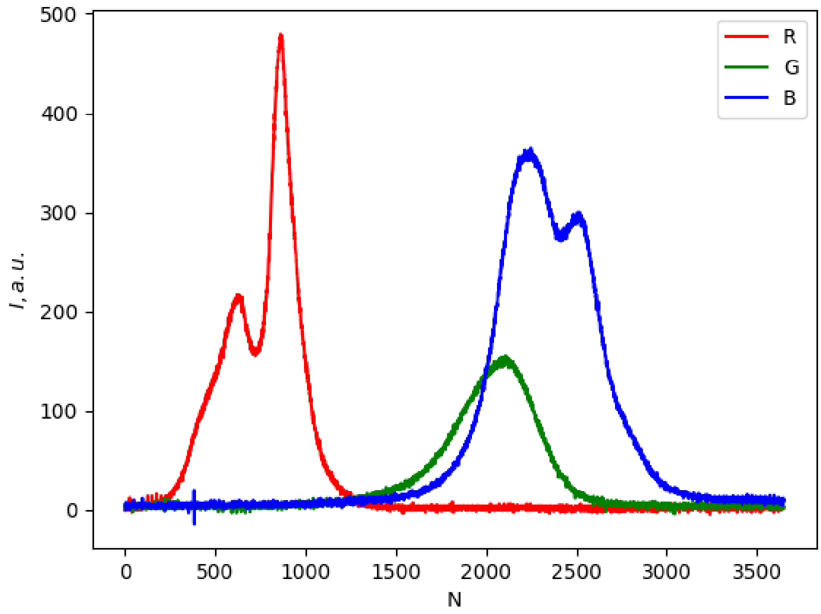
Solution

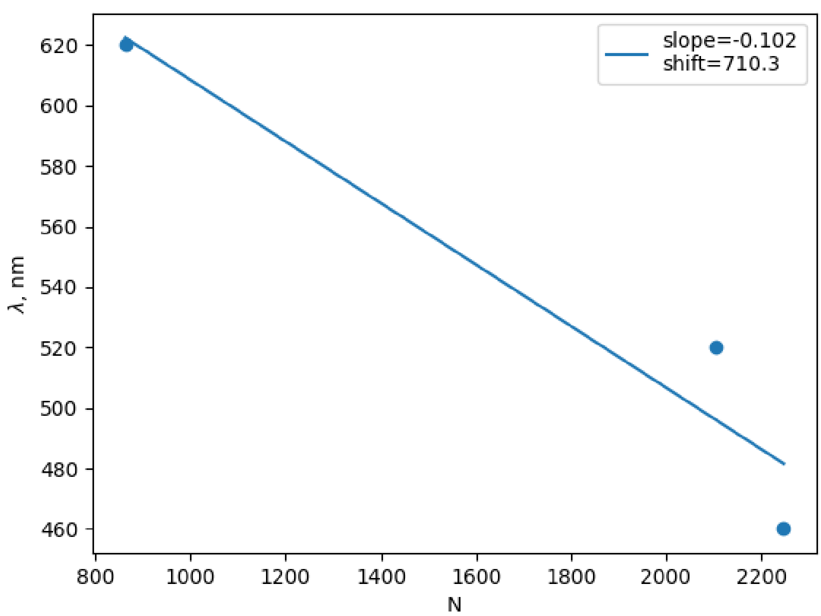
A1. The position of the spectra and their intensity in the raw data should not repeat due to the shift of the CCD array and the use of different sensitivities. However, the final results are well reproducible.



A2.

Color	N
Red	863
Green	2105
Blue	2247

A3.



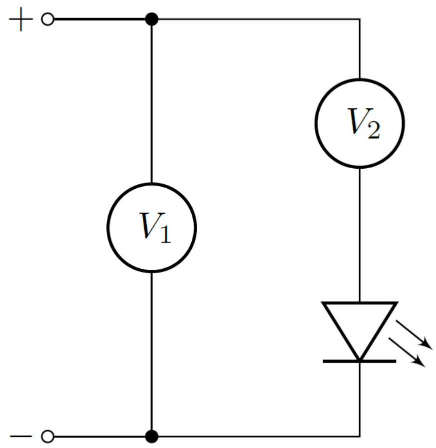
B1.

Range, V	R_V, MΩ
600	0.994
200	0.994
20	0.994
2	0.994
200m	0.993

B2.

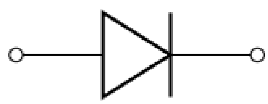
$$\boxed{R_0 = 46.1\ \Omega, \quad U_{100\ \mathrm{mA}} = 4.61\ \mathrm{V}}$$

B3.

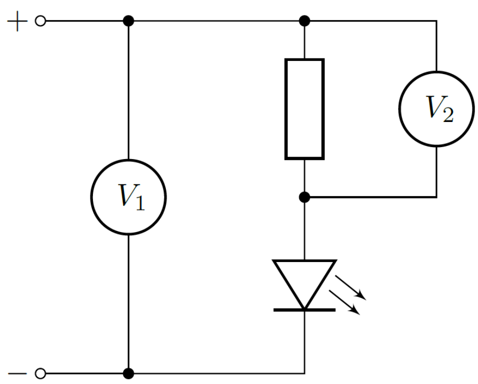


Another possible circuit configuration: the voltmeter V_1 is connected in parallel with the diode

B5.



B6.



Another possible circuit configuration: the voltmeter V_1 is connected in parallel with the diode

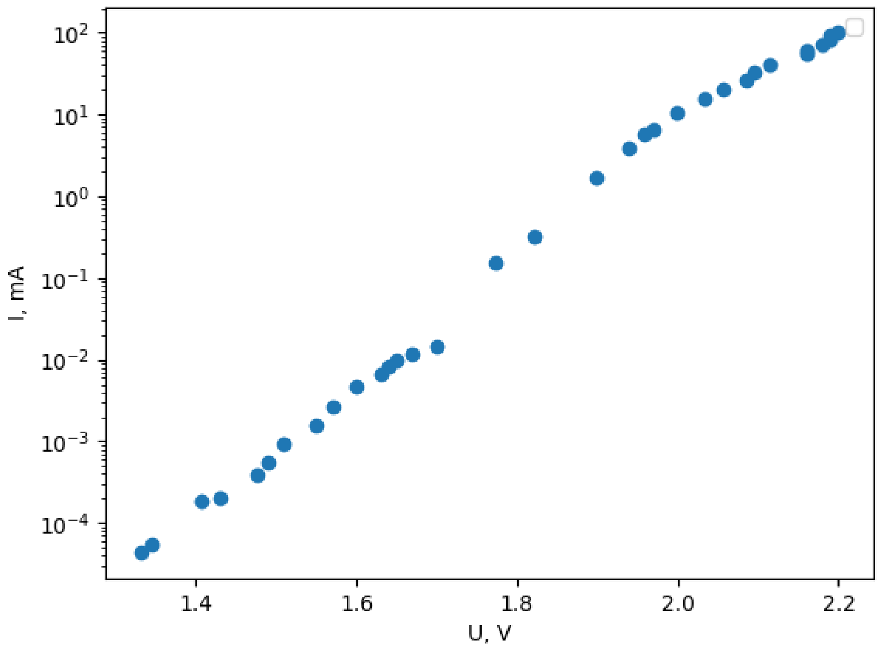
B8. For the circuit suggested in B3 the formula is:

$$I = V_2/R_V, \quad U = V_1 - V_2.$$

For the circuit suggested in B6 the formula is:

$$I = V_2/R_0, \quad U = V_1 - V_2$$

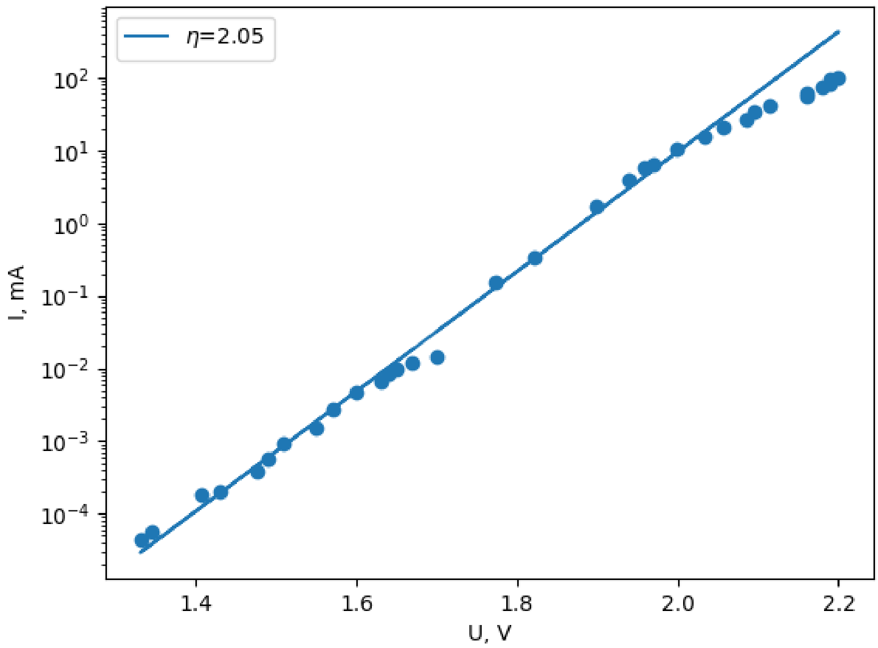
B9.



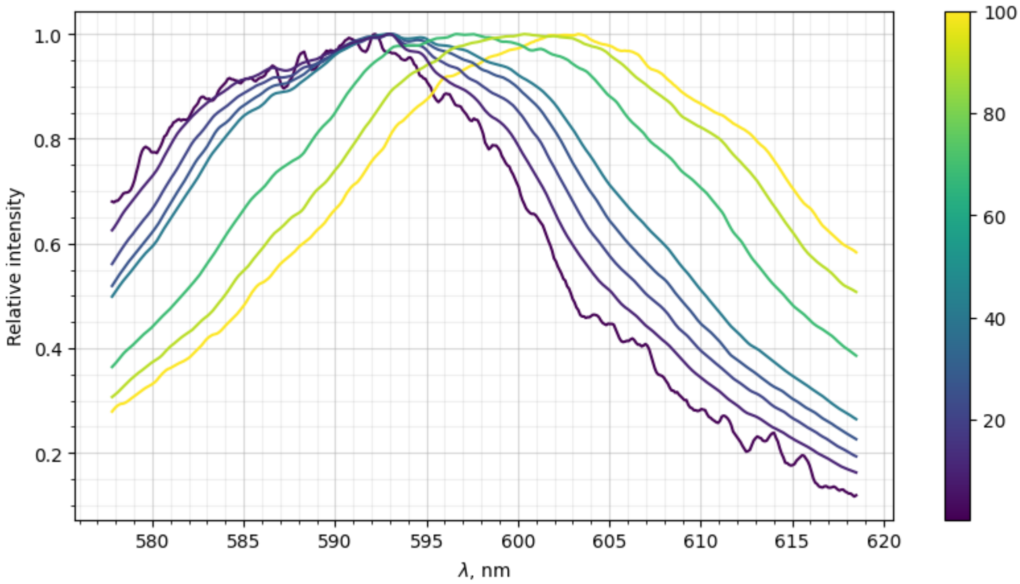
B10.

$$\boxed{\eta_0 k_B T_0/e = 51\ \mathrm{mV}}$$

B11.



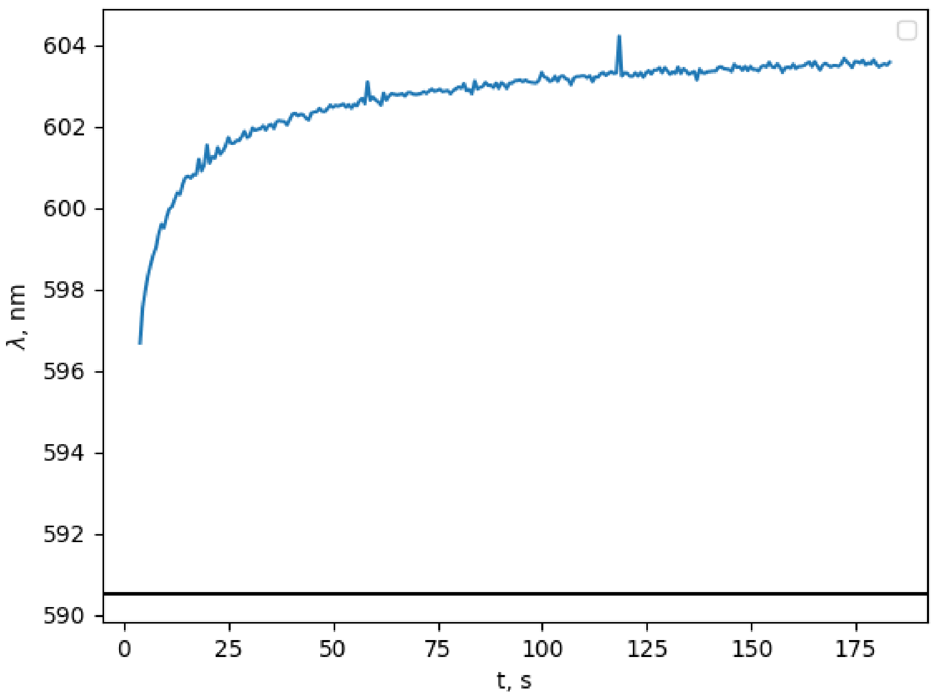
B12.



B14. Calculation the wavelength from N we do accroding to the expression:

$$\lambda = N \cdot \text{slope} + \text{shift}.$$

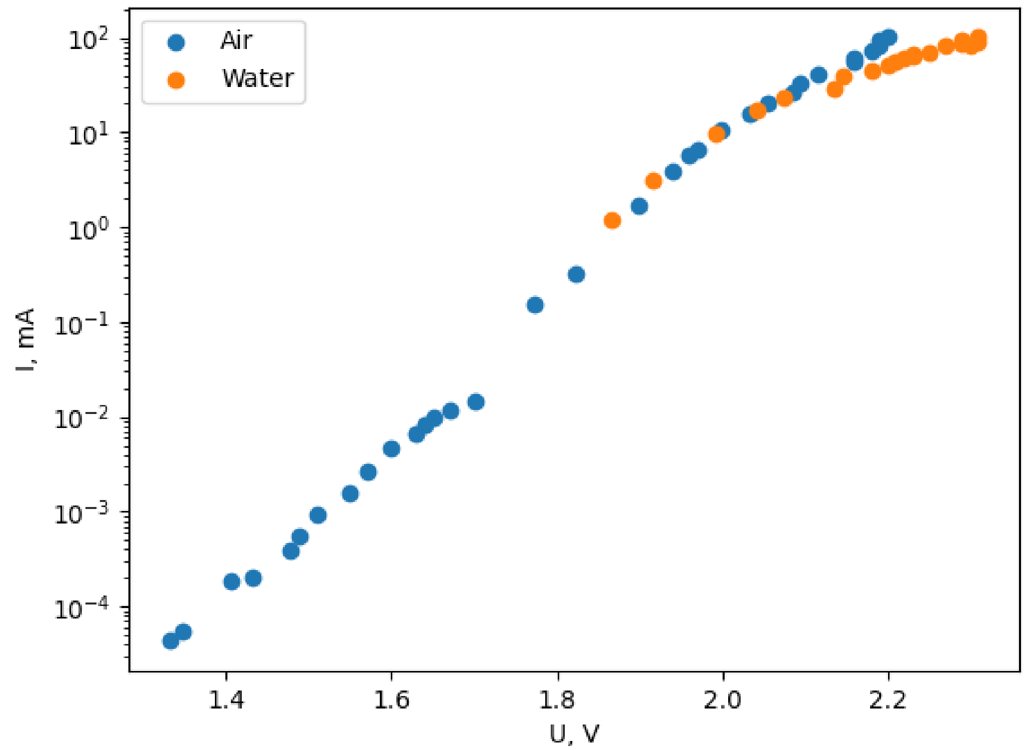
The position of maximum could be found using argmax. The real position of maximum could be deviated due to microstructure of peak. This microstructure takes place due to the image of the source, not its spectral characteristics. It's suggested to fit the range ± 5 nm from peak with parabola. The maximum of this parabola could be taken as the position of the maximum of the peak.



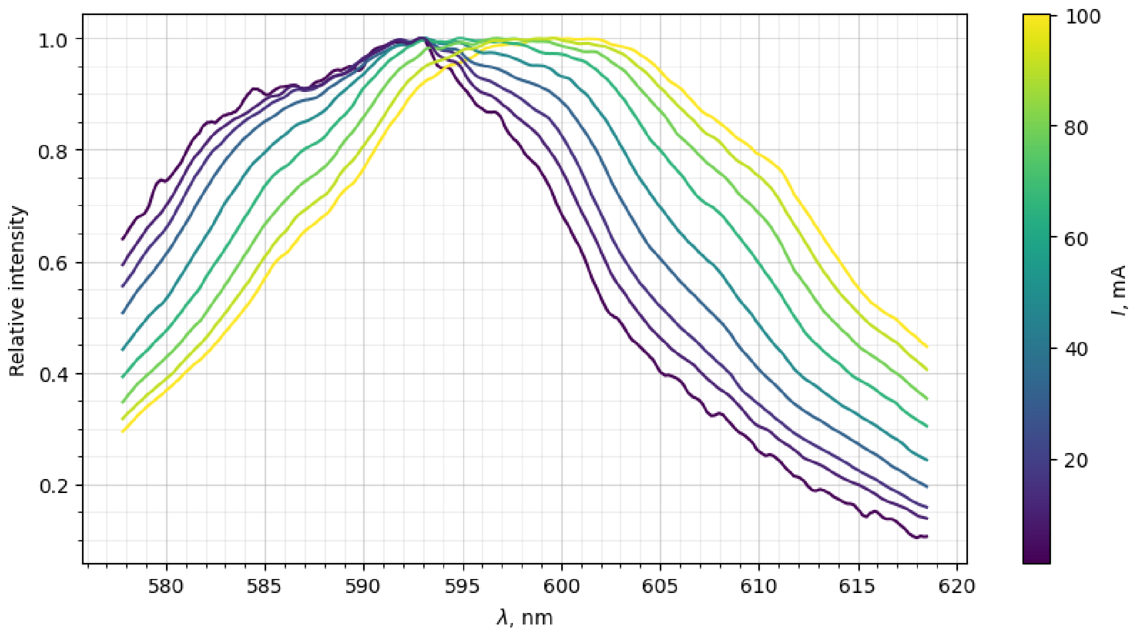
The horizontal line corresponds to the low current spectrum

C1. Circuit is the same with B6

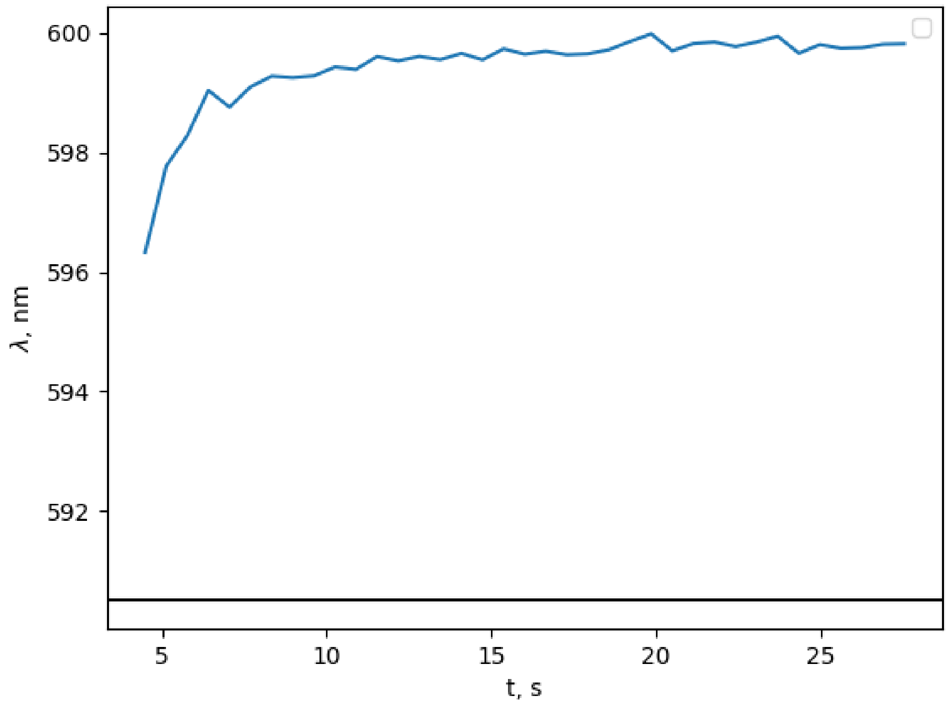
C3.


Air
Water
I, mA
U, V
10^2
10^1
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
1.4
1.6
1.8
2.0
2.2

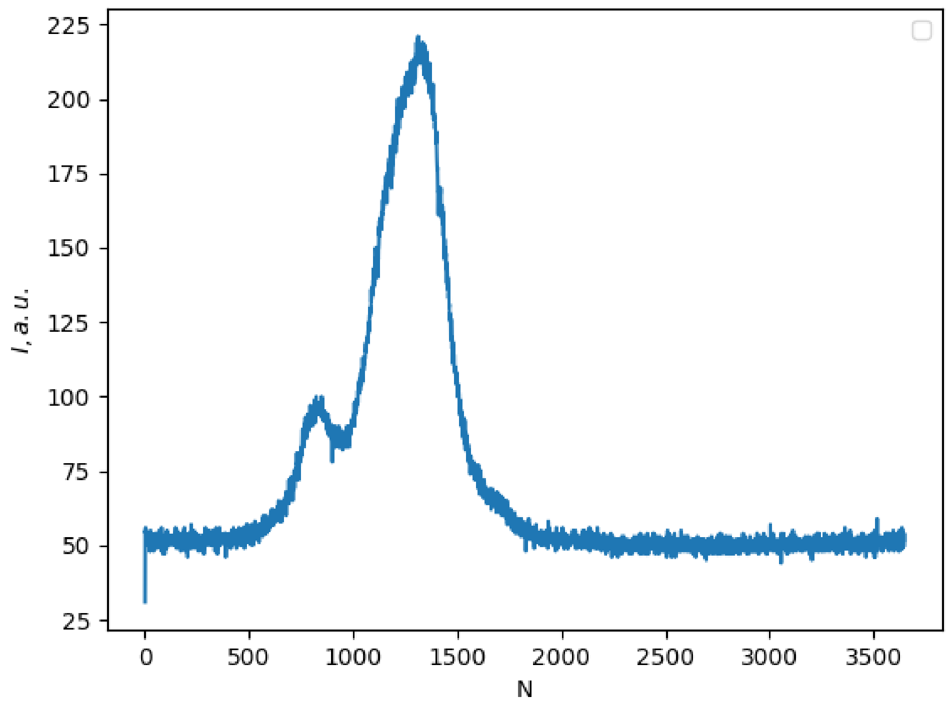
C4.


Relative intensity
λ, nm
I, mA
1.0
0.8
0.6
0.4
0.2
580
585
590
595
600
605
610
615
620
100
80
60
40
20

C6.



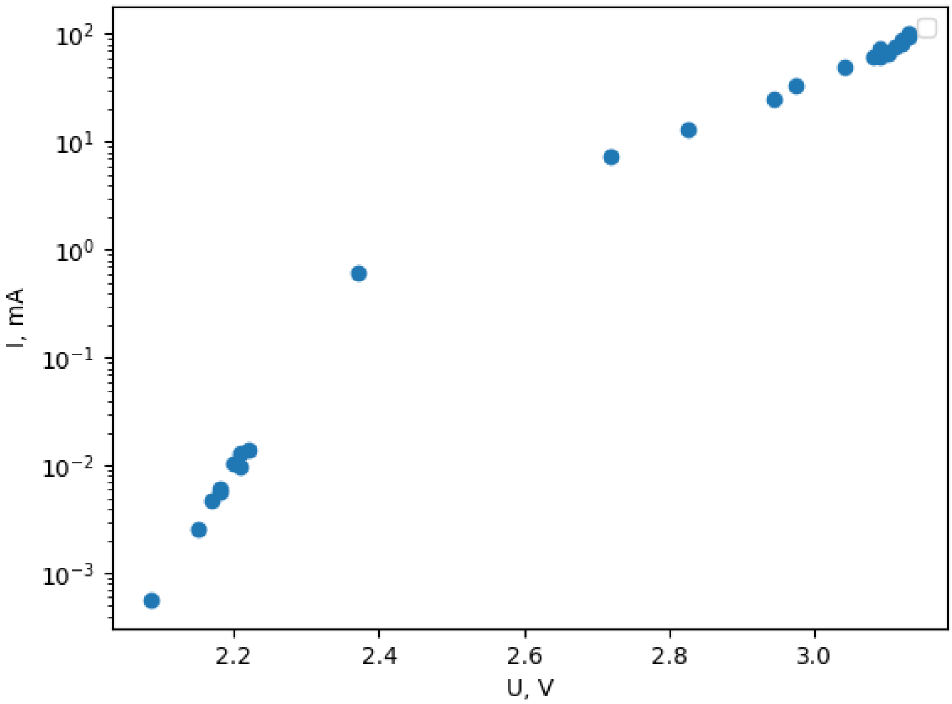
D1.



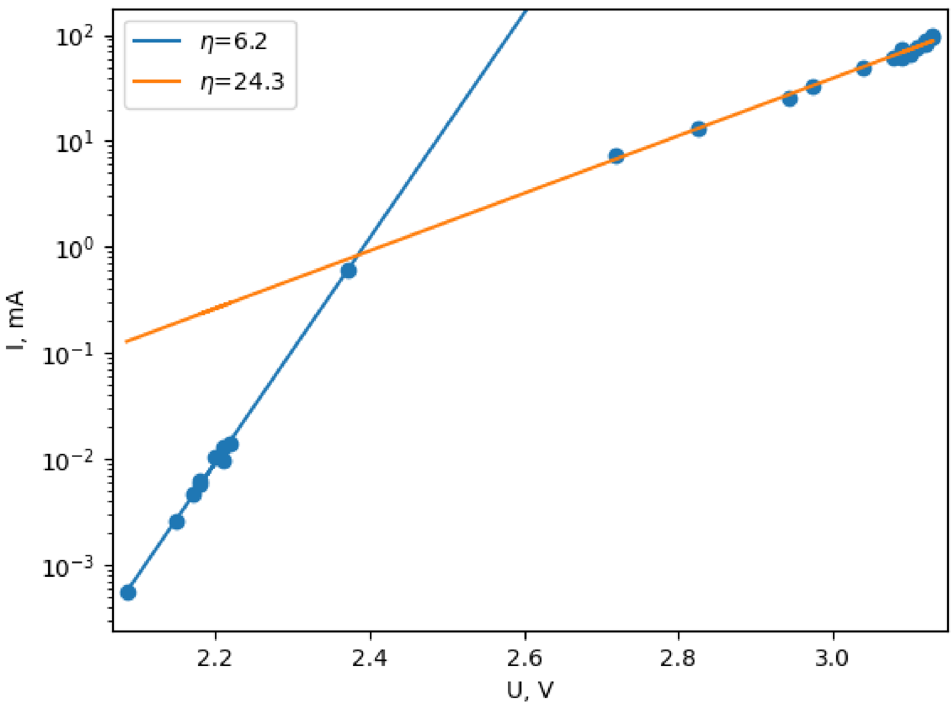
D2. Circuit is the same with B3

D3. Circuit is the same with B6

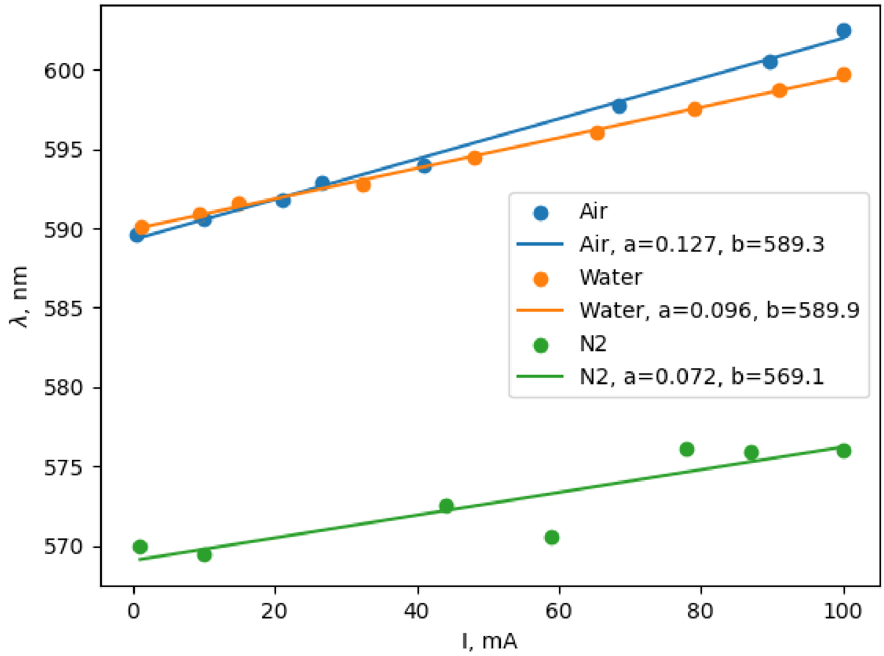
D5.


I, mA
U, V
10^2
10^1
10^0
10^{-1}
10^{-2}
10^{-3}
2.2
2.4
2.6
2.8
3.0

D6.


η=6.2
η=24.3
I, mA
U, V
10^2
10^1
10^0
10^{-1}
10^{-2}
10^{-3}
2.2
2.4
2.6
2.8
3.0

D9.



D10.

$$\boxed{\lambda_{N_2} = 569 \text{ nm}, \quad \lambda_{\text{room}} = 591 \text{ nm}}$$

D11.

$$\boxed{\alpha = 3.8 \cdot 10^{-4} \text{ K}^{-1}}$$

E1. Based on equation (1) and the energy of photon $E_g = 2\pi\hbar/\lambda$ we have the following expression:

$$\lambda(T) = \frac{2\pi\hbar c}{E_0\left(1 - \frac{\alpha T^2}{\theta + T}\right)}.$$

The value of χ is the value of the derivative of λ with respect to T, evaluated at T_0.

$$\boxed{\chi \simeq \frac{2\pi\hbar c}{E_0} \cdot \alpha T_0 \frac{2\theta + T_0}{(\theta + T_0)^2} = 0.13 \text{ nm/K}}$$

E2. A shift in the wavelength is proportional to the change of the temperature, therefore $\varkappa^{\text{air}}/\varkappa^{\text{water}}$ is equal to the ratio of slopes of λ vs I for the LED in water and air.

$$\boxed{\varkappa^{\text{air}}/\varkappa^{\text{water}} = 0.71}$$

E3. We separate variables in the differential equation:

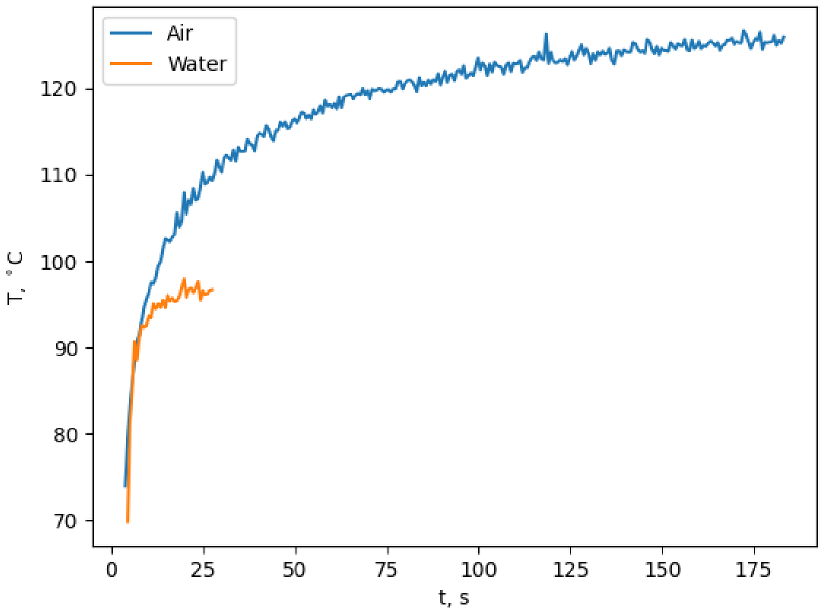
$$\frac{\mathrm{d}T}{T_\infty - T} = \frac{\varkappa}{C}\mathrm{d}t.$$

Integrating both sides and applying the initial condition $T(0) = T_0$ yields the answer.

$$\boxed{T(t) = T_\infty - (T_\infty - T_0)\exp\left(-\frac{\varkappa}{C}t\right)}$$

E4. The formula for calculation the temperature from the shift in wavelength is:

$$T = T_0 + \frac{\Delta\lambda}{\chi}$$



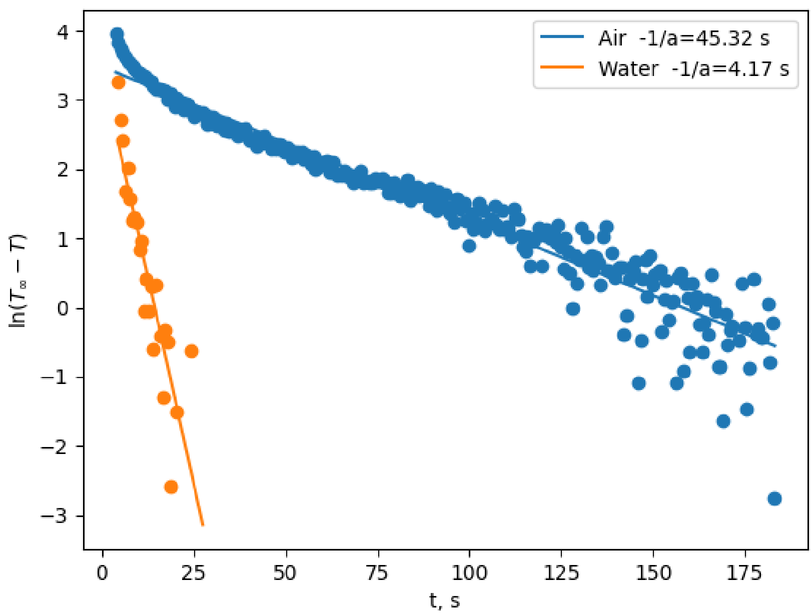
E5. From the expression for $T(t)$ (question E3) it's clear that T_∞ could be evaluated from the graph T vs. t.

The dependency could be linearized with

$$\ln\left(T_\infty - T(t)\right) = \ln\left(T_\infty - T_0\right) - \frac{\varkappa}{C}t,$$

so the slope of $\ln\left(T_\infty - T(t)\right)$ vs. t is $-\dfrac{\varkappa}{C}$.

In the beginning of the process it's significantly nonstationary, so the deviation from the linear dependency take place.



E6. Using the values of slopes:

$$\frac{C^{\text{air}}}{\varkappa^{\text{air}}} = 45 \text{ s}, \quad \frac{C^{\text{water}}}{\varkappa^{\text{water}}} = 4.2 \text{ s}$$

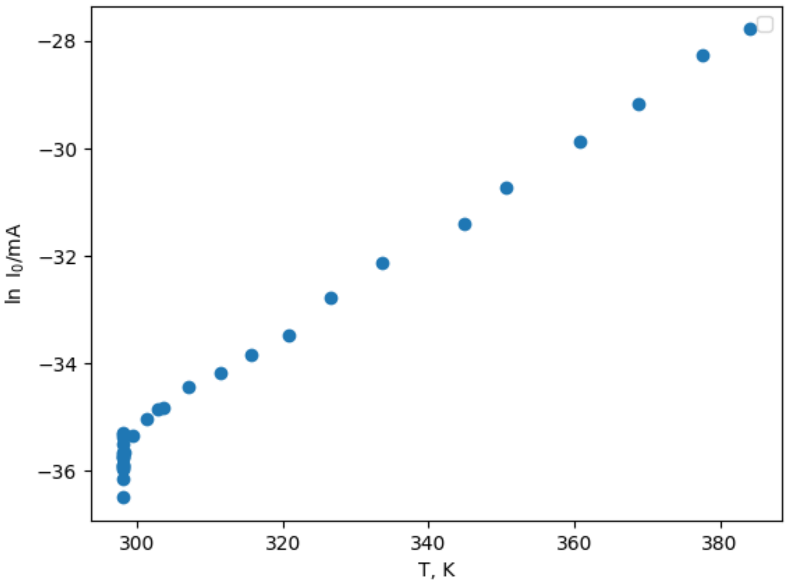
$$\boxed{C^{\text{air}}/C^{\text{water}} = 7.6}$$

F1. Using the proportionality between wavelength and current $\Delta\lambda = kI$ we have a linear dependence between the value of current and the temperature:

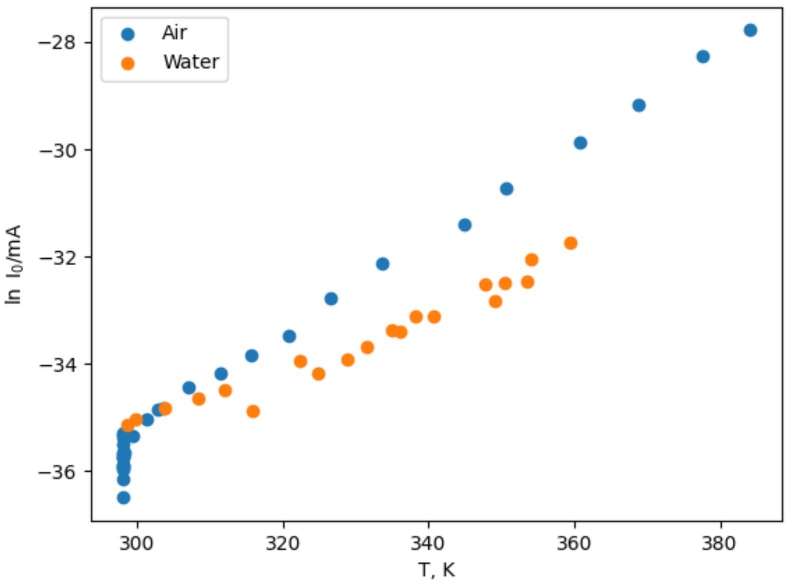
$$T = T_0 + \frac{kI}{\chi},$$

so we can calculate the temperature in the every point of current-voltage characteristics. From the Shockley equation:

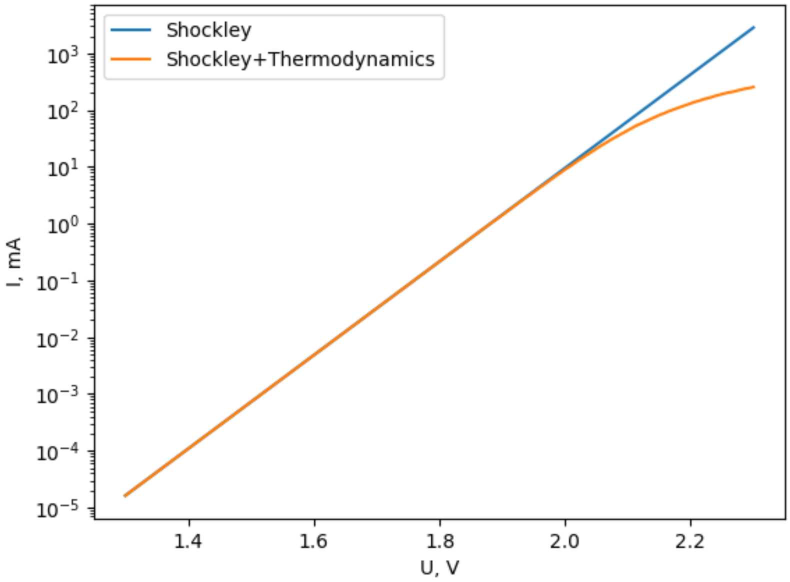
$$\ln I_0 = \ln I - \frac{eU}{\eta k_B T}$$



F2.



F3. If the temperature dependence of I_0 and η is neglected, the current-voltage characteristic of the diode under thermodynamic equilibrium conditions appears as shown in the figure below



Additional deviation of this curve can be interpreted in terms of the temperature dependence of either I_0 or η_0, as suggested in the problem.

$$\boxed{I_{+10\ \mathrm{K}}/I_0 = 6.7}$$