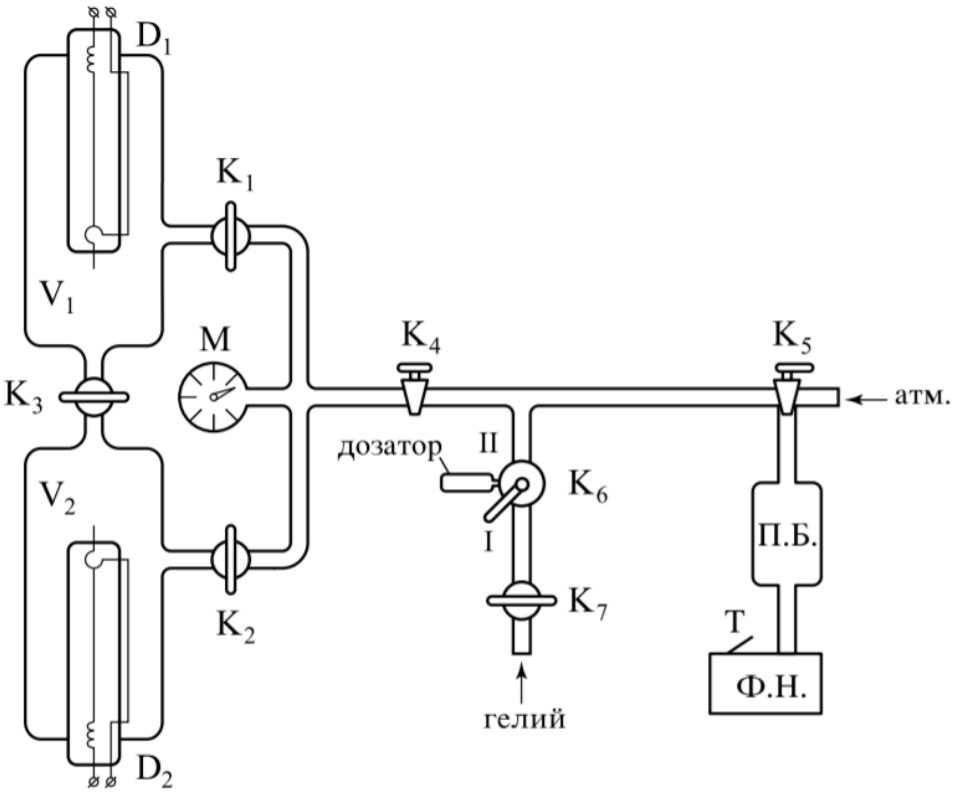
Лабораторная работа 2.2.1

Исследование взаимной диффузии газов

Ситников Арсений С01-019

Цель работы: 1) регистрация зависимости концентрации гелия в воздухе от времени с помощью датчиков теплопроводности при разных начальных давлениях смеси газов; 2) определение коэффициента диффузии по результатам измерений.

В работе используются: измерительная установка; форвакуумный насос; баллон с газом (гелий); манометр; источник питания; магазин сопротивлений; гальванометр; секундомер.



(Рис. 1)

Выставим для себя “рабочее” давление. Сначала пусть оно будет составлять 38 торр. При этом давлении измерим скорость диффузии. Для это, предварительно очистив систему и накачав нужным количеством гелия и воздуха, начнём процесс диффузии и будем записывать показания гальванометра в зависимости от времени.

$P_1 = 38$ торр

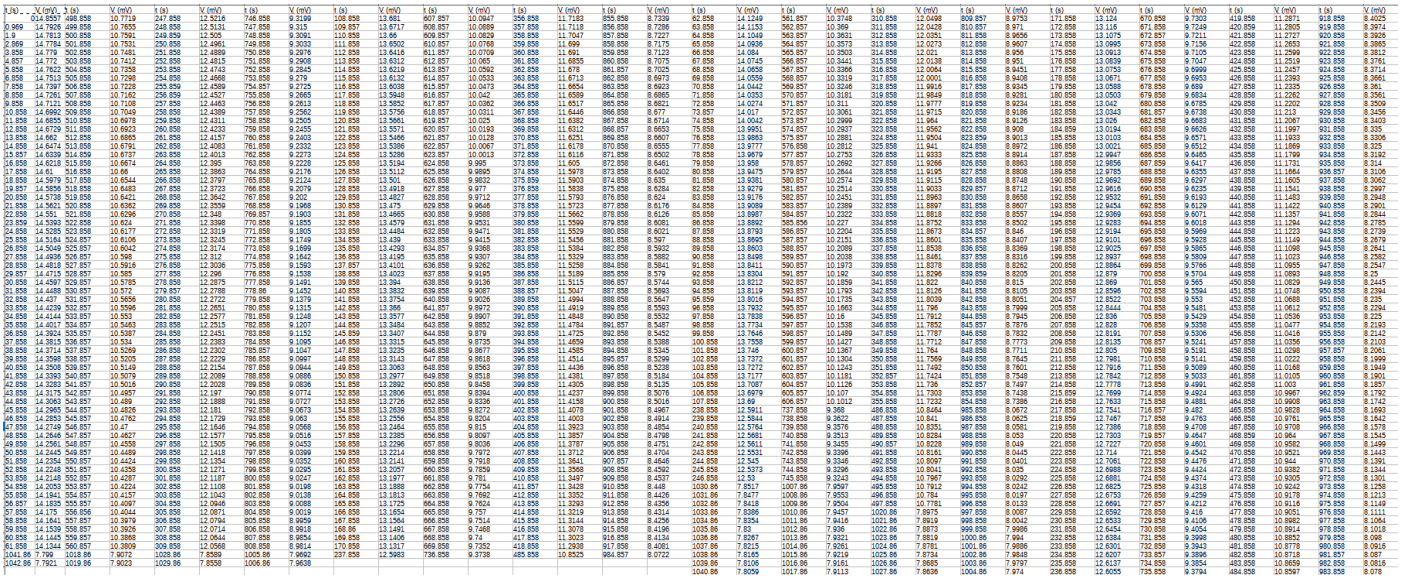
t (s)	V (mV)	t (s)	V (mV)	t (s)	V (mV)	t (s)	V (mV)
0	14.1834	62.938	11.9135	125.938	9.8732	189.938	8.15
0.969	14.3195	63.938	11.8759	126.938	9.8451	190.937	8.1244
1.94	14.2912	64.938	11.8399	127.938	9.816	191.937	8.101
2.938	14.2362	65.938	11.8055	128.938	9.7872	192.938	8.077
3.938	14.1892	66.938	11.7709	129.938	9.7568	193.937	8.0519
4.938	14.1465	67.938	11.7376	130.938	9.7268	194.938	8.0291
5.938	14.1027	68.938	11.7024	131.938	9.6988	195.938	8.0054
6.938	14.0601	69.938	11.6698	132.938	9.6696	196.938	7.9807
7.938	14.0175	70.938	11.6341	133.938	9.6422	197.938	7.9569
8.938	13.9756	71.938	11.6008	134.938	9.6148	198.937	7.9316
9.938	13.9327	72.938	11.5652	135.938	9.5857	199.937	7.9074
10.938	13.8931	73.938	11.5323	136.938	9.5578	200.938	7.884
11.938	13.854	74.938	11.499	137.938	9.5294	201.938	7.8594
12.938	13.8133	75.938	11.4627	138.937	9.5005	202.938	7.836
13.938	13.7743	76.938	11.4276	139.938	9.4714	203.938	7.8134
14.938	13.7358	77.938	11.3936	140.937	9.4442	204.938	7.7903
15.938	13.6976	78.938	11.3596	141.938	9.4158	205.938	7.7682
16.938	13.6585	79.938	11.3254	142.938	9.3883	206.938	7.7447
17.938	13.6205	80.938	11.2916	143.938	9.3606	207.937	7.7213
18.938	13.5819	81.938	11.2588	144.938	9.3319	208.938	7.6988
19.938	13.5443	82.938	11.2258	145.938	9.3042	209.938	7.6781
20.938	13.5067	83.938	11.1921	146.937	9.2778	210.938	7.6555
21.938	13.47	84.938	11.1558	147.938	9.2503	211.938	7.6309
22.938	13.4315	85.938	11.1232	148.938	9.2241	212.937	7.6084
23.938	13.3907	86.938	11.0891	149.938	9.1958	213.938	7.5869
24.938	13.3514	87.938	11.0557	150.938	9.1685	214.938	7.5666
25.938	13.3119	88.938	11.0216	151.938	9.1414	215.938	7.5458
26.938	13.272	89.938	10.9883	152.938	9.1138	216.938	7.526
27.937	13.2313	90.938	10.9562	153.938	9.0859	217.937	7.5069
28.938	13.1911	91.938	10.923	154.938	9.0572	218.938	7.488
29.938	13.1502	92.938	10.8893	155.938	9.0304	219.938	7.4708
30.938	13.1087	93.938	10.8579	156.938	9.0041	220.937	7.4504
31.938	13.0673	94.938	10.8254	157.938	8.9771	221.937	7.4299
32.938	13.0284	95.938	10.7936	158.938	8.9516	222.938	7.4091
33.938	12.9876	96.938	10.7616	159.937	8.9247	223.938	7.3856
34.938	12.9505	97.938	10.731	160.938	8.8969	224.938	7.3622
35.938	12.9119	98.938	10.6988	161.938	8.8703	225.938	7.3388
36.938	12.8742	99.938	10.6687	162.938	8.8426	226.938	7.3161
37.938	12.8367	100.938	10.6364	163.938	8.8159	227.937	7.2949
38.938	12.7978	101.937	10.6071	164.937	8.7891	228.938	7.274
39.938	12.7602	102.937	10.5772	165.938	8.7636	229.938	7.2544
40.938	12.7222	103.937	10.5459	166.938	8.7377	230.938	7.2398
41.938	12.6845	104.936	10.5145	167.938	8.7104	231.937	7.2211
42.938	12.6476	105.937	10.4843	168.938	8.6833	232.938	7.2085
43.938	12.611	106.937	10.4524	169.937	8.6577	233.938	7.1937
44.938	12.5752	107.937	10.4226	170.937	8.6326	234.938	7.1815
45.938	12.5381	108.937	10.3914	171.938	8.6076	235.938	7.1668
46.938	12.4997	109.937	10.3609	172.938	8.5822	236.937	7.1521
47.938	12.4629	110.937	10.3292	173.938	8.5555	237.937	7.1325
48.938	12.4262	111.937	10.2981	174.937	8.5311	238.937	7.113
49.938	12.39	112.937	10.2663	175.938	8.5046	239.938	7.0915
50.938	12.3534	113.937	10.2341	176.938	8.4776	240.937	7.0689
51.938	12.3158	114.937	10.202	177.938	8.4522	241.937	7.0479
52.938	12.2774	115.937	10.171	178.937	8.4278	242.938	7.0247
53.938	12.2411	116.937	10.1394	179.938	8.4023	243.938	7.0041
54.938	12.2044	117.937	10.1103	180.938	8.3749		
55.938	12.167	118.937	10.08	181.938	8.3501		
56.938	12.1297	119.936	10.0506	182.938	8.3248		
57.938	12.0945	120.937	10.0199	183.937	8.2991		
58.938	12.057	121.938	9.991	184.938	8.2739		
59.938	12.0236	122.938	9.9612	185.938	8.2481		
60.938	11.9874	123.938	9.9325	186.938	8.2242		
61.938	11.9508	124.938	9.9022	187.938	8.1981		

Проделаем аналогичные измерения ещё для 3 значений давления.

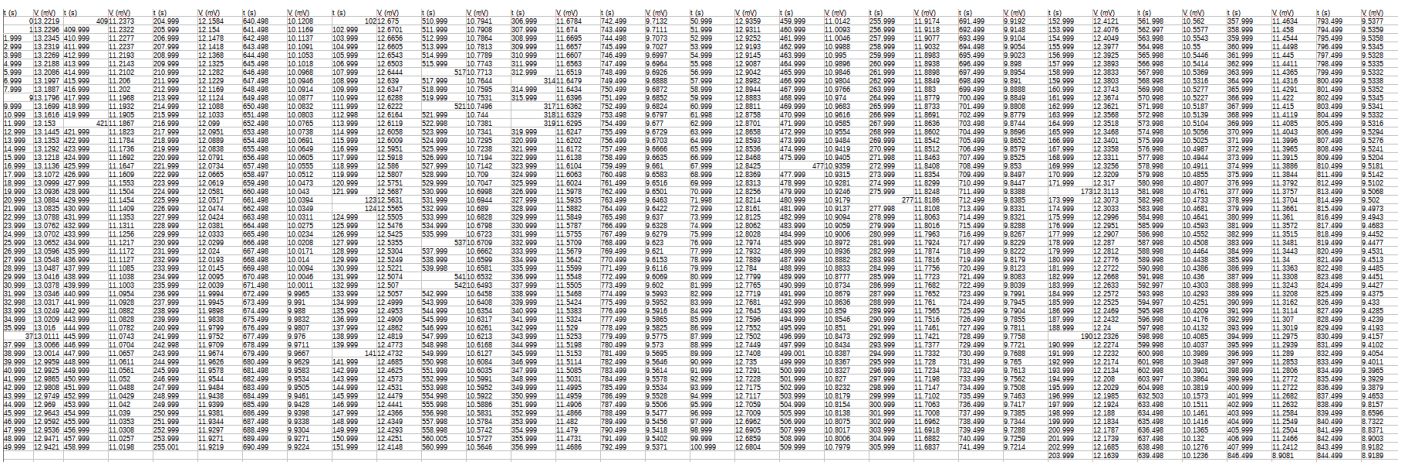
$P_2 = 110{,}5$ торр

t (s)	V (mV)	t (s)	V (mV)	t (s)	V (mV)	t (s)	V (mV)	t (s)	V (mV)	t (s)	V (mV)	t (s)	V (mV)	t (s)	V (mV)	t (s)	V (mV)
0	11.4423	109.037	9.9408	218.037	8.5124	327.037	7.2457	436.036	6.1288	73.036	10.4594	182.037	8.969	291.037	7.6606	400.036	6.4802
1.037	11.5812	110.037	9.927	219.037	8.5007	328.036	7.2339	437.036	6.1185	74.036	10.4452	183.037	8.9559	292.037	7.6471	401.036	6.4704
2.037	11.6096	111.037	9.9138	220.037	8.4881	329.036	7.2221	438.036	6.1091	75.036	10.4294	184.037	8.9424	293.037	7.6362	402.036	6.4602
3.037	11.5868	112.037	9.9001	221.037	8.4756	330.037	7.212	439.036	6.1001	76.035	10.4144	185.037	8.9296	294.037	7.6245	403.036	6.4493
4.037	11.5649	113.037	9.8856	222.036	8.4637	331.037	7.2024	440.036	6.0897	77.036	10.4	186.037	8.9172	295.037	7.6114	404.036	6.4387
5.037	11.5458	114.037	9.8702	223.037	8.452	332.037	7.1905	441.036	6.0815	78.036	10.3839	187.037	8.9046	296.037	7.6005	405.036	6.428
6.037	11.5302	115.037	9.8574	224.037	8.4386	333.036	7.1788	442.036	6.0705	79.036	10.3692	188.037	8.8924	297.036	7.5882	406.036	6.4188
7.037	11.513	116.037	9.8435	225.037	8.4255	334.037	7.1689	443.036	6.0613	80.036	10.353	189.037	8.88	298.037	7.575	407.036	6.4078
8.037	11.4972	117.037	9.8291	226.037	8.4137	335.037	7.1589	444.036	6.051	81.036	10.3369	190.037	8.8659	299.037	7.5635	408.036	6.3982
9.037	11.4797	118.037	9.8155	227.037	8.4013	336.037	7.1478	445.036	6.0419	82.036	10.3232	191.037	8.8504	300.037	7.5514	409.036	6.3874
10.037	11.4609	119.037	9.8023	228.037	8.391	337.037	7.137	446.036	6.0337	83.036	10.3093	192.037	8.839	301.037	7.5399	410.036	6.3779
11.037	11.4444	120.037	9.7882	229.037	8.3778	338.037	7.1274	447.037	6.0233	84.036	10.2961	193.036	8.8269	302.037	7.5287	411.036	6.3691
12.037	11.4292	121.036	9.7752	230.036	8.3665	339.036	7.1168	448.036	6.0143	85.036	10.2815	194.037	8.814	303.036	7.517	412.036	6.3584
13.037	11.4123	122.037	9.7609	231.037	8.3526	340.037	7.1067	449.036	6.005	86.036	10.2662	195.037	8.8012	304.037	7.5061	413.036	6.3486
14.037	11.3964	123.037	9.7479	232.037	8.3414	341.037	7.095	450.036	5.996	87.036	10.2513	196.036	8.7871	305.037	7.4951	414.036	6.3395
15.037	11.3794	124.037	9.7337	233.037	8.331	342.037	7.0852	451.036	5.9859	88.036	10.2369	197.036	8.7742	306.037	7.4839	415.036	6.3302
16.037	11.3638	125.037	9.7183	234.037	8.3202	343.036	7.0742	452.036	5.9759	89.036	10.2217	198.036	8.7626	307.037	7.4736	416.036	6.3207
17.037	11.3475	126.037	9.7054	235.037	8.3077	344.036	7.0643	453.036	5.9669	90.035	10.2072	199.037	8.7489	308.037	7.4608	417.036	6.3102
18.037	11.3312	127.037	9.6917	236.037	8.2946	345.037	7.0536	454.036	5.9577	91.036	10.193	200.037	8.7361	309.037	7.4487	418.036	6.3014
19.037	11.3136	128.037	9.6765	237.037	8.2822	346.037	7.0438	455.036	5.9485	92.036	10.1779	201.037	8.7247	310.037	7.4376	419.036	6.2912
20.037	11.2972	129.037	9.6627	238.037	8.2712	347.037	7.0308	456.036	5.9396	93.036	10.1627	202.037	8.7117	311.036	7.425	420.036	6.2802
21.036	11.2789	130.037	9.6479	239.037	8.2593	348.036	7.0201	457.036	5.93	94.036	10.1482	203.037	8.6986	312.037	7.414	421.036	6.2708
22.037	11.2611	131.037	9.6338	240.037	8.2461	349.036	7.0084	458.036	5.9208	95.036	10.1343	204.037	8.6851	313.037	7.4021	422.036	6.2608
23.037	11.2435	132.037	9.6201	241.037	8.2365	350.037	6.9967	459.036	5.9114	96.036	10.1179	205.037	8.6735	314.037	7.3898	423.036	6.2511
24.037	11.2261	133.037	9.6066	242.037	8.2243	351.037	6.9864	460.036	5.9019	97.036	10.1036	206.037	8.661	315.037	7.3795	424.036	6.2408
25.037	11.2098	134.037	9.5929	243.037	8.212	352.037	6.9747	461.037	5.892	98.036	10.0889	207.037	8.6482	316.037	7.367	425.036	6.2318
26.037	11.1937	135.036	9.5783	244.037	8.1985	353.037	6.9643	462.036	5.8831	99.036	10.0753	208.037	8.6373	317.037	7.3528	426.036	6.2221
27.037	11.1779	136.037	9.5659	245.036	8.1865	354.037	6.9543	463.036	5.8727	100.036	10.0615	209.037	8.6241	318.037	7.3433	427.036	6.2124
28.037	11.1613	137.037	9.5525	246.037	8.174	355.037	6.9427	464.036	5.8634	101.036	10.0481	210.037	8.6106	319.037	7.3328	428.036	6.2039
29.037	11.1449	138.037	9.539	247.037	8.1632	356.036	6.9324	465.036	5.8531	102.036	10.0347	211.037	8.5988	320.036	7.3218	429.036	6.1948
30.037	11.1291	139.037	9.5251	248.037	8.152	357.036	6.9219	466.036	5.844	103.036	10.0212	212.037	8.5854	321.037	7.3109	430.036	6.1855
31.037	11.1126	140.037	9.512	249.036	8.1407	358.036	6.9116	467.037	5.8345	104.036	10.0079	213.037	8.5735	322.037	7.3002	431.037	6.1752
32.037	11.0958	141.037	9.4981	250.037	8.1302	359.037	6.9021	468.037	5.8257	105.037	9.995	214.037	8.5615	323.037	7.2872	432.037	6.1663
33.037	11.0788	142.037	9.4855	251.036	8.1191	360.037	6.8914	469.036	5.8176	106.037	9.9811	215.037	8.5506	324.037	7.277	433.037	6.1565
34.037	11.0615	143.038	9.4734	252.037	8.108	361.037	6.8812	470.036	5.808	107.037	9.9679	216.036	8.5376	325.037	7.2667	434.036	6.1466
35.037	11.0451	144.037	9.4591	253.037	8.0949	362.037	6.8698	471.036	5.7992	108.037	9.9541	217.036	8.525	326.037	7.2555	435.036	6.1382
36.037	11.0278	145.036	9.4459	254.037	8.0849	363.037	6.8589	55.037	10.731	164.037	9.1993	273.037	7.8649	382.037	6.667		
37.037	11.0106	146.037	9.4313	255.037	8.0724	364.037	6.8468	56.037	10.7154	165.037	9.1851	274.037	7.8532	383.037	6.658		
38.037	10.9939	147.037	9.4205	256.036	8.0614	365.036	6.8358	57.037	10.7001	166.037	9.1735	275.037	7.8426	384.036	6.6474		
39.037	10.9782	148.037	9.4067	257.037	8.0505	366.037	6.8245	58.037	10.6837	167.036	9.1614	276.037	7.8314	385.037	6.6376		
40.037	10.9609	149.036	9.3934	258.036	8.0377	367.037	6.8149	59.037	10.6684	168.037	9.149	277.036	7.82	386.036	6.6261		
41.037	10.9448	150.037	9.3805	259.036	8.0269	368.037	6.8052	60.037	10.6527	169.037	9.1361	278.036	7.8075	387.037	6.6155		
42.037	10.9297	151.037	9.3664	260.037	8.016	369.037	6.7942	61.037	10.6376	170.037	9.1227	279.037	7.7962	388.037	6.6053		
43.037	10.9147	152.037	9.3541	261.037	8.0029	370.037	6.7853	62.037	10.6225	171.037	9.1094	280.037	7.7848	389.036	6.5956		
44.037	10.8991	153.037	9.3408	262.037	7.9915	371.037	6.7749	63.036	10.6075	172.037	9.0974	281.037	7.7745	390.037	6.5851		
45.037	10.8854	154.036	9.3304	263.037	7.9794	372.037	6.7645	64.036	10.5919	173.036	9.0844	282.037	7.7627	391.036	6.5743		
46.037	10.8701	155.037	9.3172	264.036	7.9684	373.037	6.7562	65.036	10.5772	174.037	9.0711	283.037	7.7514	392.036	6.5639		
47.037	10.8557	156.037	9.305	265.037	7.956	374.037	6.7445	66.036	10.562	175.037	9.0585	284.037	7.7403	393.037	6.5522		
48.037	10.84	157.037	9.2927	266.037	7.9447	375.037	6.7348	67.036	10.5475	176.037	9.0474	285.037	7.7294	394.036	6.5426		
49.037	10.8239	158.037	9.278	267.037	7.9338	376.037	6.7245	68.036	10.5324	177.037	9.0348	286.037	7.7181	395.036	6.531		
50.037	10.8061	159.036	9.2654	268.037	7.9222	377.036	6.715	69.036	10.5177	178.037	9.0224	287.037	7.7064	396.036	6.5203		
51.037	10.7915	160.037	9.2522	269.037	7.9091	378.037	6.7051	70.036	10.5037	179.037	9.0089	288.037	7.6943	397.036	6.5092		
52.037	10.7762	161.037	9.2393	270.037	7.898	379.037	6.6945	71.036	10.4889	180.037	8.9952	289.037	7.6833	398.036	6.5		
53.037	10.7607	162.037	9.2262	271.037	7.8865	380.037	6.6865	72.035	10.4735	181.037	8.9824	290.037	7.6716	399.036	6.4902		
54.037	10.7457	163.037	9.2133	272.037	7.8756	381.036	6.6767										

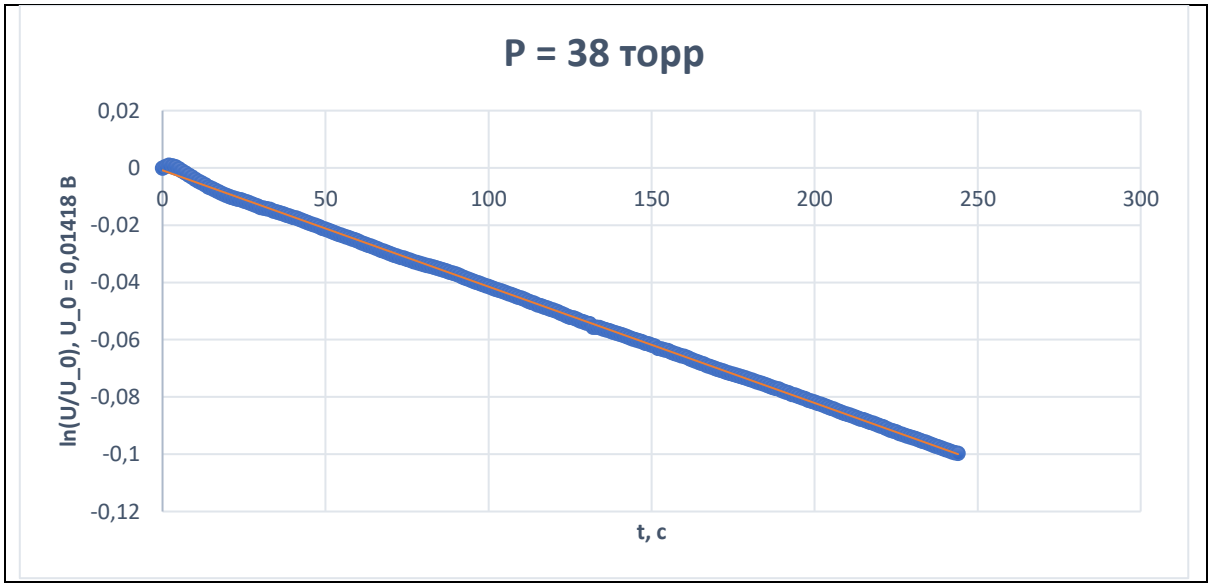
$P_3 = 220{,}1$ торр



$P_4 = 289{,}8$ торр



Проверим, что наша диффузия подчиняется формуле $n_1 - n_2 = (n_2 - n_1)_0 e^{-t/\tau}$. Для этого построим график $\ln(U/U_0)(t)$, где U_0 = 0,01418 В.



Линейный вид функции подтверждает факт, того всё сделано верно. Нам известно, что:

$N = N_0 e^{-t/\tau}$, где N – показания гальванометра.

$\tau = \frac{V_1 V_2}{V_1+V_2}\frac{L}{SD}$, где V_1, V_2- объёмы сосудов с воздухом и гелием, L/S -отношение длины трубки, соединяющей сосуды к её сечению, D – коэффициент диффузии. Следовательно:

$D = -\frac{V}{2}\frac{Lk}{S}$, где k – тангенс угла наклона графика.

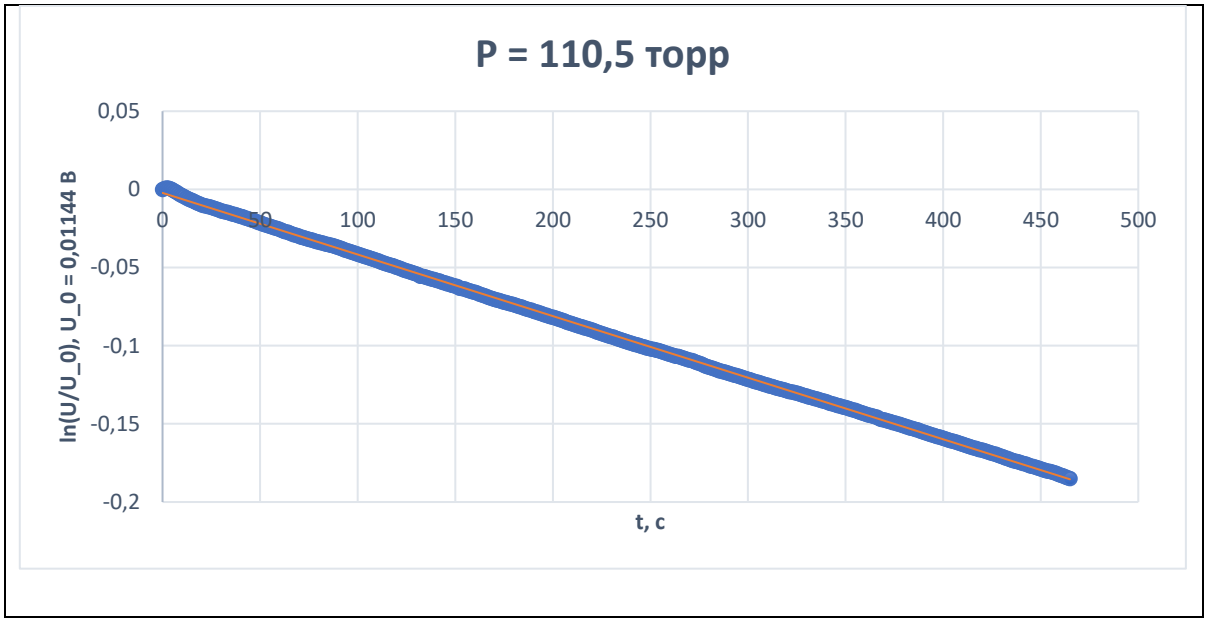
$V = V_1 = V_2 = 1200 \pm 30 см^3, L/S = 550 \pm 50\ 1/м$

$k = -0{,}003 \pm 0{,}00001\ c^{-1}$

$D_{38} = 0{,}0128\ м^2/с$

$\sigma_{D_{40}} = \sqrt{(\frac{Vk}{2}\sigma_{L/S})^2 + (\frac{VL}{2S}\sigma_k)^2 + (\frac{Lk}{2S}\sigma_V)^2} = 0{,}0009 м^2/с$

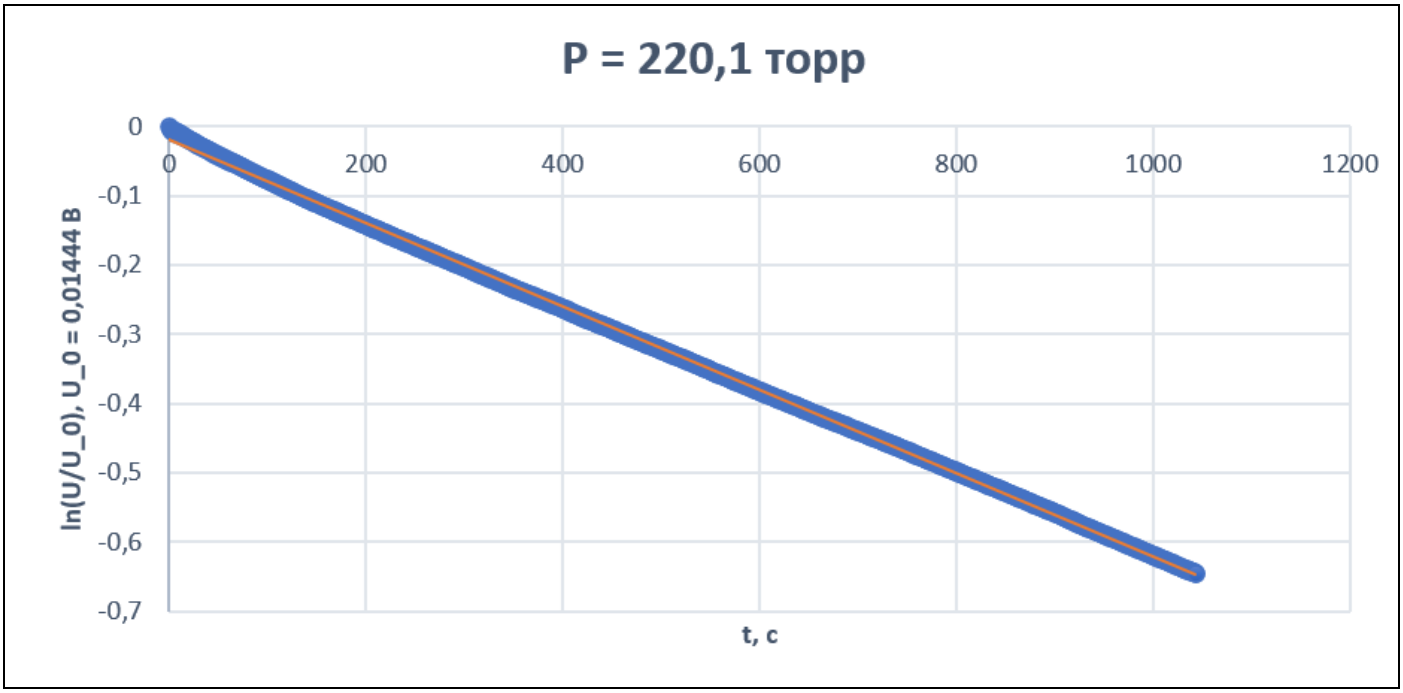
Проделаем аналогичные операции при других давлениях.



$k = -0{,}0014 \pm 0{,}00002\ c^{-1}$

$D_{100,5} = 0{,}00639\ м^2/с$

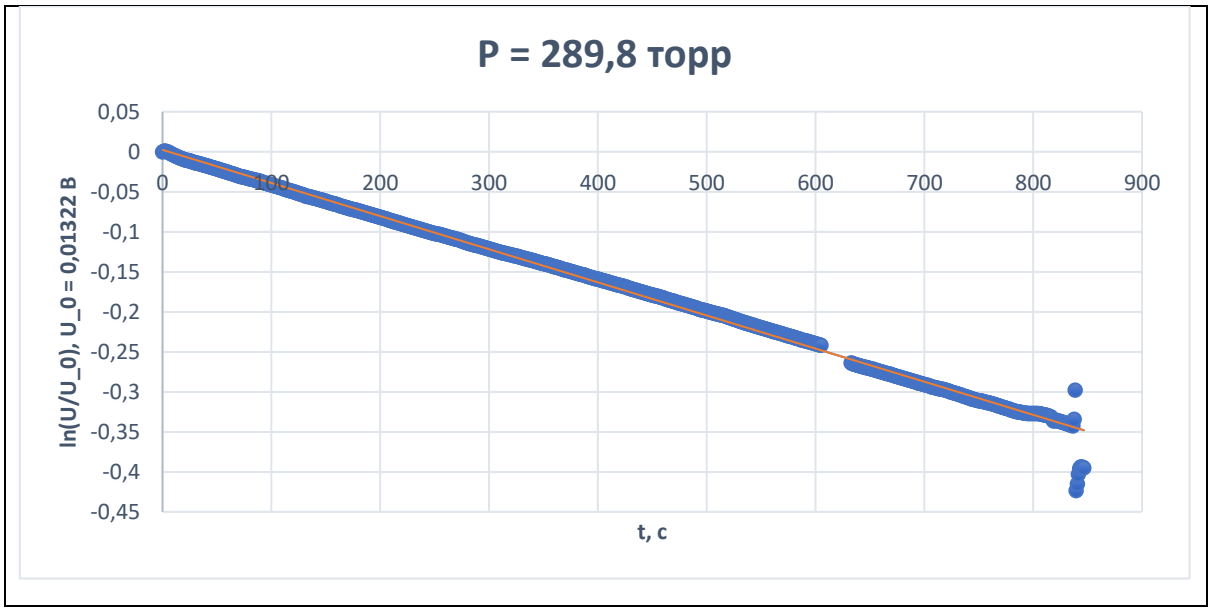
$\sigma_{D_{100,5}} = \sqrt{(\frac{Vk}{2}\sigma_{L/S})^2 + (\frac{VL}{2S}\sigma_k)^2 + (\frac{Lk}{2S}\sigma_V)^2} = 0{,}0004 м^2/с$



k = -0,0006 $\pm 0{,}000002\ c^{-1}$

$D_{220,1} = 0{,}00256\ м^2/с$

$\sigma_{D_{220,1}} = \sqrt{(\frac{Vk}{2}\sigma_{L/S})^2 + (\frac{VL}{2S}\sigma_k)^2 + (\frac{Lk}{2S}\sigma_V)^2}$ = 0,00018$м^2/с$



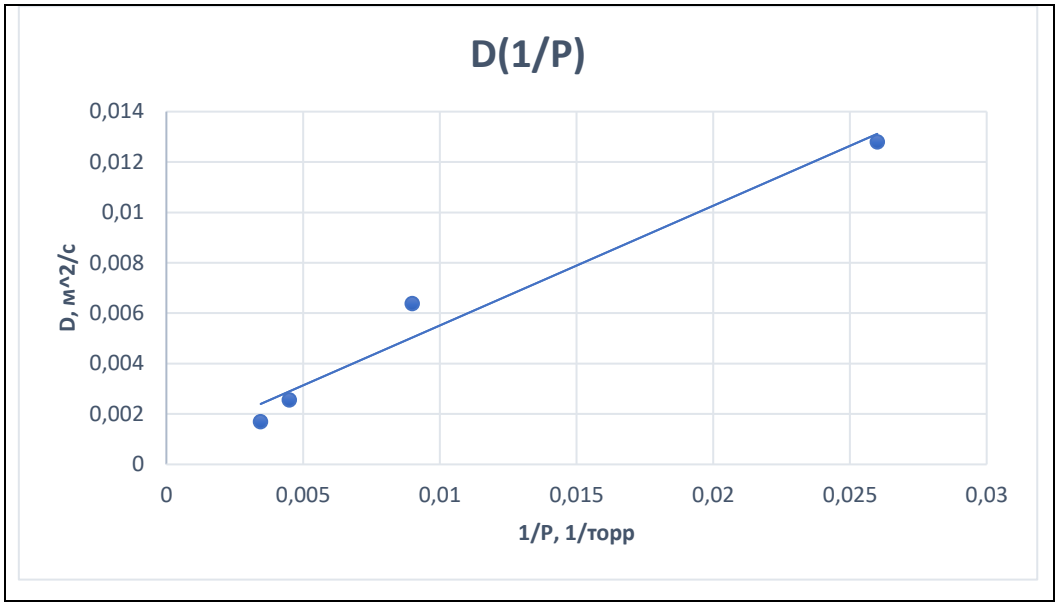
k = -0,0004 $\pm 0{,}000004\ c^{-1}$

$D_{289,8} = 0{,}00170\ м^2/с$

$\sigma_{D_{289,8}} = \sqrt{(\frac{Vk}{2}\sigma_{L/S})^2 + (\frac{VL}{2S}\sigma_k)^2 + (\frac{Lk}{2S}\sigma_V)^2}$ = 0,00012 $м^2/с$

Построим график зависимости D(1/P).

D, м*м/с	0,0128	0,00639	0,00256	0,00170
P, торр	38	110,5	220,1	289,8
1/P, 1/торр	0,026	0,009	0,0045	0,00345



Посчитаем коэффициент диффузии для атмосферного давления. $P_{атм} = 735,5$ торр.

Получаем, что $D_{атм} = 0,00064 \pm 0,00006 \frac{м^2}{с}$. Табличное значение составляет $0,00062 \frac{м^2}{с}$,

Оценим по полученным результатам длину свободного пробега и размер молекулы.

$\lambda = 3D/\langle v \rangle \approx 4156$нм

$\sigma_\lambda = 3\sigma_D/\langle v \rangle \approx 390$ нм

$d = \sqrt{\frac{1}{\sqrt{2}\pi n \lambda}} \approx 4,52 * 10^{-9}$м

$\sigma_d = 1/2 * d * \sigma_\lambda/\lambda \approx 2,12 * 10^{-10}$м

Вывод:

1) Рассчитали коэффициенты диффузии системы воздух-гелий при разных давлениях.

2) Получили зависимость коэффициента диффузии от давления и нашли коэффициент диффузии при атмосферном давлении.

3) Оценили длину свободного пробега атомов гелия в воздухе и размер молекулы.