	0,424
180	41	0,446

laser color: Red



Laser color: Violet



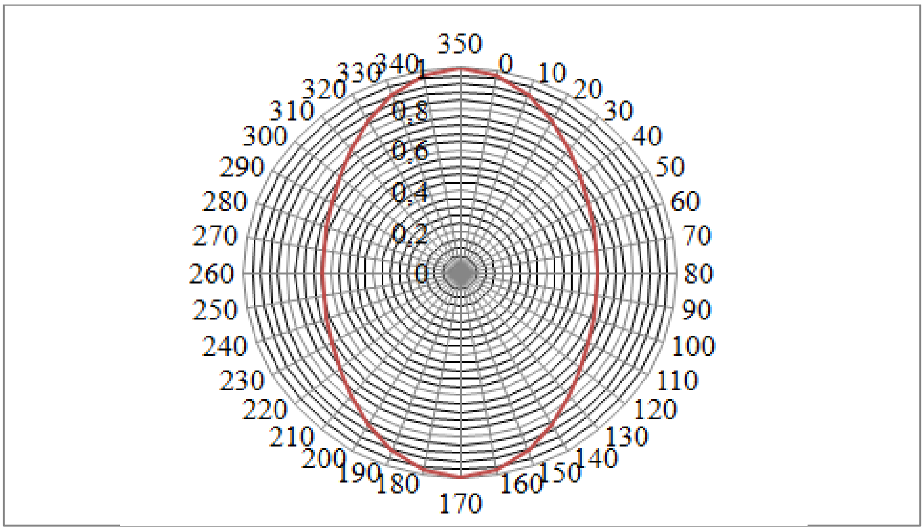
Point 4-4

Derivation of the formula: Let α – be the angle between CP and LP in CP (equal to 45^o). Then if after LP in CP the amplitude of the wave is A, then the amplitudes of ordinary and extraordinary waves are equal to $A\cos(\alpha)$ and $A\sin(\alpha)$ correspondingly During the passage the amplitudes do not change (we ignore this effect) and the ordinary and extraordinary waves differ only by a phase shift of δ. This waves pass through the LP and we get for the amplitudes of ordinary and extraordinary waves $A\sin(\alpha)\sin(\alpha+\varphi)$ and $A\cos(\alpha)\cos(\alpha+\varphi)$ correspondingly. $I \sim A^2$. Taking into account the interference of the waves which passed through the polarizer we get (by inserting α = 45^o): $$I = C\big(\cos^2(\beta)+\sin^2(\beta)+2\cos(\beta)\sin(\beta)\cos(\delta)\big),$$ where β = φ + α. From the latter we obtain $$I = C\left(1+\cos(\delta)\sin\left(2\left(\frac{\pi}{4}+\varphi\right)\right)\right) = I_0\big(1+\cos(\delta)\cos(2\varphi)\big).$$	**Total: 5,0** **1,0*2** for expressions for the intensities I_1 and I_2 or for correspdoning amplitudes **3,0 f**or derivation of the final formula (–1,0 mark for incorrect angle in the formula) Any alternative derivation giving the correct final formula is given a total mark

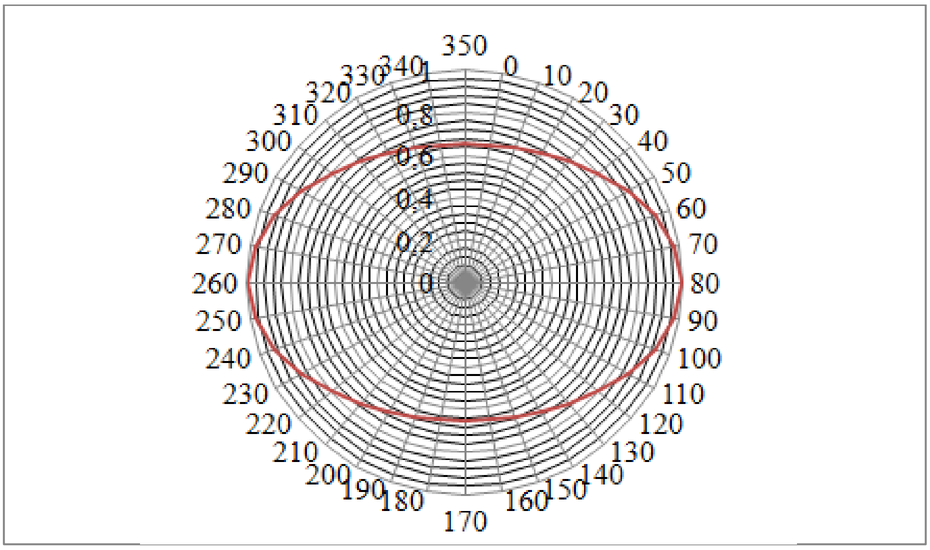
Point 4-5

Since the intensity is proportional to the square of the amplitude we have $\frac{E_{max}}{E_{min}} = \sqrt{\frac{I_{max}}{I_{min}}}$. From this knowing the ratio of maximum and minimum intensities from Point 4-3 for each of the laser we can obtain the ratio of the ellipse semiaxis. Also from the measurements in point 4-3 know the orientation of the ellipse relative to polarization plane of LP in CP. This allows to sketch the ellipses.	**Total: 3,5** **0,5** for derivation of the formula 1*3=**3,0** for points plotted on 3 graphs: –0,5 for correct orientation of the semiaxis –0,5 for correct ratio of the semiaxis

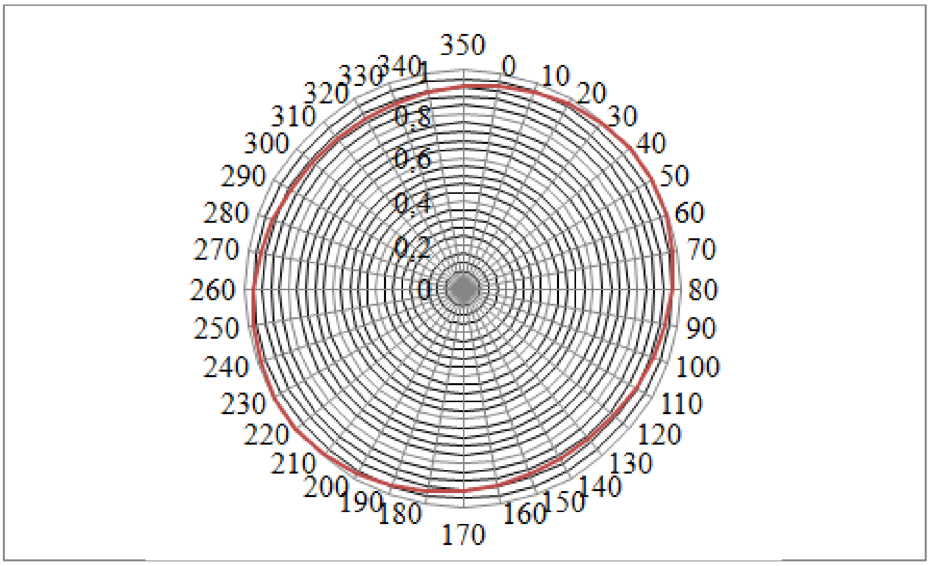
The color of the laser: red



The color of the laser: violet



The color of the laser: Green



Point 4-6

<table>
<tr><td>
Formula:
From formula in point 4-3 it follows, that for $cos(\delta) > 0$ $(0 < \delta < \pi)$

$$\begin{cases} I_{max} = I_0(1 + cos\delta) \\ I_{min} = I_0(1 - cos\delta) \end{cases}$$

Then

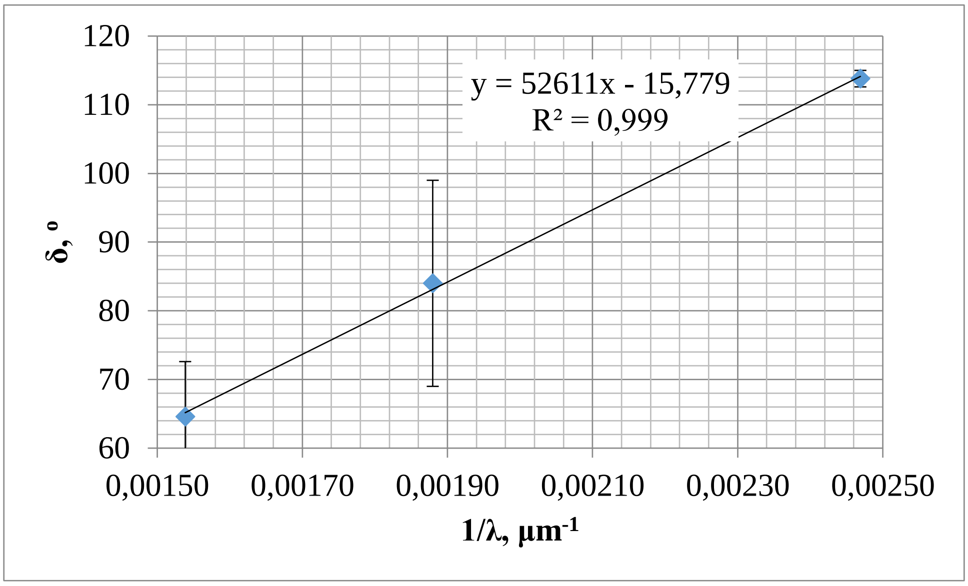
$$tan\frac{\delta}{2} = \sqrt{\frac{1 - cos\delta}{1 + cos\delta}}$$

From which we get
$\delta = 2tan^{-1}\sqrt{\frac{I_{min}}{I_{max}}}$.
At $cos(\delta) < 0$ I_{max} and I_{min} interchange and the required
$\delta = \pi - 2tan^{-1}\sqrt{\frac{I_{min}}{I_{max}}}$. (this takes place for violet color).

Draw a graph δ(1/λ), taking into account that point for the green color isn’r very reliable because of the instability of the intensity of the laser:
</td>
<td>
Total: 11
2,0 for pointing then maximum and minimum
2,0 for any mentioning of using the supplementary angle for violet color
1,5 – the table

0,5 – scale
0,5 – labeled axis
1,5 – points are plotted
0,5 – error bars
</td></tr>
<tr><td>

λ, μm	1/λ, μm^{-1}	δ,°	Δδ,°
405	0,00247	113,8	1,2
532	0,00188	84	15
650	0,00154	64,6	8



</td><td></td></tr>
</table>

Wavelength: Getting from the graph the value for the $\delta = 90^o$, we obtain the required wavelength: $\lambda = 497 \pm 18$ nm.	**2,0** – the answer in the range of [450; 550] nm 1,0 – the answer in the range of [400; 600] nm **0,5** – error is calculated

Total: 100