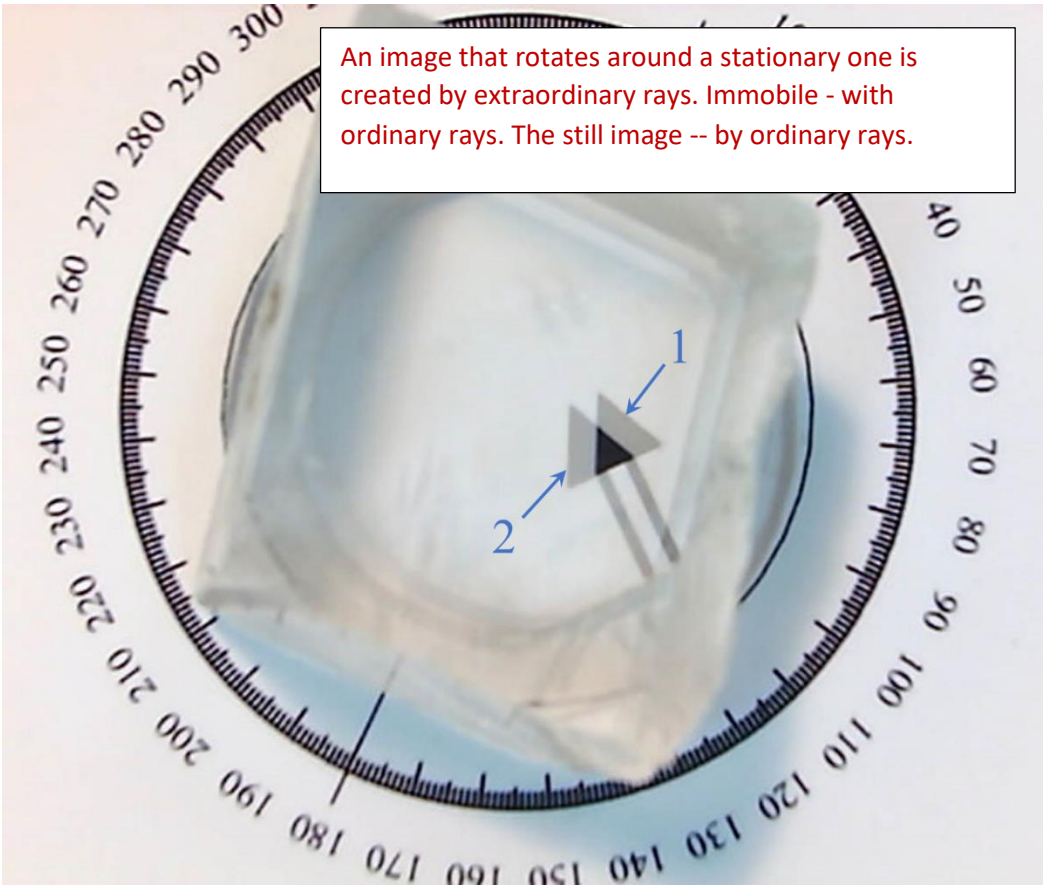
Answer Sheet

Question 1.

Which of the images (1 and 2) is formed by ordinary rays, and which by extraordinary?



Answer 1

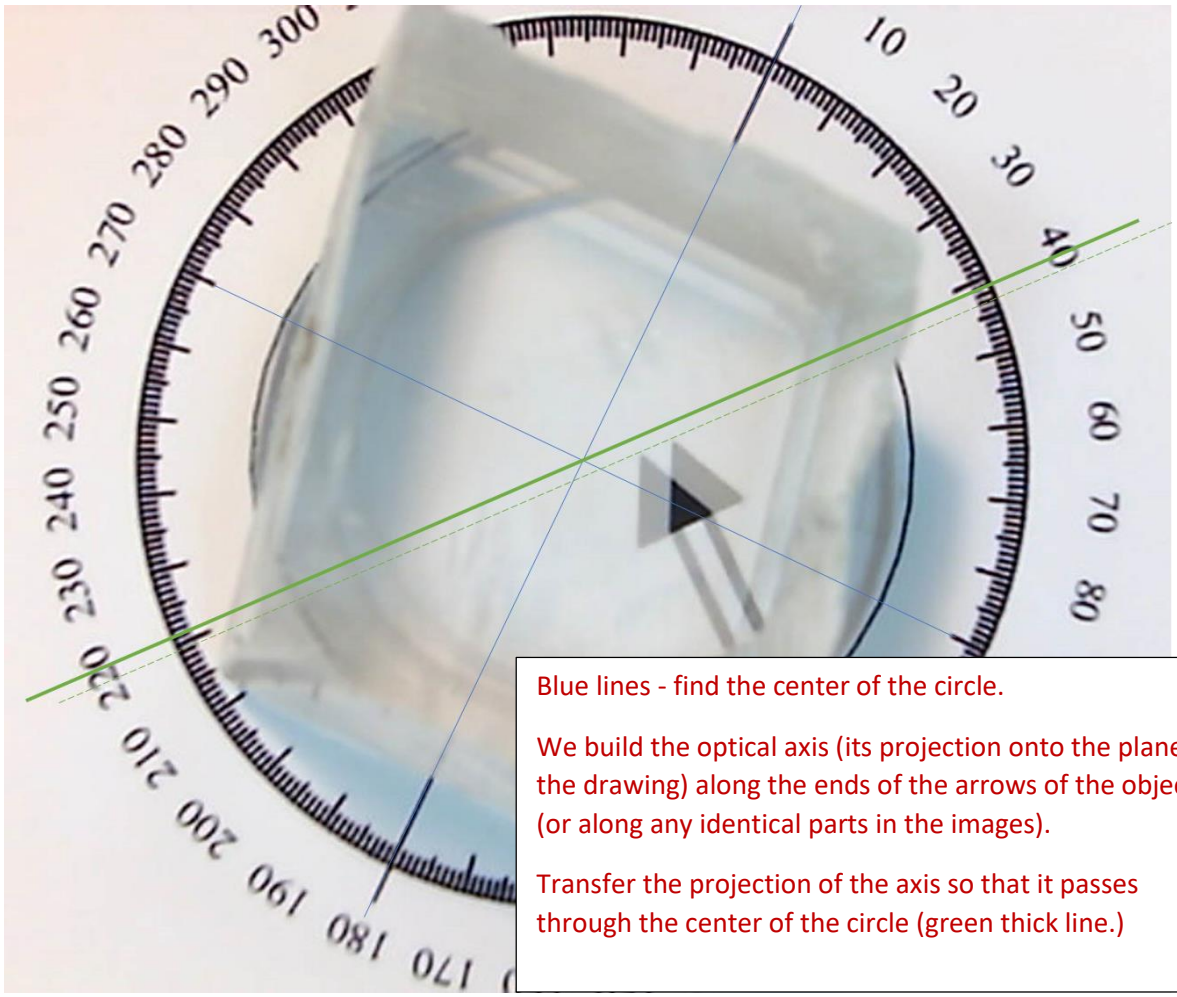
Ordinary 2

Extraordinary 1

Question 2.

In the figure draw the direction of projection of the optical axis of the crystal onto the horizontal plane. Draw this line through the center of the circle of the protractor. Write down the angles that this line crosses on the protractor scale.

Answer 2



Blue lines - find the center of the circle.

We build the optical axis (its projection onto the plane of the drawing) along the ends of the arrows of the object (or along any identical parts in the images).

Transfer the projection of the axis so that it passes through the center of the circle (green thick line.)

Angles: ___ 41 ___ and ___ 221 ___

±2 degrees. The main thing is that the sum is 180 deg (**179-181**)

Question 3.

What of the images of the object is deeper, which is formed by ordinary rays, or which is formed by extraordinary rays?

Answer 3

The image formed by ___ Extraordinary ___ rays is deeper.

$n_e < n_o$ – crystal is negative. And you can see from the video.

Question 4.

Q.4 a)

What property of the smartphone screen is associated with "switching" between images? Give your answer in English.

Answer 4 a) Smartphone screen **light is polarized**

Q 4 b)

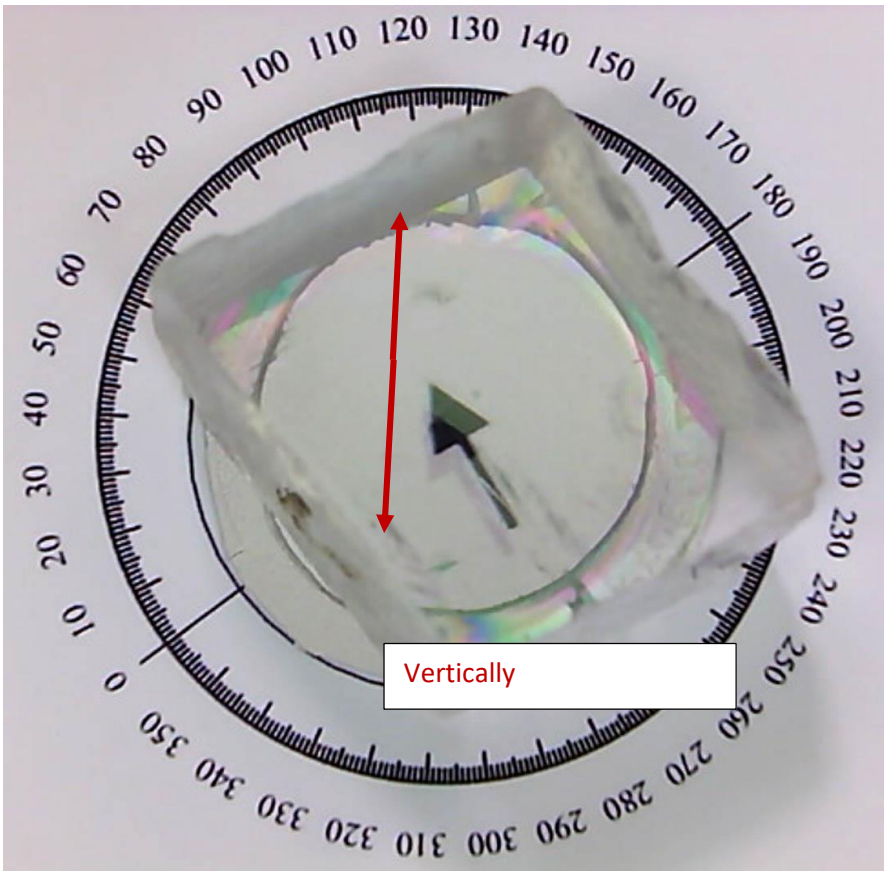
What characteristic of this property can you determine? Give your answer in English.

Answer 4 b) Polarization direction. **Polarization plane.**

Q 4 c)

Is it possible to depict this characteristic in the figure? And if possible, draw it.

Answer 4 c) Yes



Question 5.

Why does illumination of the screen disappear at a certain angular position of the Analyzer? Write down a short answer in English.

Answer 5 _____

The laser **light is POLARIZED**.

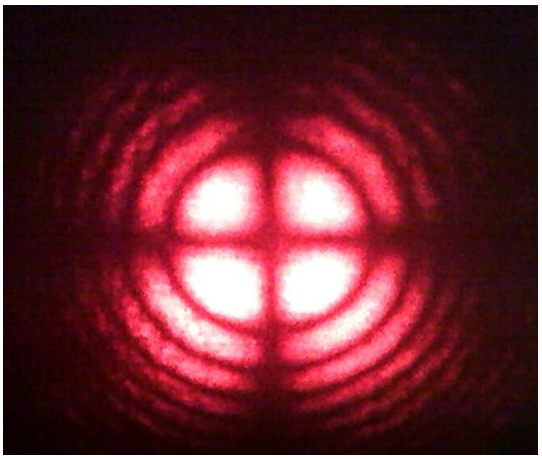
Polarized LINEARLY and vertically.

Question 6.

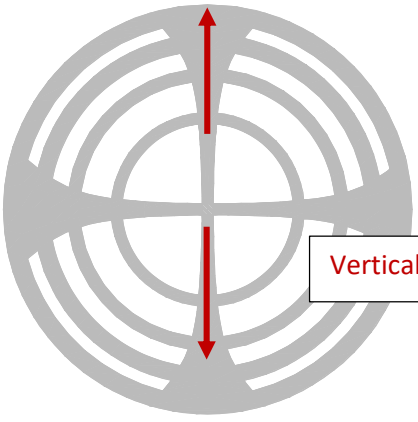
Q.6 a)

What is the polarization of the light before the analyzer on the vertical stripe of the dark cross? Draw the direction in the picture.

Answer 6 a)



Draw the direction here



Q 6 b)

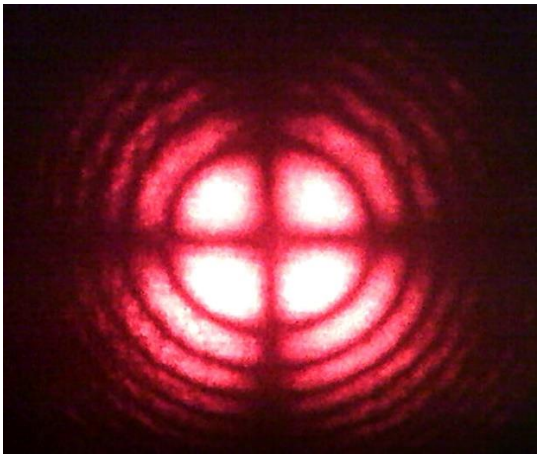
What rays inside the crystal, ordinary or extraordinary, form the vertical dark stripe?

Answer 6 b) Extraordinary

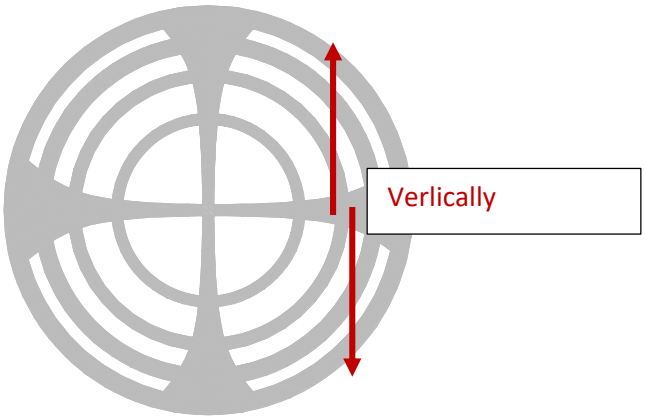
Q.6 c)

What is the polarization of the light before the analyzer on the horizontal stripe of the dark cross? Draw the direction in the picture.

Answer 6 c)



Draw the direction here



Q.6 d)

What rays inside the crystal, ordinary or extraordinary, form the horizontal dark stripe?

Answer 6 d) _____

Q.6 e)

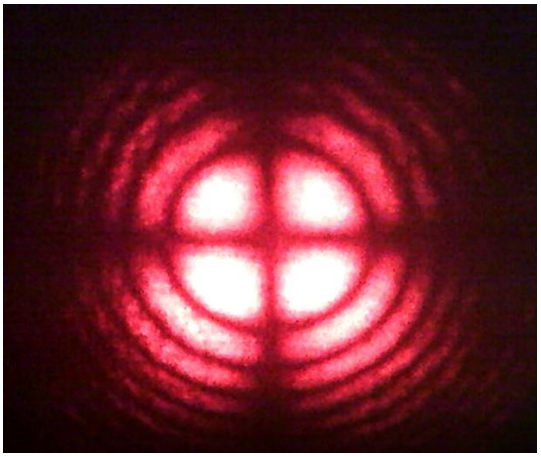
What is the polarization of light at most points in bright areas? Write your answer in a few words in English.

Answer 6 e) Elliptical

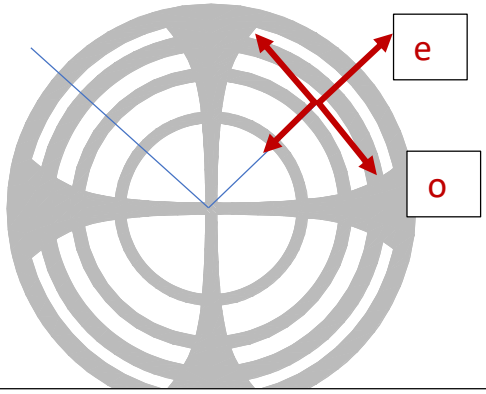
Q.6 f)

In which direction is the polarization of the ordinary and extraordinary rays directed at a point that lies on the bisector of the angle between the dark stripes of the cross? Draw in the picture.

Answer 6 f)



Draw the directions here.
Mark the direction for ordinary as «o», and for extraordinary as «e».



In any quadrant: e - radial, o - tangential

Question 7.

Q.7 a)

Write down the formula linking the number of the ring N, measured from the center of the picture, with the wavelength of light λ corresponding to the color of the ring, and with the optical path difference l of the ordinary and extraordinary rays falling into a certain point of the ring.

Answer 7 a) $N = l/\lambda$

Q.7 b)

Using formulas and inequalities, write a short explanation of why the red ring of some number N is larger in diameter than the blue or green ring of the same number. When answering this question, disregard the phenomenon of dispersion.

Answer 7 b) $\lambda_{red} > \lambda_{blue,\ green}$

Question 8.

At what angle you should rotate a half-wave plate to change the laser beam power from the maximum to the minimum value? Write down the answer in degrees.

Answer 8 45 deg

Question 9.

What is the peak power of the laser beam? Write down the answer in Watts.

Answer 9 120 kW

Question 10.

Q.10 a)

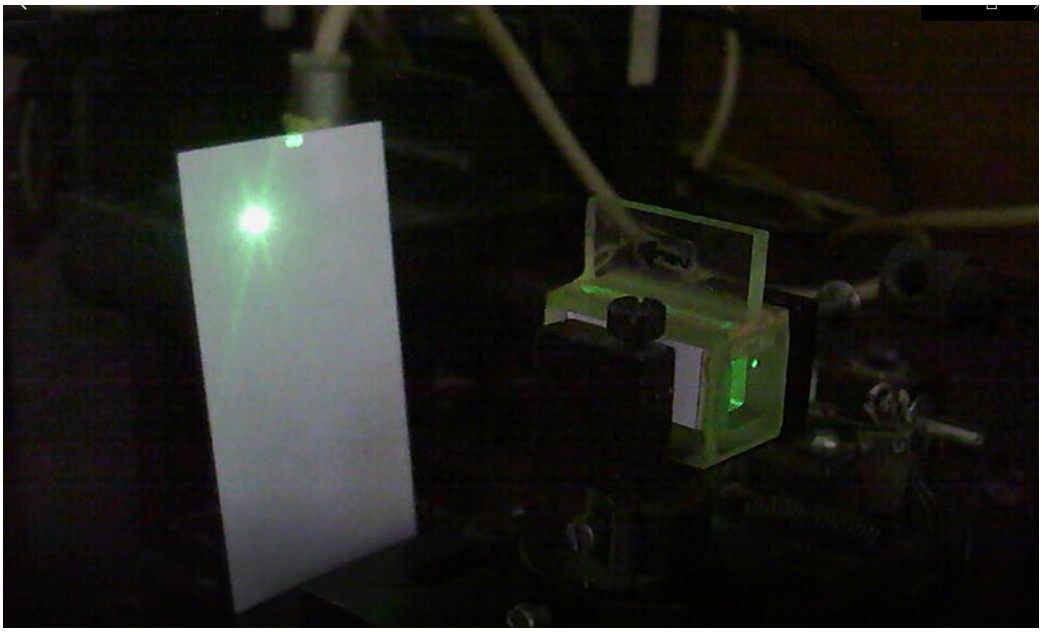
What is the second harmonic wavelength if the first harmonic wavelength is 1064 nm?

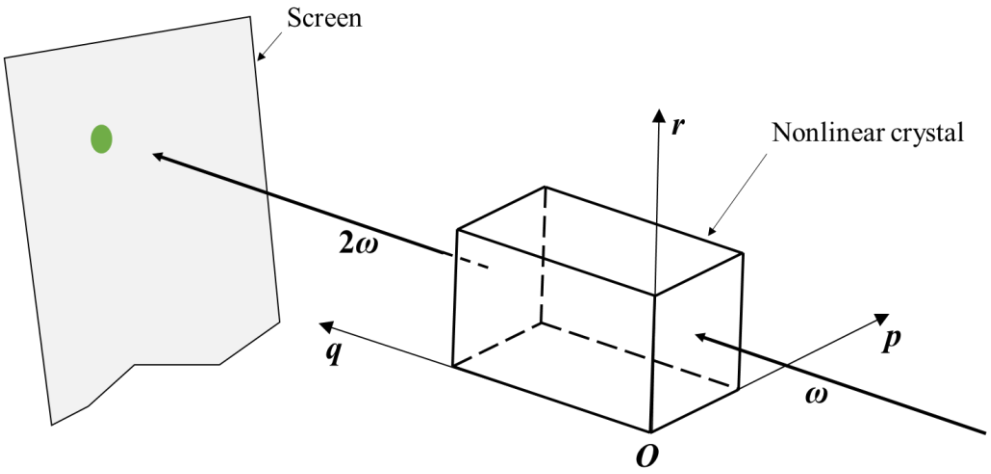
Answer 10 a) 532 нм $\frac{\lambda_1}{2} = \frac{1064}{2} = 532$ нм

Q.10 b)

In what plane does the optical axis of the crystal lie?

Answer 10 b) In horizontal plane, qOp, pOq, …

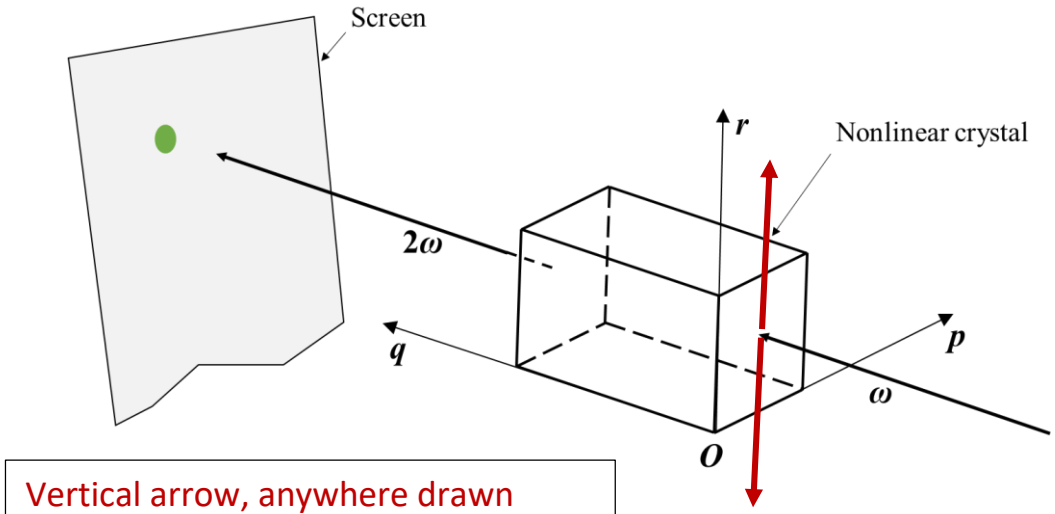




Q.10 c)

In what plane does the first harmonic polarization lie? In the figure, indicate the direction.

Answer 10 c) qOr, rOq

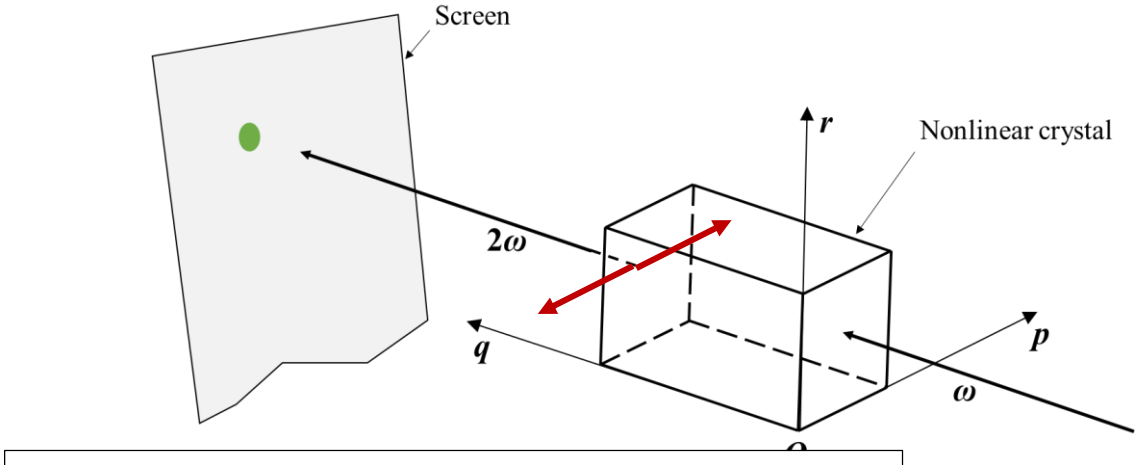


Vertical arrow, anywhere drawn

Q.10 d)

In what plane does the second harmonic polarization lie? In the figure, indicate the direction.

Answer 10 d) qOp, pOq



Horizontal arrow, anywhere drawn

Question 11.

Q.11 a)

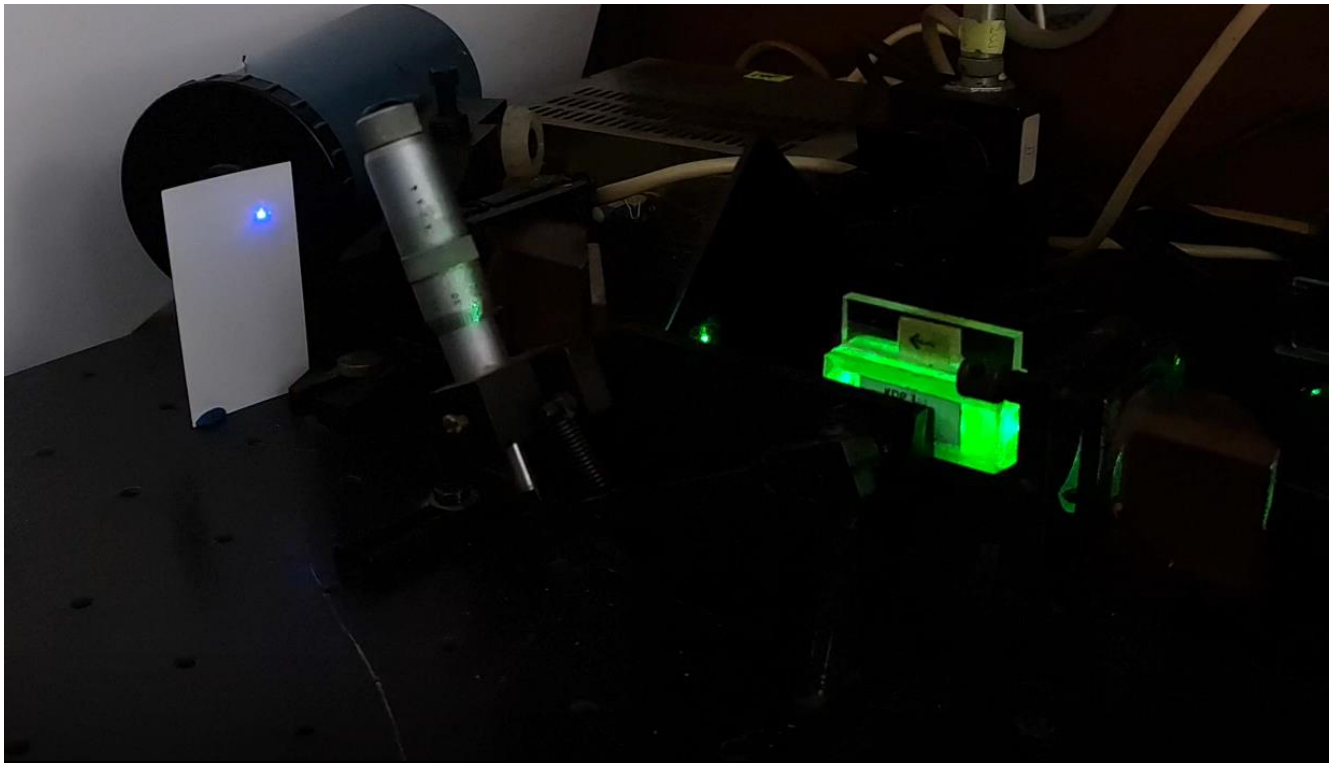
What is the wavelength of the third harmonic radiation?

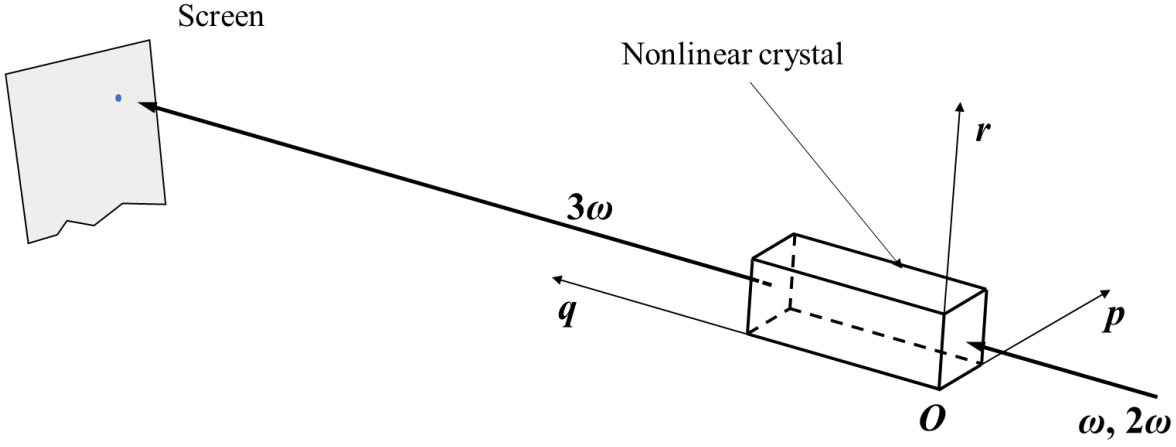
Answer 11 a) **354 - 355** nm $\frac{\lambda_1}{3} = \frac{1064}{3} = 354.666 \ldots$ нм

Q.11 b)

In what plane is the optical axis of this crystal?

Answer 11 b) In vertical, qOr, rOq

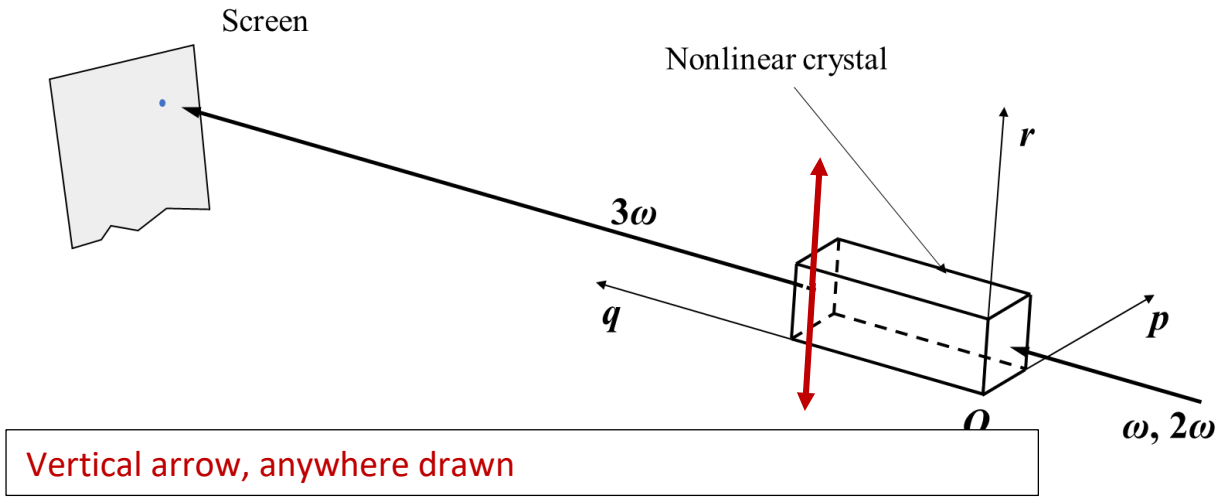




Q.11 c)

In what plane does the polarization of the third harmonic radiation lie? In the figure, indicate the direction.

Answer 11 c) In vertical , qOr, rOq



Vertical arrow, anywhere drawn

Q.11 d)

What wave, ordinary or extraordinary, is the radiation of the first harmonic for this crystal?

Answer 11 d) Extraordinary

Q.11 e)

What wave, ordinary or extraordinary, is the second harmonic radiation for this crystal?

Answer 11 e) Ordinary

Question 12.

The calculation must be done for all three KDP crystals of different lengths.

Q.12 a)

What is the maximum conversion efficiency to the second harmonic from the first for each of the crystals - 0.5 cm, 2.0 cm, and 4.0 cm? Write down the result as a percentage.

Answer 12 a)

KDP 0.5 cm — 0.107 %, ***0,09 - 0,11%*** - OK

KDP 2.0 cm — 1.51943 %, ***1,43 - 1,52%***- OK

KDP 4.0 cm — 2.787%, ***2,7 – 2,8%***- OK

The main thing is to count at maximum power. $\frac{P_{max}(2\omega)}{P_{max}(\omega)} \cdot 100\%$

Q.12 b)

Is it possible to apply the fixed field approximation for each of the KDP crystals of different lengths - 0.5 cm, 2.0 cm, and 4.0 cm?

Answer 12 b)

KDP 0.5 cm — Yes

KDP 2.0 cm — Yes

KDP 4.0 cm — Yes

For all crystals, conversion efficiency < 10%

Q.12 c)

To what function of the first harmonic power should be proportional the second harmonic power theoretically? Write down the formula.

Answer 12 c)

$P_{2\omega} \sim P_{\omega}^2$

$I_{2\omega} \sim I_{\omega}^2$

Quadratic dependence

Q.12 d)

The dependence of the second harmonic power on the first harmonic power can be expressed as follows, $I_{2\omega} = A \cdot I_{\omega}^{B}$.

From the experimental data, calculate the power *B* to which you need to raise the power of the first harmonic to get a result proportional to the power of the second harmonic. Also calculate the proportionality factor *A*.

Answer 12 d)

KDP 0.5 cm	$A =$	$10^{-9}...19^{-8}$	$B =$	1.993 ≈ 2
KDP 2.0 cm	$A =$	$10^{-8}...19^{-7}$	$B =$	2.0001 ≈ 2
KDP 4.0 cm	$A =$	$10^{-7}...19^{-6}$	$B =$	2.0185 ≈ 2

Plot dependencies in double logarithmic scale. Draw a line (i.e., reveal the slope) and calculate the degree. All degrees are about 2. Taking into account the inaccuracy of the plots. The values of the coefficients A are not so important. The order of magnitude is important. See Additional Forms 1.

Question 13.

Assuming that for the shortest KDP crystal, the incident wave of the first harmonic is a plane wave, calculate what width of angular phase matching should be obtained for KDP crystals 2 cm and 4 cm long. Write down the answer in milliradians.

Answer 13

$as\ \Delta\Theta_c \sim {}^{1}/_{L}$

KDP 2.0 cm	$\Delta\Theta_{pm} =$	3.75/4 ≈ 0.9375 mrad - ***0,93-0,94***
KDP 4.0 cm	$\Delta\Theta_{pm} =$	3.75/8 ≈ 0.46875 mrad - ***0, 46-0,47***

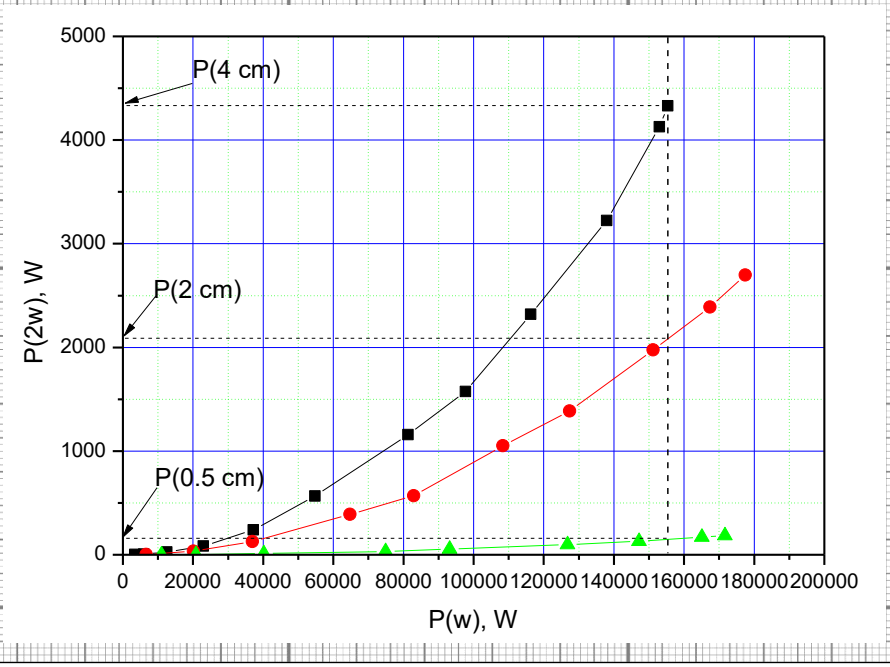
Question 14.

Q.14 a)

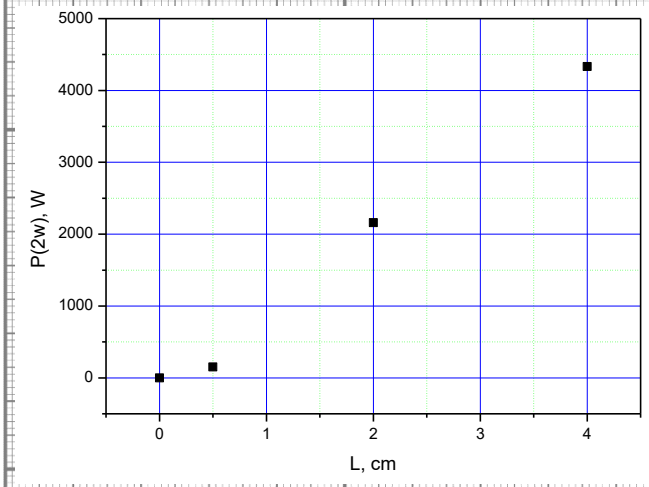
Using the experimental data on the dependence of the second harmonic power on the first harmonic power for all crystals, plot the dependence of the second harmonic power on the crystal length for the same maximum possible power of the first harmonic.

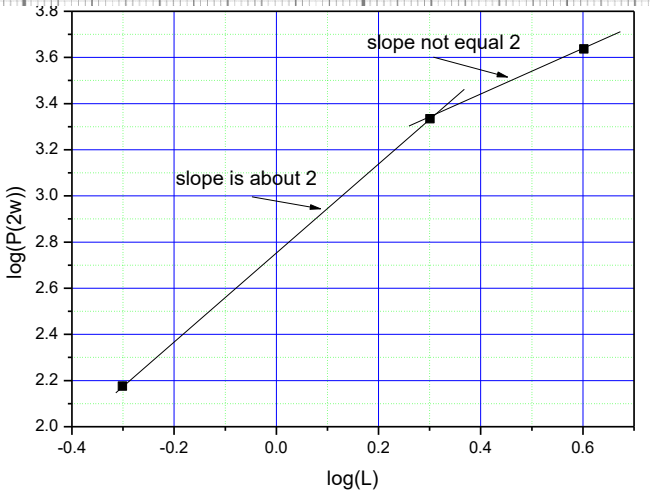
Answer 14 a)

You need to plot somewhere all three graphs P (2w) versus P (w). Understand that you need to take the power P (2w) with the same power and maximum possible power P (w).



Plot the dependence of P (w) on L. And it is best on a double logarithmic scale.





There is also a point (0, 0) on the linear scale. There are only three crystals (0.5, 2 and 4 cm), but nobody canceled zero. It can be seen that this is not a power dependence.

On a logarithmic scale (even if there is no zero point), it is obvious that this is not a power dependence.

Q.14 b)

Can this dependence of the second harmonic power on the crystal length be expressed in terms of a power function? If possible, indicate the degree.

Answer 14 b) No

From the previous logarithmic graph, you can see that it is impossible.

Q.14 c)

Briefly describe the reason why the experimental dependence of the second harmonic power on the crystal length differs from the theoretical one. Write down the answer in English.

Answer 14 c)

This is due to the laser **beam divergence**. The divergence width of the laser beam is comparable to the phase matching width for crystals of 2 and 4 cm. Therefore, not all of the beam energy is converted equally effectively into SH. Theory is for plane waves. The longer the crystal, the more it differs from theory.

Question 15.

Q.15 a)

What function of the power of the first harmonic should be proportional to the power of the third harmonic theoretically? Write down the formula.

Answer 15 a) $P_{3\omega} \sim P_{\omega}^{3}$ ***Cubic dependence***

Q.15 b)

What function of the second harmonic power should be proportional to the third harmonic power theoretically? Write down the formula.

Answer 15 b) $P_{3\omega} \sim P_{2\omega}^{3/2}$ ***Degree «one and a half»***

Q.15 c)

The dependence of the third harmonic power on the first harmonic power or the second harmonic power can be expressed as follows, $I_{3\omega} = A \cdot I_{\omega}^{B}$ or $I_{3\omega} = A \cdot I_{2\omega}^{B}$

From the experimental data, calculate the power *B* to which you need to raise the power of the first harmonic to get a result proportional to the power of the third harmonic. Also calculate the proportionality factor *A*.

Answer 15 c)

for $I_{3\omega} = A \cdot I_{\omega}^{B}$ $A =$ 10^{-10}... 10^{-9} $B =$ 2.38.. **2 < B < 3**

The main thing is that B is less than 3, but more than 2

Q.15 d)

From the experimental data, calculate the power B to which you need to raise the power of the second harmonic to get a result proportional to the power of the third harmonic. Also calculate the proportionality factor A.

The main thing is that B is less than 1.5, but more than 1

Answer 15 d)

for $I_{3\omega} = A \cdot I_{2\omega}^{B}$ $A =$ 10^{-2}...10^{-1} $B =$ 1.2.. **1 < B < 1.5**

Построить зависимости в двойном логарифмическом масштабе. Провести линию (т.е. выявить наклон) и вычислить степень. Учитывая неточность построений. Величины коэффициентов А не так важны. Важен порядок величины. См. дополнительные листы.

Q.15 e)

Briefly describe the reason why the experimental dependences of the third harmonic power on the first and second harmonics power do not coincide with the theoretical ones. Write down the answer in English.

Answer 15 e)

The video showed that when we remove the crystal for 3w, then a signal remains on the photodetector 3. When we close 3 FP, then the signal is less, when we open, then more. This means that either w or 2w radiation passes through the filter, which should be absorbed.

The filter transmits radiation of the fundamental and second harmonics.

Experimental data for second harmonic generation.

KDP 0.5 cm	
First harmonic Power, Watts	Second harmonic Power, Watts
11040	0.801
20850	2.517
40230	10.111
74900	32.14
93200	54.09
126800	97.89
147200	131.1
165100	169.7
171700	184.2

KDP 2.0 cm	
First harmonic Power, Watts	Second harmonic Power, Watts
6662	3.725
20170	35.31
36980	126.1
64740	390.2
82900	569
108400	1050
127400	1387
151200	1977
167400	2388
177500	2697

KDP 4.0 cm	
First harmonic Power, Watts	Second harmonic Power, Watts
3413	1.902
5990	5.867
12580	26.88
22940	84.08
37210	240.2
54780	565.9
81350	1157
97730	1574
116300	2319
138000	3224
153000	4127
155400	4331

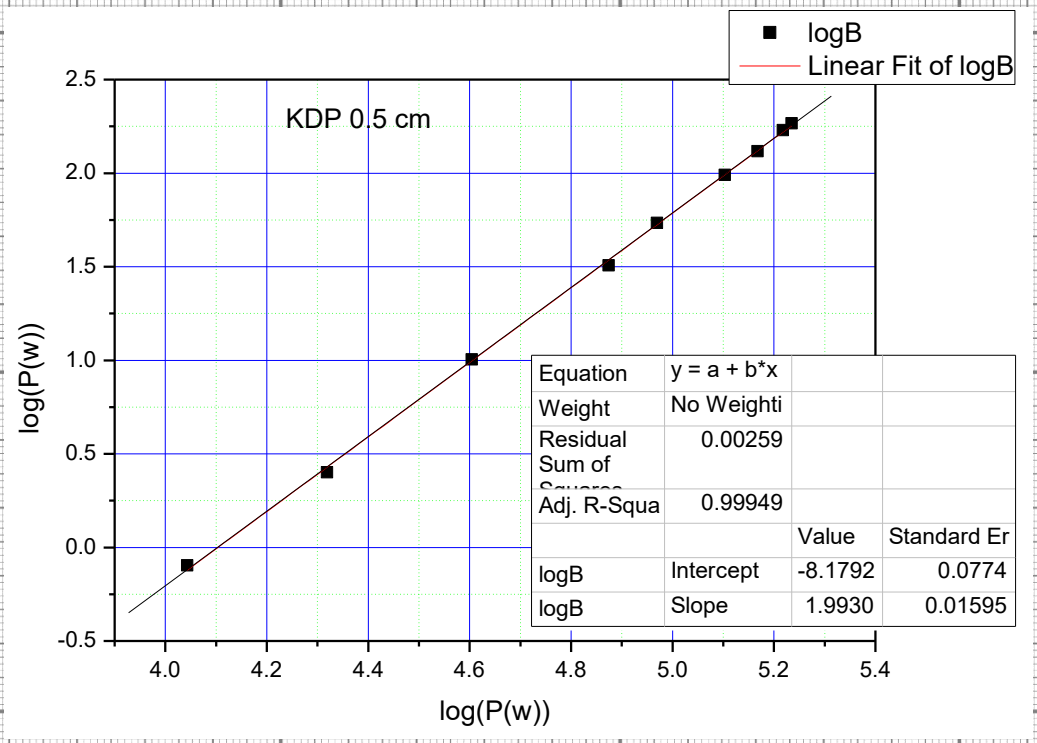
Experimental data for third harmonic generation.

First harmonic Power, Watts	Third harmonic Power, Watts
7768	0.4
12950	1.5
26010	9.2
40890	30.77
58310	70.1
76790	110.9
98830	210
117900	265.5
137000	412.9
154600	502.8
162900	685.1
166200	676.7

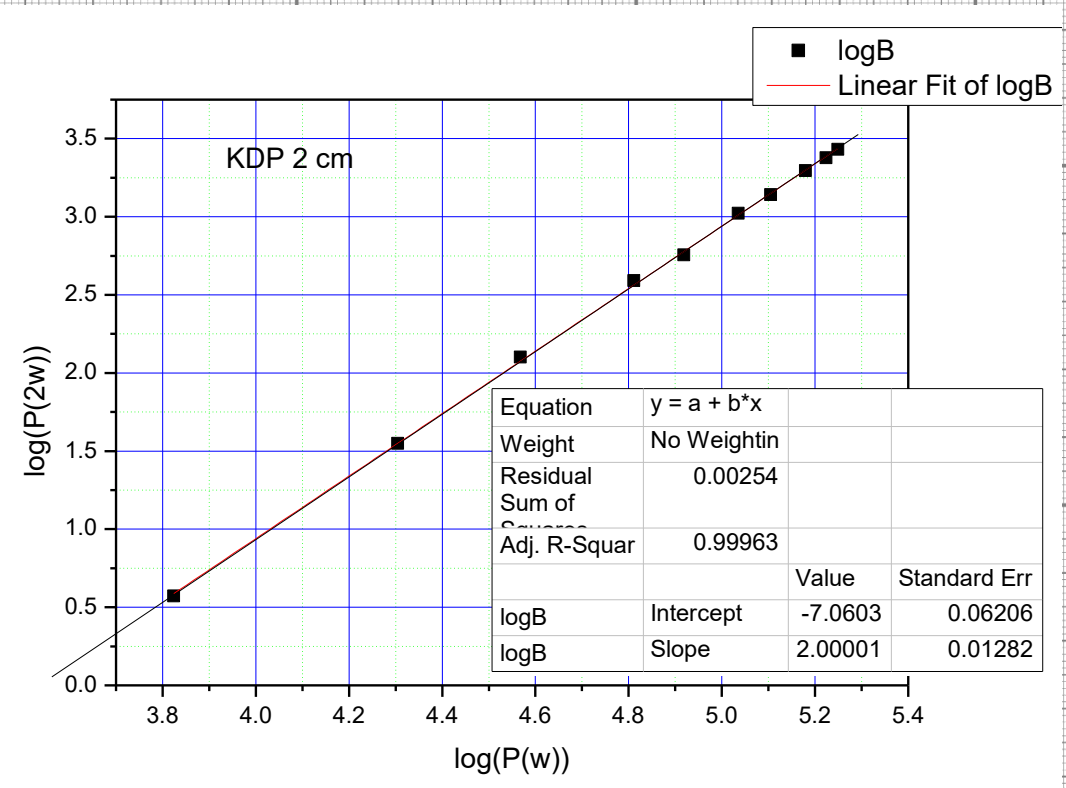
Second harmonic Power, Watts	Third harmonic Power, Watts
147	9.01
432.8	30.13
667.8	51.41
1384	123.9
2182	217.3
3000	318.9
4546	557
4913	577.8
5550	678.3

Additional forms 1

For crystal 0.5 см, B = 1.993 ≈ 2

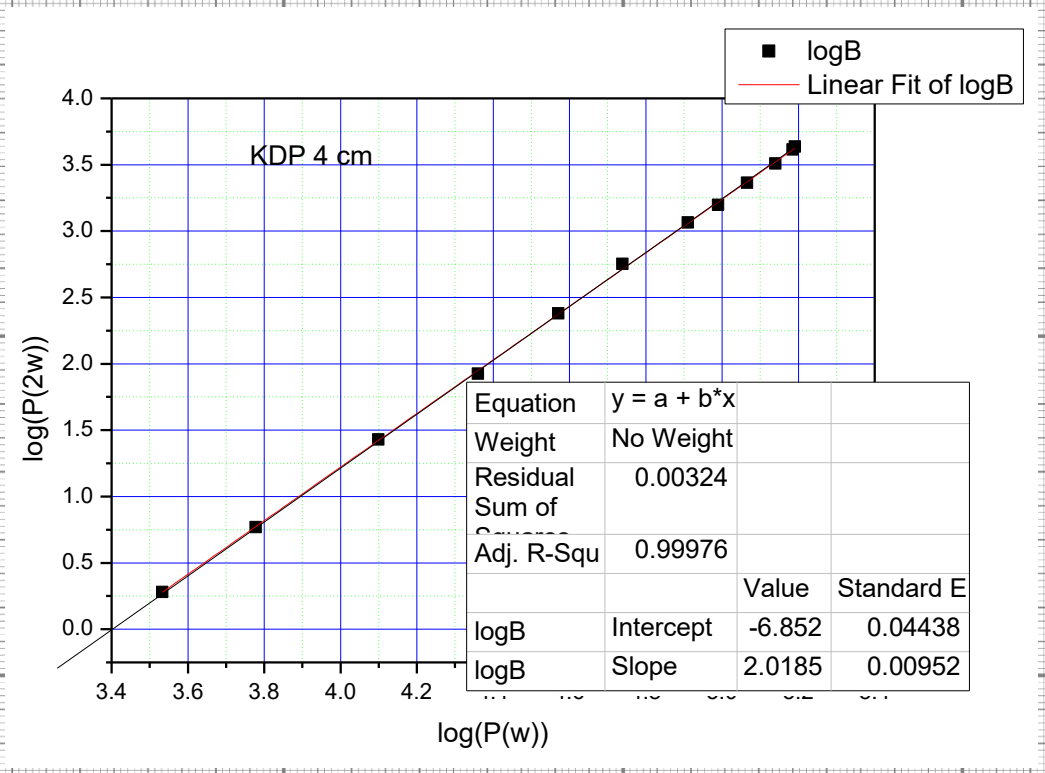


For crystal 2 см, B = 2.0001 ≈ 2



Additional forms 2

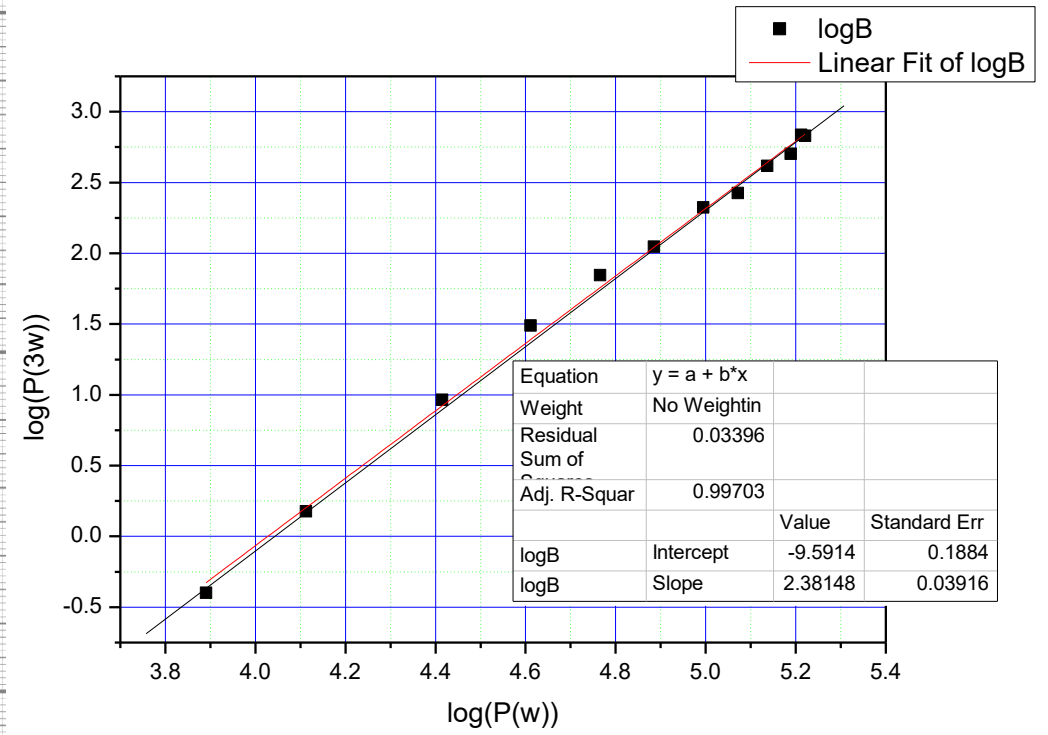
For crystal 4 см, B = 2.0185 ≈ 2



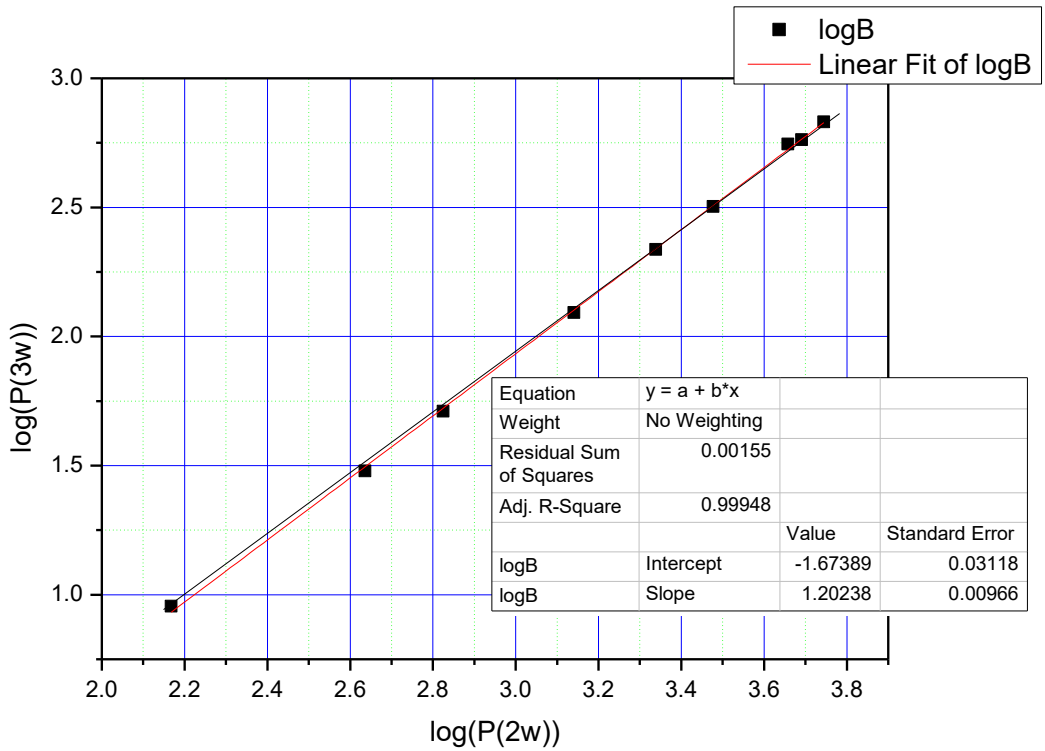
Equation	y = a + b*x		
Weight	No Weight		
Residual Sum of	0.00324		
Adj. R-Squ	0.99976		
		Value	Standard E
logB	Intercept	-6.852	0.04438
logB	Slope	2.0185	0.00952

Additional forms 3

Third harmonic versus first. B = 2.38



Third harmonic versus second. B = 1.2



Additional forms 4