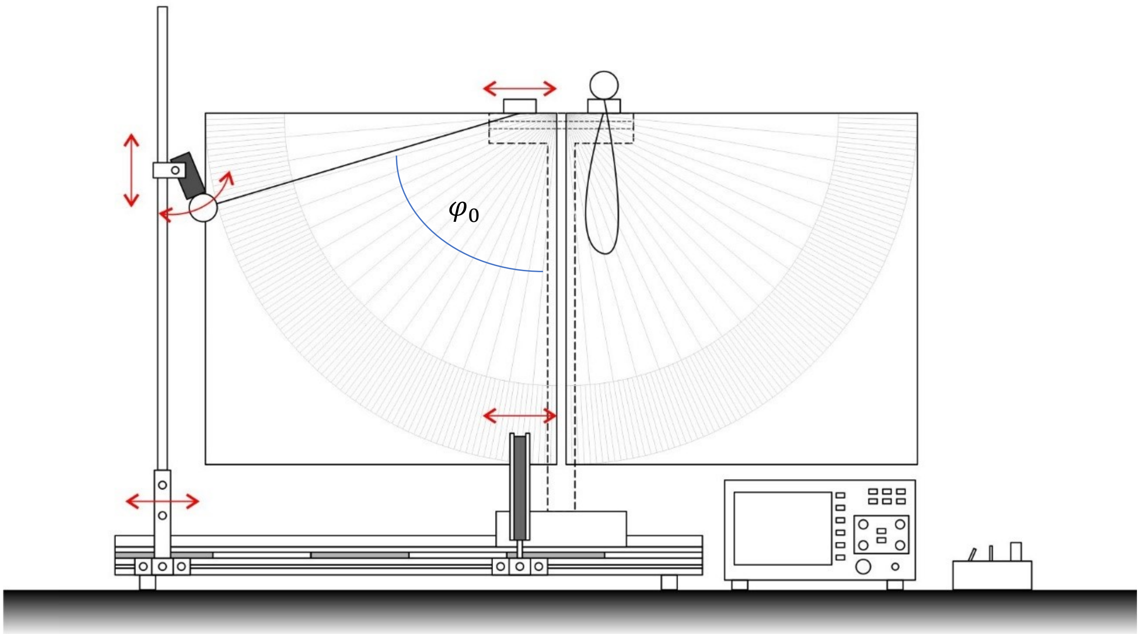
Experiment №1 English (Official)

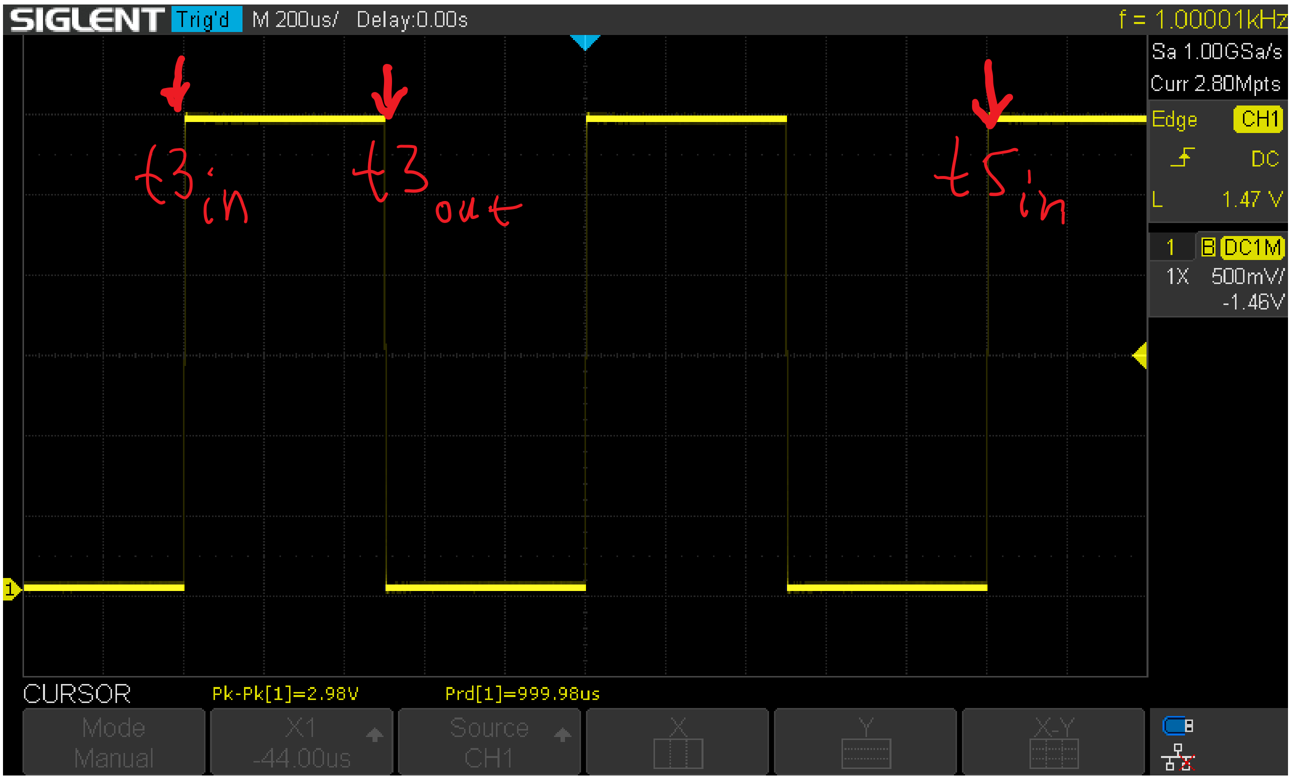
S1-1

Q1 HERTZIAN CONTACT STRESS

PART A. LARGE ANGLE PENDULUM



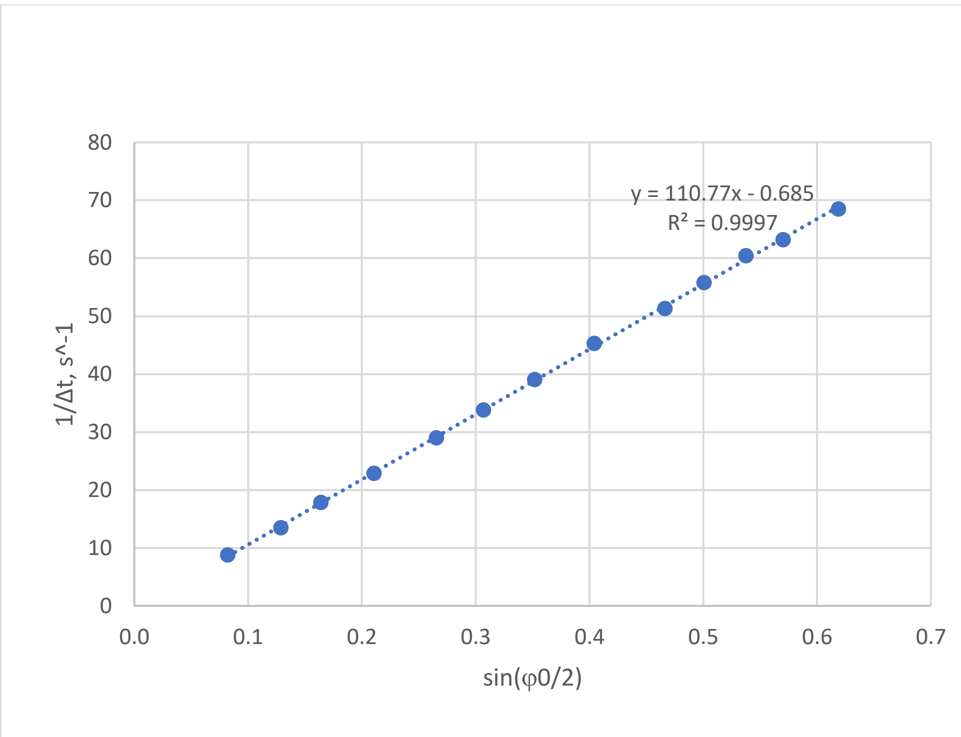
A.1. Δt *and* v



This record table includes both measurements A1 (Δt- time required for the fall to pass through the photogate) and B1($T - period\ of\ oscillation$) for each angle φ_0, in a single table, students can save time by doing both measurements at same angle.

Table №1

№	$\varphi_0,°$	$\sin\frac{\varphi_0}{2}$	$t3_{in}$, s	$t3_{out}$, s	$t5_{in}$, s	Δt, s	$\frac{1}{\Delta t}$, s^{-1}	T, s $t5_{in} - t3_{in}$	v, m/s
1	77.0	0.6188	1.257570	1.272170	2.51094	0.01460	68.49	1.25337	2.174
2	70.0	0.5701	1.227325	1.243150	2.45284	0.01583	63.19	1.22552	2.006
3	65.5	0.5376	1.218315	1.234875	2.43444	0.01656	60.39	1.21612	1.917
4	60.5	0.5006	1.203485	1.221420	2.40432	0.01794	55.76	1.20083	1.770
5	56.0	0.4664	1.188010	1.207500	2.37514	0.01949	51.31	1.18713	1.629
6	48.0	0.4041	1.170770	1.192860	2.34031	0.02209	45.27	1.16954	1.437
7	41.5	0.3519	1.158360	1.183990	2.31476	0.02563	39.02	1.15640	1.238
8	36.0	0.3069	1.147050	1.176660	2.29352	0.02961	33.77	1.14647	1.072
9	31.0	0.2654	1.140020	1.174520	2.27940	0.03450	28.99	1.13938	0.9200
10	24.5	0.2107	1.135300	1.179100	2.26742	0.04380	22.83	1.13212	0.7246
11	19.0	0.1639	1.115780	1.171840	2.24334	0.05606	17.84	1.12756	0.5662
12	14.9	0.1288	1.100050	1.174300	2.22485	0.07425	13.47	1.12480	0.4275
13	9.5	0.0822	1.107750	1.221600	2.23065	0.11385	8.78	1.12290	0.2789



graph №1: $\frac{1}{\Delta t}$ vs $\sin\frac{\varphi_0}{2}$

$$\mathrm{grad}_{1/\Delta t} = 110.77\ s^{-1} \quad (1)$$

A.2. Speed of ball: $v = k_v \sin\frac{\varphi_0}{2}$

$$\frac{mv^2}{2} = mgl(1-\cos\varphi_0) = 2mgl\sin^2\frac{\varphi_0}{2}$$

$$v = 2\sqrt{gl}\sin\frac{\varphi_0}{2} \quad (2)$$

$$v = \frac{d}{\Delta t}$$

$$\frac{1}{\Delta t} = 2\frac{\sqrt{gl}}{d}\sin\frac{\varphi_0}{2} \quad (3)$$

$$\mathrm{grad}_{1/\Delta t} = 2\frac{\sqrt{gl}}{d} = \frac{gT_0}{\pi d} = 110.77\ \mathrm{s}^{-1} \ (4)$$

$$d = 3.175 * 10^{-2}\ \mathrm{m}$$

$$v = k_v \sin\frac{\varphi_0}{2} \quad (5)$$

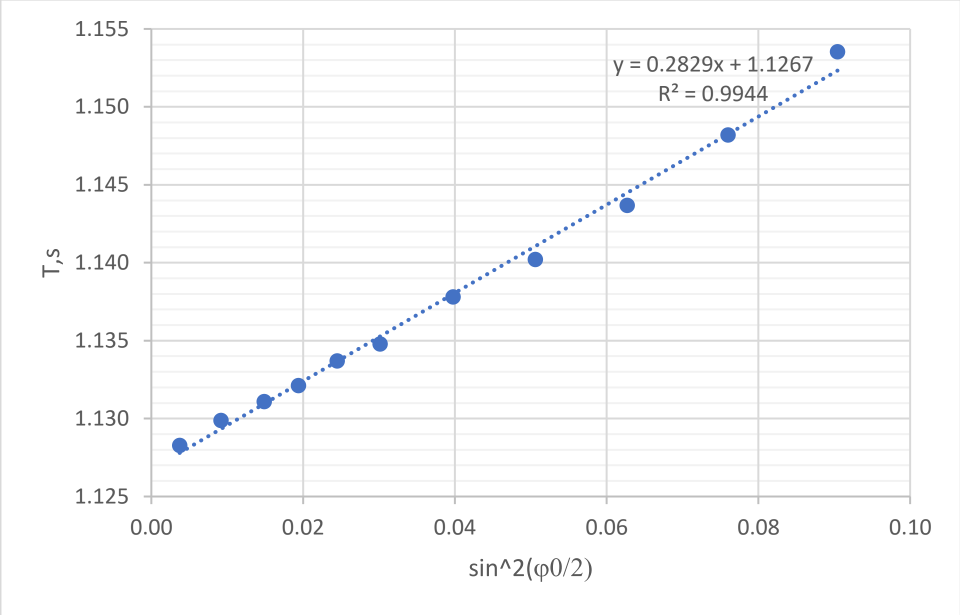
$$k_v = 3.517\frac{\mathrm{m}}{\mathrm{s}}$$

PART B. PERIOD OF THE OSCILLATION

B.1. PERIOD OF OSCILLATION: T_0, α, β

Table 2. Measurement at smaller angles

№	$\varphi_0,°$	$\sin\frac{\varphi_0}{2}$	$\sin^2\frac{\varphi_0}{2}$	$t3_{in}$, s	$t3_{out}$, s	$t5_{in}$, s	T, s	Δt, s	$\frac{1}{\Delta t}$, s^{-1}
1	35.0	0.3007	0.09042	1.153908	1.183840	2.307440	1.1535	0.02993	33.41
2	32.0	0.2756	0.07598	1.148388	1.181756	2.296584	1.1482	0.03337	29.97
3	29.0	0.2504	0.06269	1.138780	1.176372	2.282468	1.1437	0.03759	26.60
4	26.0	0.2250	0.05060	1.140252	1.182736	2.280460	1.1402	0.04248	23.54
5	23.0	0.1994	0.03975	1.133444	1.181036	2.271252	1.1378	0.04759	21.01
6	20.0	0.1736	0.03015	1.117848	1.175064	2.252636	1.1348	0.05722	17.48
7	18.0	0.1564	0.02447	1.133656	1.197872	2.267360	1.1337	0.06422	15.57
8	16.0	0.1392	0.01937	1.128688	1.204768	2.260812	1.1321	0.07608	13.14
9	14.0	0.1219	0.01485	1.131244	1.232416	2.262348	1.1311	0.10117	9.884
10	11.0	0.0958	0.00919	1.130564	1.269412	2.260456	1.1299	0.13885	7.202
11	7.0	0.0610	0.00373	1.127648	1.338152	2.255932	1.1283	0.21050	4.751



graph №2: T vs $\sin^2\frac{\varphi_0}{2}$

$$\sin^4\frac{30°}{2} = 4.5 * 10^{-3} \ll 1$$

$$T \approx T_0\left(1 + \alpha * \sin^2\frac{\varphi_0}{2}\right)$$

$$T_0 = 1.1267 \text{ s}$$

$$\alpha T_0 = 0.2829 \text{ s}$$

$$\alpha = \frac{0.2829}{1.1267} = 0.251$$

$$\alpha_{theor} = \frac{1}{4} = 0.250$$

$$\varepsilon_\alpha < 1\%$$

Experiment №1

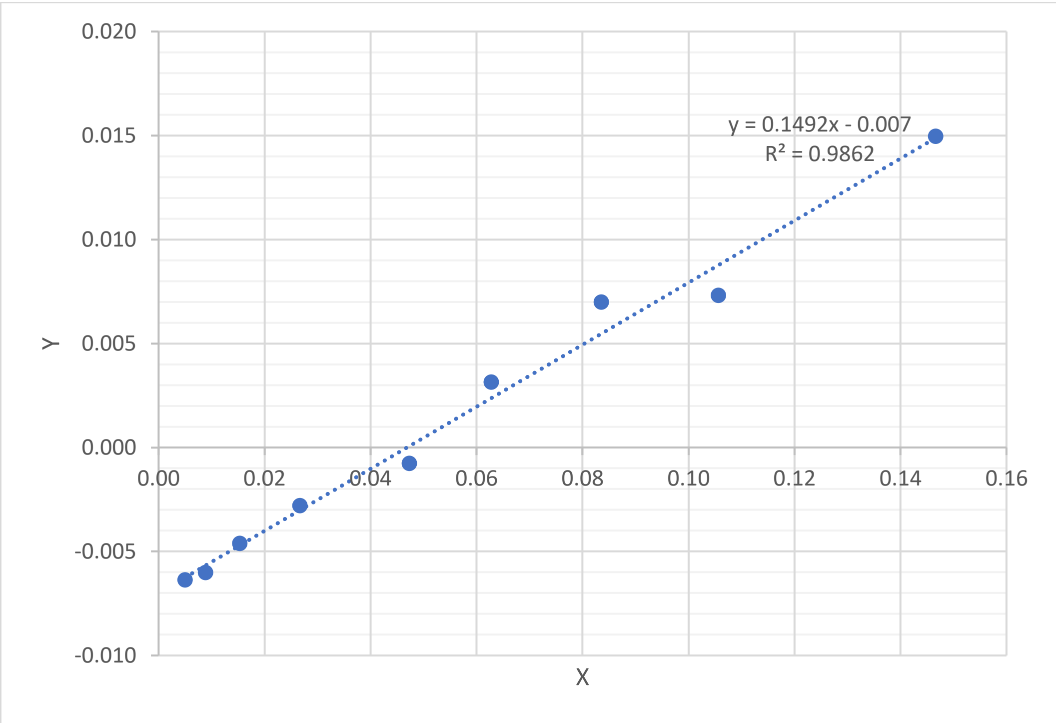
Table 3. Measurement at higher angles

№	$\varphi_0, ^\circ$	$t3_{in}$, s	$t5_{in}$, s	$\sin\frac{\varphi_0}{2}$	$\sin^2\frac{\varphi_0}{2}$	$X = \sin^4\frac{\varphi_0}{2}$	$T = t5_{in} - t3_{in}$, s	Y
1	77.0	1.257570	2.50900	0.6188	0.3829	0.1466	1.25143	0.0150
2	70.0	1.227325	2.45380	0.5701	0.3250	0.1056	1.22648	0.0073
3	65.5	1.218315	2.43430	0.5376	0.2890	0.08353	1.21599	0.0070
4	60.5	1.203485	2.40432	0.5006	0.2506	0.06279	1.20083	0.0031
5	56.0	1.188010	2.37514	0.4664	0.2176	0.04734	1.18713	-0.0008
6	48.0	1.170770	2.34031	0.4041	0.1633	0.02665	1.16954	-0.0028
7	41.5	1.158360	2.31476	0.3519	0.1238	0.01534	1.15640	-0.0046
8	36.0	1.147050	2.29352	0.3069	0.09420	0.00887	1.14647	-0.0060
9	31.0	1.140020	2.27940	0.2654	0.07044	0.00496	1.13938	-0.0064
10	24.5	1.135300	2.26742	0.2107	0.04440	0.00197	1.13212	-0.0063
11	19.0	1.115780	2.24334	0.1639	0.02686	0.000722	1.12756	-0.0060
12	14.9	1.100050	2.22485	0.1288	0.01658	0.000275	1.12480	-0.0058
13	9.5	1.107750	2.23065	0.0822	0.00676	0.000046	1.12290	-0.0051

$$T = T_0\left(1 + \alpha * \sin^2\frac{\varphi_0}{2} + \beta * \sin^4\frac{\varphi_0}{2}\right)$$

$$Y = \frac{T}{T_0} - 1 - \alpha * \sin^2\frac{\varphi_0}{2};\ X = \sin^4\frac{\varphi_0}{2}$$

$$Y = \beta X$$



graph №3: Y vs X

$$\beta = 0.149$$

$$\beta_{theor} = \frac{9}{64} = 0.141$$

$$\varepsilon_\beta = 6\%$$

B.2 Free fall acceleration in UB: g_{UB}

$$d = 31.75\ \mathrm{mm}$$

$$\mathrm{grad}_{1/\Delta t} = 2\frac{\sqrt{gl}}{d} = \frac{gT_0}{\pi d} = 110.77\ \mathrm{s}^{-1} \quad \text{from A.1 (4)}$$

$$T_0 = 1.1267\ \mathrm{s}$$

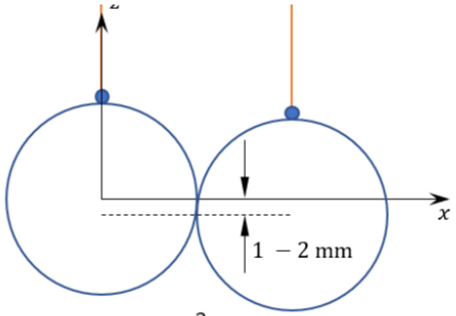
$$g_{exp} = \frac{\pi d * \mathrm{grad}_{1/\Delta t}}{T_0} = \frac{3.142 * 3.175 * 10^{-2} * 110.77}{1.1267} = 9.808\ \frac{\mathrm{m}}{\mathrm{s}^2}$$

$$g_{UB} = 9.804\ \frac{\mathrm{m}}{\mathrm{s}^2}$$

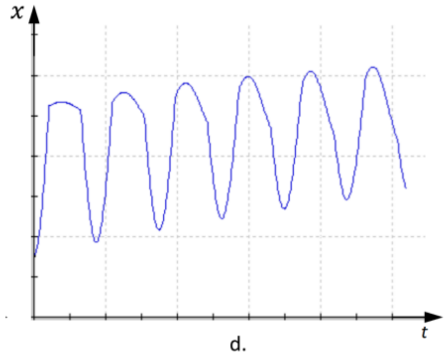
$$\varepsilon_g < 1\%$$

PART C: BEHAVIORS OF THE COLLISIONS

C1

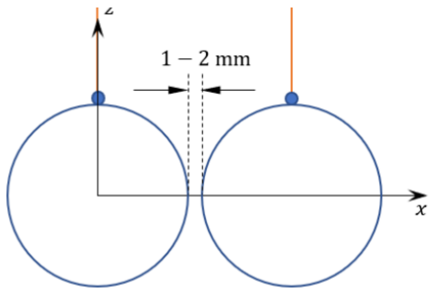


a.

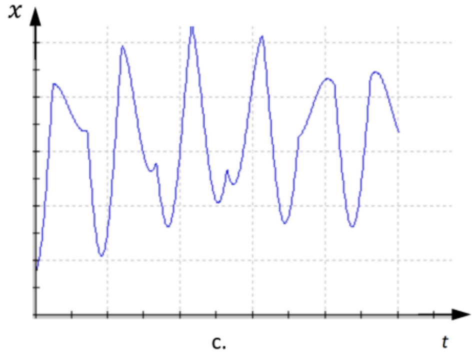


d.

C2

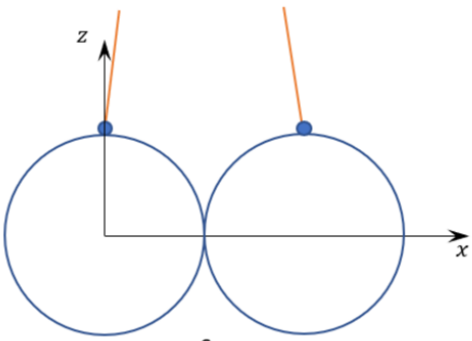


b.

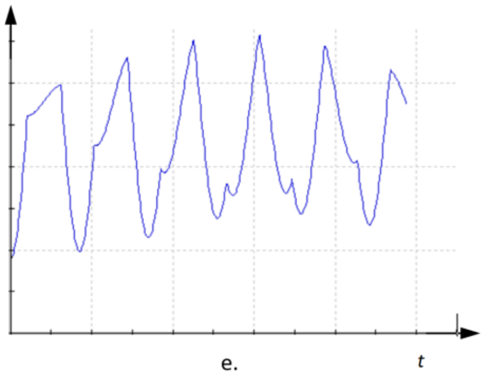


c.

C3

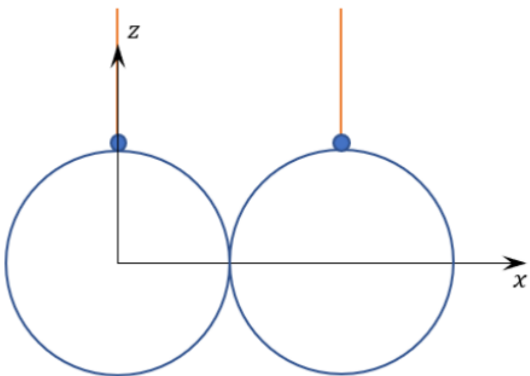


c.

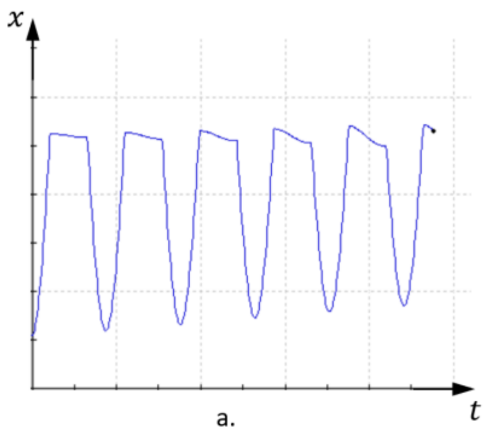


e.

C4



d.



a.

PART D: TIME OF COLLISIONS

D.1 Collision time equation: dimensional analysis

$$\tau = A * M^{\varepsilon_1} E^{\varepsilon_2} R^{\varepsilon_3} v^{\varepsilon_4} \quad (6)$$

$$M - \ mass; E - Young's\ modulus; R - radius; v - speed; A - dimensionless\ constant$$

$$\tau = M^{\varepsilon_1} M^{\varepsilon_2} L^{-\varepsilon_2} T^{-2\varepsilon_2} L^{\varepsilon_3} L^{\varepsilon_4} T^{-\varepsilon_4}$$

$$\begin{cases} M: 0 = \varepsilon_1 + \varepsilon_2 \\ L:\ 0 = -\varepsilon_2 + \varepsilon_3 + \varepsilon_4 \\ T: 1 = -2\varepsilon_2 - \varepsilon_4 \end{cases}$$

Three equations, Four exponents ($\varepsilon_1,\ \varepsilon_2, \varepsilon_3, \varepsilon_4$). You have to determine some exponent in an experimental way.

D.2 Exponent of speed

$$\tau = const * v^{\varepsilon_4}$$

For expression (5)

$$v = k_v \sin\frac{\varphi_0}{2}$$

$$k_v = 3.517\,\frac{\mathrm{m}}{\mathrm{s}}$$

$$m = 131.48\ \mathrm{g};\ \ d = 31.73\ \mathrm{mm}; l = 29.7\ \mathrm{cm}; \text{sound speed in steel } c = \sqrt{\frac{E'}{\rho}} = 5180\,\frac{\mathrm{m}}{\mathrm{s}}$$

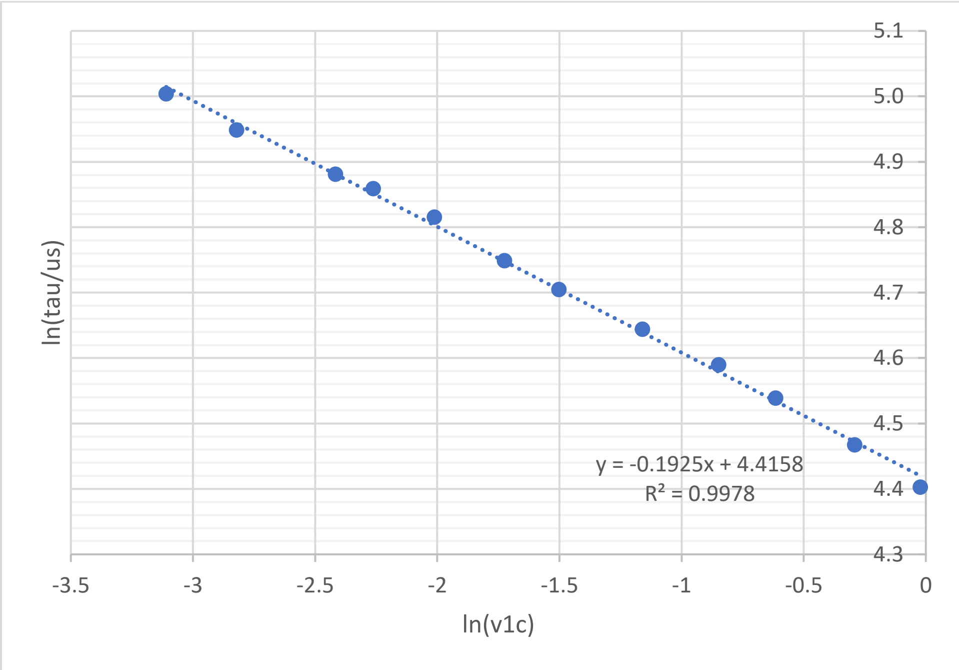
Table 4. Time of collisions as a function of speed

$\varphi_0, °$	corrected	$v, \mathrm{m/s}$	$v_{1c}, \mathrm{m/s}$	$\tau, \mu s$	ln (v_{1c}, m/s)	Ln ($\tau, \mu s$)
70.0	69.98	1.96	0.978	81.7	-0.0227	4.403
52.0	51.99	1.49	0.747	87.14	-0.2916	4.468
37.0	36.99	1.08	0.541	93.58	-0.6148	4.539
29.1	29.09	0.86	0.428	98.47	-0.8483	4.590
21.2	21.19	0.63	0.313	104.00	-1.1600	4.644
15.0	15.00	0.44	0.222	110.50	-1.5030	4.705
12.0	12.00	0.36	0.178	115.50	-1.7252	4.749
9.0	9.00	0.27	0.134	123.40	-2.0121	4.815
7.0	7.00	0.21	0.104	128.90	-2.2630	4.859
6.0	6.00	0.18	0.089	131.80	-2.4169	4.881
4.0	4.00	0.12	0.059	141.00	-2.8222	4.949
3.0	3.00	0.09	0.045	149.00	-3.1098	5.004
1.0	1.0	0.03	0.015	207.00	-4.2083	5.333

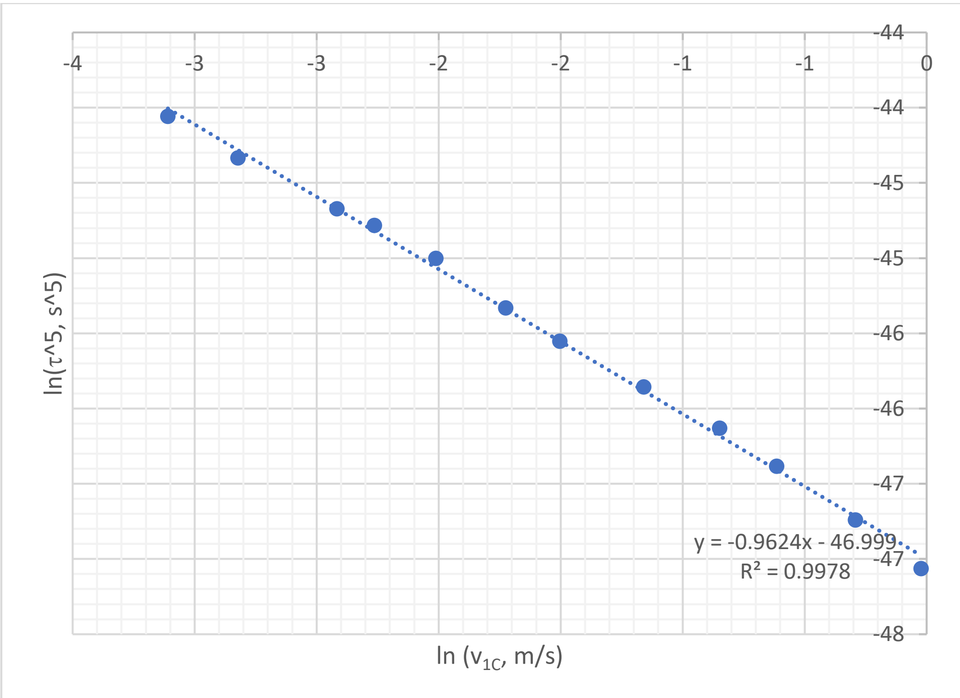
$$v_{1c} = \frac{v}{2}$$

$$\varepsilon_4 = -0.193\ (3.5\ \%)$$

$$\varepsilon_{4theor} = -0.200$$

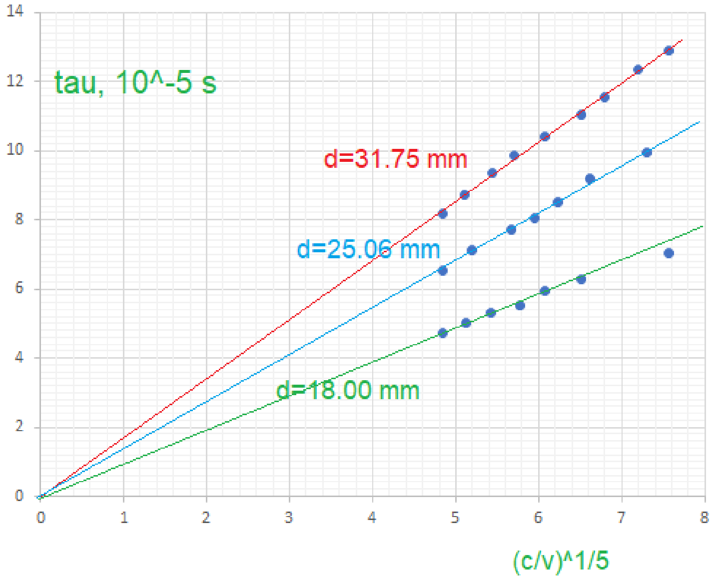


graph №4: $\tau\ vs\ v_{1c}$



$$\varepsilon_4 = -0.96/5 \approx -1/5\ (rel.error = 4\ \%)$$

Exponent of radius



graph №5: $\tau\ vs\ \left(\frac{c}{v}\right)^{\frac{1}{5}}$ at different diameters of balls

$$grad1 : grad2 : grad3 = 12 : 9.5 : 6.8 = 1.76 : 1.40 : 1$$

$$d_1 : d_2 : d_3 = 31.75 : 25.06 : 18.00 = 1.76 : 1.40 : 1$$

Result:

$$\tau \sim (R_1 + R_2)$$

D.3 Solution of exponents:

$$\varepsilon_1 = \frac{2}{5}$$

$$\varepsilon_2 = -\frac{2}{5}$$

$$\varepsilon_3 = -\frac{1}{5}$$

$$\varepsilon_4 = -\frac{1}{5}$$

$$\tau^5 \sim M^2 E^{-2} R^{-1} v^{-1}$$

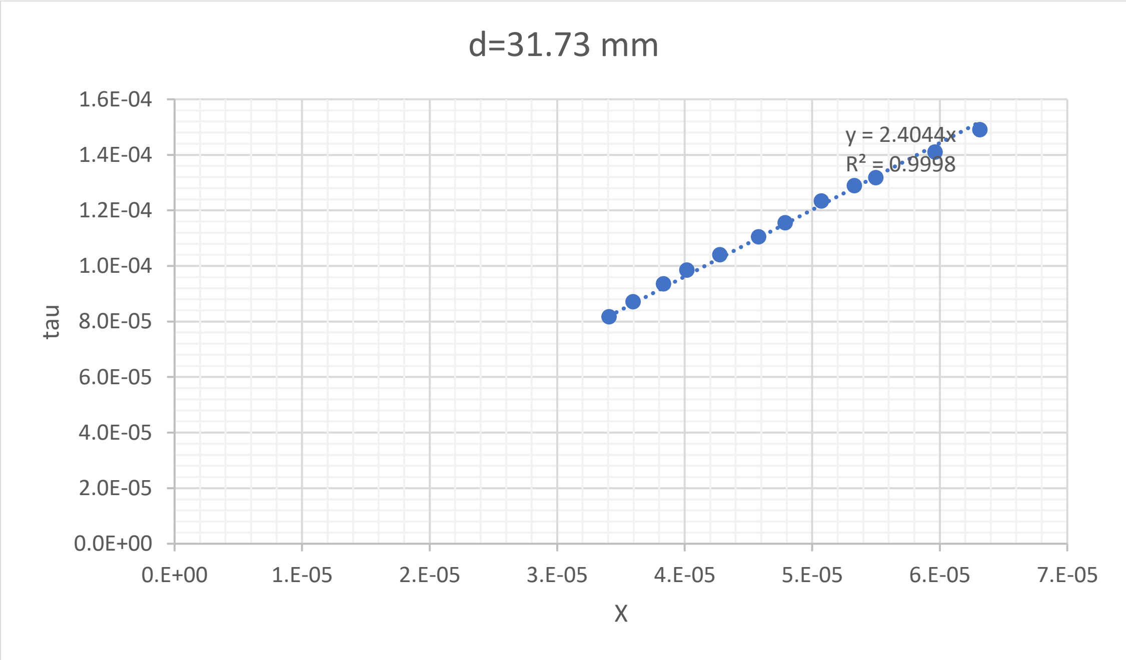
$$\tau^5 \sim \frac{M^2}{E^2 R v}$$

$$\tau^5 \sim \frac{\rho^2 R^6}{E^2 R v} \sim \frac{R^6}{c^4 R v} \sim \frac{R^5}{c^5} * \frac{c}{v}$$

$$\tau \sim \frac{R_1 + R_2}{c} * \left(\frac{c}{v}\right)^{\frac{1}{5}} = X$$

D.4 Numerical value of A in (6)

$$m = 131.48\ \mathrm{g};\ \ d = 31.73\ \mathrm{mm};\ l = 29.7\ \mathrm{cm};\ c = 5180\frac{\mathrm{m}}{\mathrm{s}}$$



graph №6: $\tau\ vs\ X$

$$A_{exp} = 2.40$$

$$\tau = 2.40\frac{R_1 + R_2}{c} * \left(\frac{c}{v}\right)^{\frac{1}{5}} \qquad (6')$$

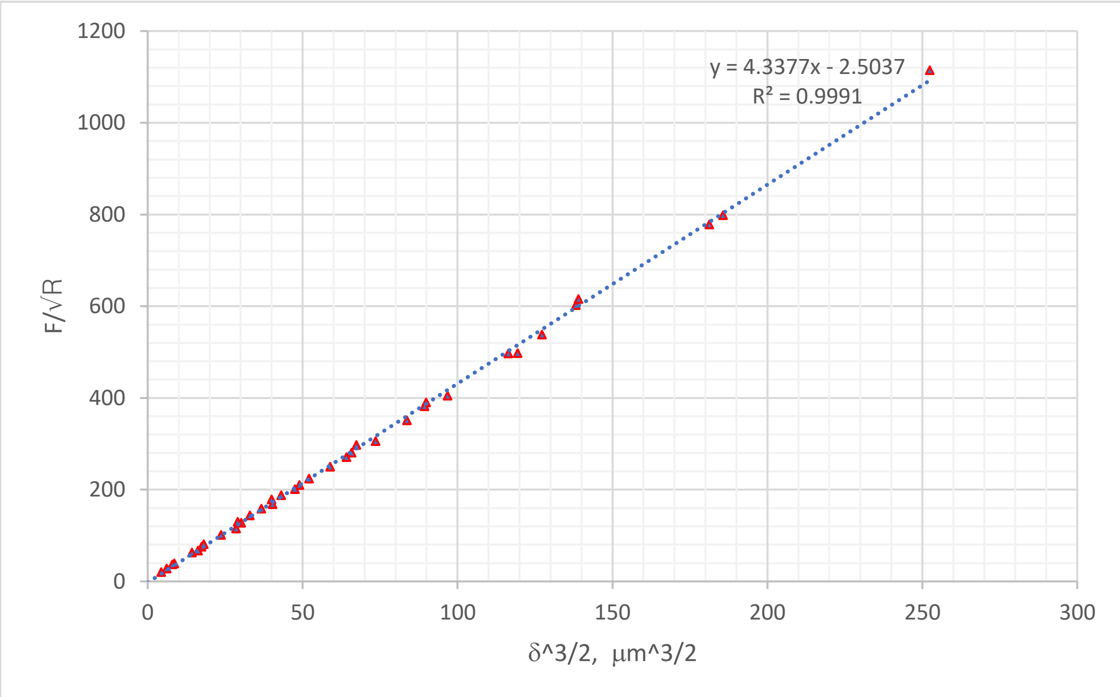
PART E: THE PARAMETERS OF HERTZ DEFORMATION

Table 5. Force, Hertz Deflection, Hertz Radius, Hertz Pressure.

Balls	φ_0, ,	v, m /s	τ, µs	Δp, Ns	F_{av}, N	δ, µm	$\delta^{\frac{1}{5}}$, $\mu m^{1.5}$	$\frac{F_{av}}{\sqrt{R}}$, $Nm^{-0.5}$	a, mm	P_0, GPa
d/mm	70.0	1.96	81.70	0.2565	3139	39.93	252.3	1114.2	0.55	4.88
31.74	52.0	1.49	87.14	0.1960	2249	32.55	185.7	798.4	0.50	4.37
m/g	37.0	1.08	93.58	0.1419	1516	25.30	127.3	538.1	0.43	3.83
131.48	29.1	0.86	98.47	0.1123	1141	21.08	96.8	404.9	0.40	3.48
	21.2	0.63	104.00	0.0822	791	16.30	65.8	280.7	0.35	3.08
	15.0	0.44	110.50	0.0584	528	12.29	43.1	187.5	0.31	2.70
	12.0	0.36	115.50	0.0467	405	10.29	33.0	143.6	0.28	2.47
	9.0	0.27	123.40	0.0351	284	8.25	23.7	100.9	0.25	2.19
	7.0	0.21	128.90	0.0273	212	6.71	17.4	75.2	0.23	1.99
	6.0	0.18	131.80	0.0234	178	5.88	14.3	63.0	0.21	1.87
	4.0	0.12	141.00	0.0156	111	4.19	8.6	39.3	0.18	1.60
	3.0	0.09	149.00	0.0117	79	3.32	6.1	27.9	0.16	1.43
d/mm	70.0	1.958	65.43	0.1274	1947	32.02	181.2	778.1	0.44	4.87
25.42	47.1	1.362	71.20	0.0886	1245	24.24	119.4	497.4	0.38	4.2
m/g	30.1	0.909	77.27	0.0591	765	17.55	73.5	305.8	0.32	3.54
67.55	23.5	0.693	80.40	0.0451	561	13.93	52.0	224.2	0.29	3.22
	18.5	0.552	85.20	0.0359	422	11.76	40.3	168.5	0.26	2.92
	13.8	0.407	91.85	0.0265	288	9.34	28.6	115.2	0.23	2.59
	8.4	0.257	99.70	0.0167	168	6.41	16.2	67.1	0.19	2.13
d/mm	70.0	2.022	47.15	0.0497	1054	23.84	116.4	496.8	0.32	4.91
18.00	50.5	1.523	50.25	0.0374	745	19.13	83.7	351.0	0.28	4.35
m/g	37.5	1.142	53.00	0.0281	529	15.13	58.9	249.6	0.25	3.89
24.57	27.5	0.849	55.10	0.0209	379	11.70	40.0	178.5	0.22	3.47
	21.1	0.653	59.25	0.0161	271	9.68	30.1	127.7	0.2	3.11
	15.0	0.439	62.80	0.0108	172	6.89	18.1	81.0	0.18	2.72
	7.0	0.226	70.20	0.0056	79	3.97	7.9	37.3	0.13	2.04
	4.0	0.136	78.80	0.0033	42	2.68	4.4	20.0	0.1	1.63
R1, R2/mm	70.0	1.956	54.89	0.0809	1475	26.83	139.0	615.2	0.39	4.71
9.00	69.0	1.931	55.37	0.0799	1443	26.73	138.2	602.3	0.38	4.68
15.88	46.5	1.346	59.61	0.0557	934	20.06	89.8	389.9	0.33	4.04
m1, m2/g	45.9	1.329	60.13	0.0550	915	19.98	89.3	381.8	0.33	4.02
24.57	36.5	1.068	62.00	0.0442	713	16.55	67.3	297.4	0.3	3.7
131.18	34.2	1.002	63.92	0.0415	649	16.02	64.1	270.8	0.29	3.58

Experiment №1 English (Official)

R, mm	27.4	0.807	66.30	0.0334	504	13.38	49.0	210.3	0.27	3.29
5.74	26.5	0.781	67.10	0.0323	482	13.11	47.5	201.1	0.27	3.24
μ, g	21.5	0.636	69.46	0.0263	379	11.04	36.7	158.1	0.25	2.99
20.69	18.0	0.533	70.90	0.0221	311	9.45	29.1	129.9	0.23	2.8



graph №7: *Unified graph for balls*

Equivalent mass

$$\mu = \frac{m_1 m_2}{m_1 + m_2} \qquad (7)$$

$$v_{relarive} = v_{1x} - v_{2x} = v_1 - 0 = v_1$$

$$\Delta p = 2\mu v_{\text{relative}} \qquad (8)$$

$$F_{av} = \frac{\Delta p}{\tau} \qquad (9)$$

$$K_{\text{system,C}} = \frac{1}{2}\mu \text{v}_{\text{relative}}^2 \quad (10)$$

$$K_{\text{system,C}} = F_{av}\delta$$

$$\delta = \frac{K_{\text{system,C}}}{F_{av}} \qquad (11)$$

Deflection

$$\delta \lesssim \frac{K_{\text{system,C}}}{F_{av}}$$

$$\delta \lesssim \frac{v_{\text{relative}}}{4}\tau \quad (12)$$

Hertz radius

From fig Q1:

$$a^2 = R^2 - \left(R - \frac{\delta}{2}\right)^2 \approx R\delta$$

$$a = \sqrt[3]{\frac{3FR}{4E'}} = \sqrt{R\delta} \quad \text{Hertz radius} \quad (13)$$

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} \qquad (14)$$

$$\delta = \sqrt[3]{\frac{9F_{av}^2}{16RE'^2}} \quad \text{Hertz deformation} \quad (15)$$

Reduced Youngs Modulus

$$\frac{1}{E'} = \frac{1-\nu_1^2}{E_1} + \frac{1-\nu_2^2}{E_2} = 2\frac{1-\nu_1^2}{E_1}$$

Poisson’s ratio

$$\nu_1 = \nu_2 = 0.3$$

Hertz pressure

$$P_{av} = \frac{1}{\pi a^2}\int_0^a P(r)2\pi r dr = -P_0\int_0^a \left(1-\frac{r^2}{a^2}\right)^{\frac{1}{2}} d\left(1-\frac{r^2}{a^2}\right) = \frac{2}{3}P_0$$

$$P_0 = \frac{3}{2}P_{av} \qquad (16)$$

$$P_0 = \frac{2}{\pi}E' * \left(\frac{\delta}{R}\right)^{\frac{1}{2}} \quad (17)$$

$$F_{max} = \frac{3}{2}F_{av} \qquad (18)$$

$$F_{av} \sim \sqrt{R\delta^3} \qquad (19)$$

Problem 2: Interference from thermally deformed surface (thermos-deformation)

Part A [0.8 points]

The resulting pattern exhibits reversibility and shrinkage up to a certain power value. The upper boundary value corresponding to the thermo-elastic range which is known as yield strength should be determined.

A.1	Determine the power associated with this yield strength (p_{max}).	0.3pt
	For 350-400 mW 0.3 pts For 300-350 mW 0.2 pts For 400-450 mW 0.1 pts	

I, mA	V, V	P, mW	P_{avg}, mW
97.3	3.74	363.90	363.6
98.3	3.75	368.63	
97.6	3.74	365.02	
96.5	3.73	359.95	
96.7	3.73	360.69	

A.2	Determine the diameter of the outermost bright fringe when the laser power is set to the level associated with the yield strength.	0.5pt
	The outermost diameter determined by locating the screen farther from target as following: Determined the diameter value 0.3 pts Distance between the target and screen 0.2 pts	

$L = 49.2\ cm$

D_{out}, cm	$< D_{out} >$, cm
27.0	27.5
26.0	
28.0	
28.5	
28.0	

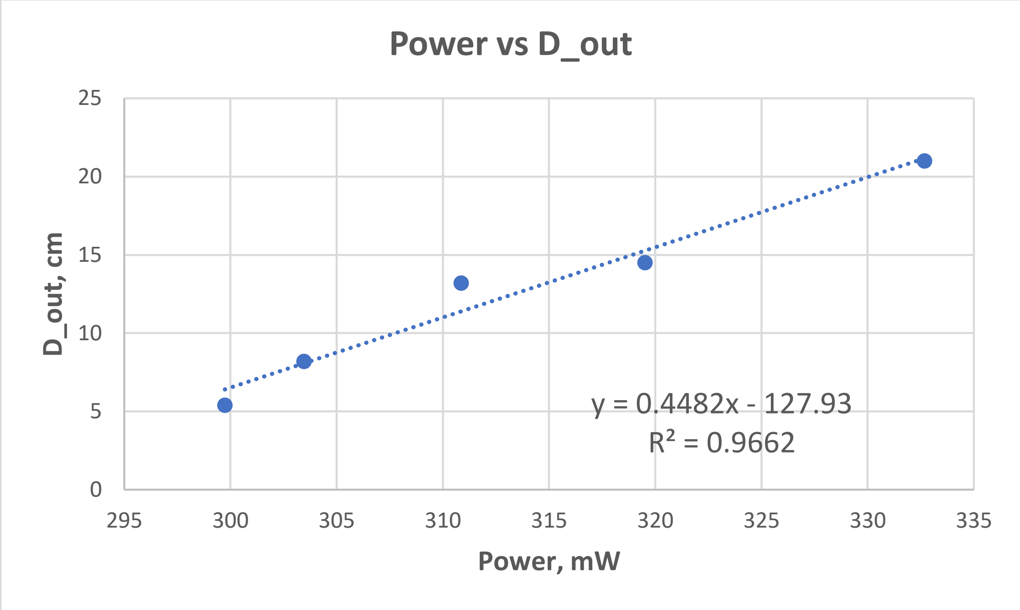
L, cm	49.2	45	40	35	30	25	20	15	10	5
D, cm	27.5	25.6	22.8	19.9	17.1	14.2	11.4	8.5	5.7	2.8

Part B [3.5 points]

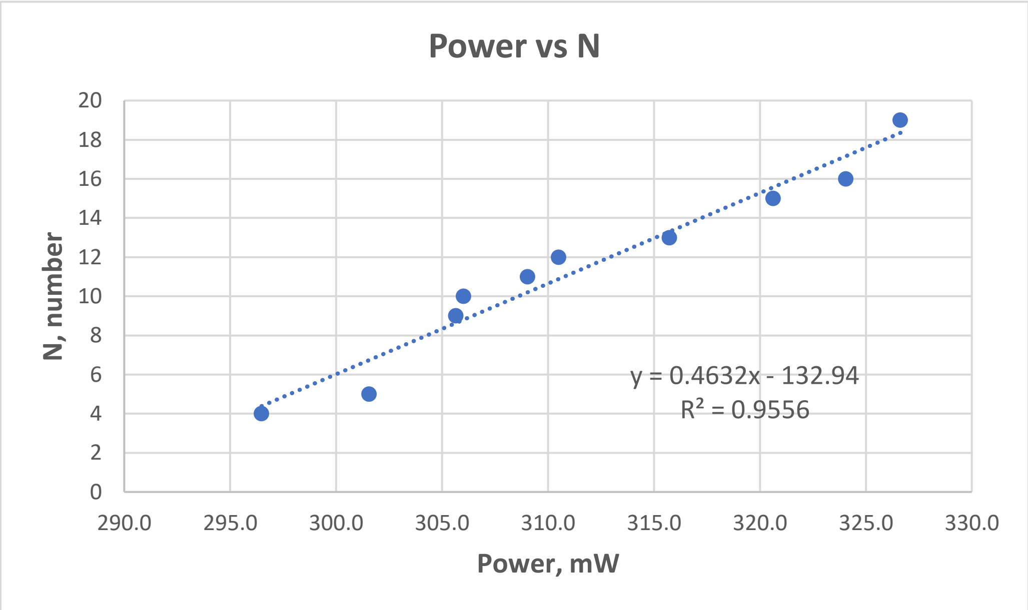
B.1	The diameter of the outermost light fringe and the number of fringes formed in this test are measured in relation to the power and the results should be recorded in an Answer sheet table.	1.5pt
	• At least 10 measurement points 0.3 pts For 7-9 points 0.2 pts For 5-6 points 0.1 pts For 150-300 mW 0.3 pts For 100-150 mW 0.2 pts • Measured voltage for all rows in the table 0.2 pts For 7-9 points 0.1 pts • Measured current for all rows in the table 0.2 pts For 7-9 points 0.1 pts • Calculated power for all rows in the table 0.2 pts For 7-9 points 0.1 pts • Significant figure all same number 0.3 pts	

№	I, mA	U, V	P, mW	N
1	81.9	3.62	296.5	4
2	83.3	3.62	301.5	5
3	84.2	3.63	305.6	9
4	84.3	3.63	306.0	10
5	84.9	3.64	309.0	11
6	85.3	3.64	310.5	12
7	86.5	3.65	315.7	13
8	87.6	3.66	320.6	15
9	88.3	3.67	324.1	16
10	89.0	3.67	326.6	19
11	92.1	3.70	340.8	20
12	94.3	3.72	350.8	21

B.2	Construct a graph depicting the relationship between the diameter of the outermost light interference fringe on the screen and the corresponding power level.	1.0pt
	At least 10 measured points appear in the graph 0.4 pts The data covers at least 75% of each coordinate length 0.4 pts There are labels in each axis 0.2 pts	



B.3	Plot the number of interference fringes on the screen is measured as a function of power.	1.0pt
	At least 10 measured points appear in the graph 0.4 pts The data covers at least 75% of each coordinate length 0.4 pts There are labels in each axis 0.2 pts	



Part C [3.7 points]

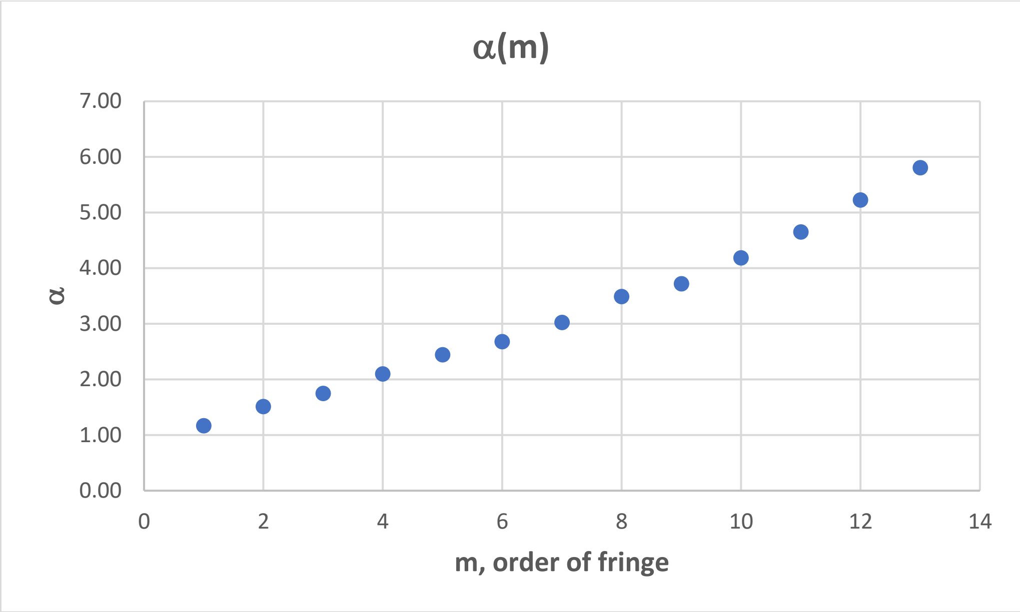
C.1	Measure the angular width (an angle between the ray of nth order fringe and the ray of $n+1$th order fringe) and visible angle (an angle between the ray of nth order fringe and x-axis) of the dark fringe at a constant power level, depending on the number of the fringe, and record the results in Answer Sheet Table.	1.2pt
	At least 10 measurement points 0.4 pts For 7-9 points 0.2 pts For 5-6 points 0.1 pt The power determined 0.1 pts The visible angle values determined 0.2 pts The angular width values determined 0.3 pts Significant figure all same number 0.2 pts	

m	R, cm	L, cm	$\tan(\alpha_m)$	α_m, °	α_m, mrad	$\Delta\alpha_m$, °	$\Delta\alpha_m$, mrad
1	1.0	49.2	0.020	1.16	20.3	0.35	6.1
2	1.3		0.026	1.51	26.4	0.23	4.0
3	1.5		0.030	1.75	30.6	0.35	6.1
4	1.8		0.037	2.10	36.7	0.35	6.1
5	2.1		0.043	2.44	42.6	0.23	4.0
6	2.3		0.047	2.68	46.8	0.35	6.1
7	2.6		0.053	3.03	52.9	0.46	8.0
8	3.0		0.061	3.49	60.9	0.23	4.0
9	3.2		0.065	3.72	65.0	0.46	8.0
10	3.6		0.073	4.18	73.0	0.46	8.0
11	4.0		0.081	4.65	81.2	1.04	18.2
12	4.5		0.100	5.69	99.3	1.04	18.2
13	5.0		0.118	6.72	117.3		

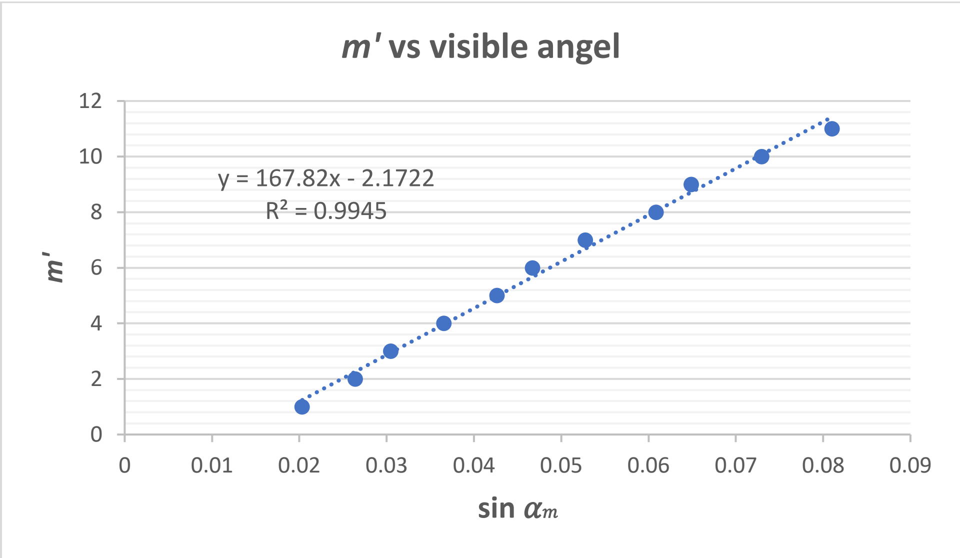
C.2. Plot a linear graph of the relationship between the visible angle vs order of fringe.

C.2	Plot a linear graph of the relationship between the visible angle vs order of fringe.	1.0pt
	At least 10 measured points appear in the graph 0.4 pts The data covers at least 75% of each coordinate length 0.4 pts There are labels in each axis 0.2 pts	

1. **Non-linear graph (0.2pts)**



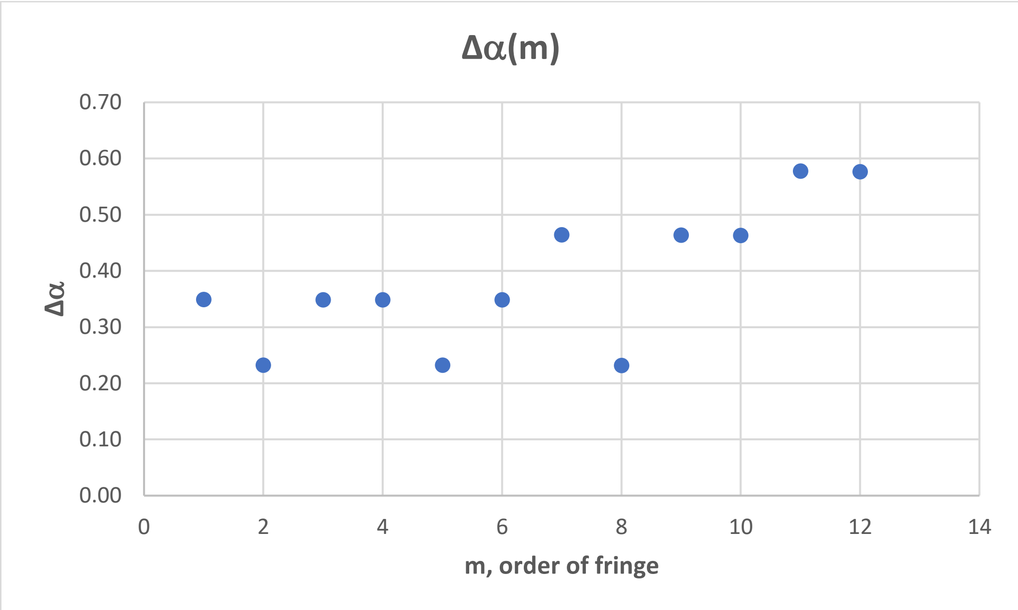
2. Linearized graph (0.8pts)



C.3	Find the slope and Y-intercept of the graph plotted in Task C.2.	0.5pt
	Plotted regression line and calculate slope 0.3 pts Value of grad 0.2 pts	

$$m' = 167.82 \cdot \sin \alpha_m - 2.1722$$

C.4	Construct a graph of angular width as a function of the order of fringes.	1.0pt
	At least 10 measured points appear in the graph 0.2 pts The data covers at least 75% of each coordinate length 0.2 pts There are labels in each axis 0.2 pts Plotted regression line and calculate slope 0.2 pts Value of grad 0.2pts	

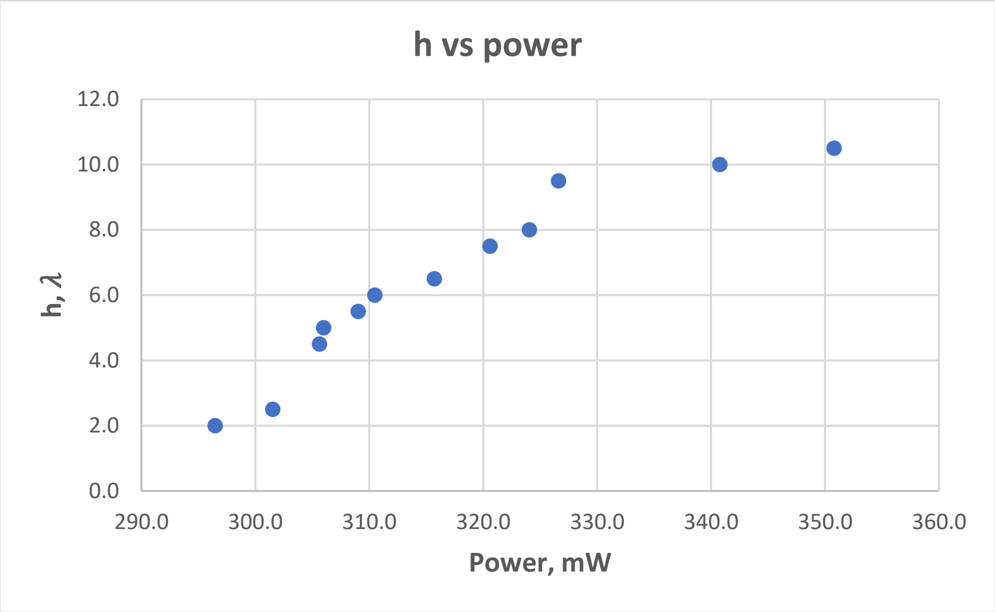


Part D [2.0 points]

D.1	By counting the number of the fringes determine the highest order of the fringes. Determine the height of the thermal deformation in terms of the laser wavelength as a function of the laser power. Plot a graph of your data. Hint: ensure your data includes the range of $200mW$ to $400mW$.	1.4pt
	Each data point 0.1 pt (10 datas) At least 8 measured points appear in the graph 0.2 pts There are labels in each axis 0.2 pts	

№	m_{max}	P, mW	h, λ
1	4	296.5	2.0
2	5	301.5	2.5
3	9	305.6	4.5
4	10	306.0	5.0

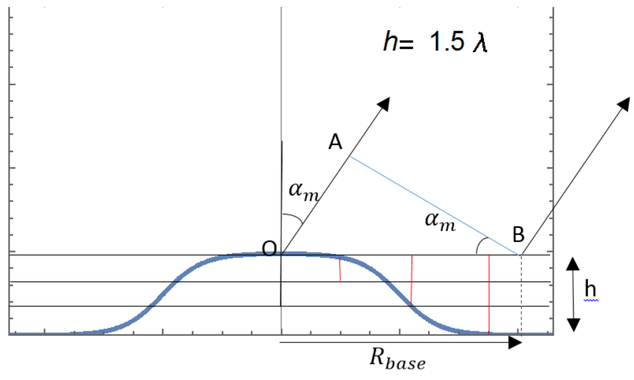
5	11	309.0	5.5
6	12	310.5	6.0
7	13	315.7	6.5
8	15	320.6	7.5
9	16	324.1	8.0
10	19	326.6	9.5
11	20	340.8	10.0
12	21	350.8	10.5



D.2	What are the thermal deformation heights for the following input laser powers? Give your answers in units of the number of laser wavelengths. • 200 mW • 300 mW • 400 mW	0.6pt
	For 200 mW 0.2 pts For 300 mW 0.2 pts For 400 mW 0.2 pts	

P, mW	h, λ
200	-12.6
300	3.6
400	19.8

Appendix



Maximum optical path difference of rays is 2h for central maximum.

For m^th fringe which is observed by visible angle α_m, the optical path difference for the rays from the top and bottom of a bump is:

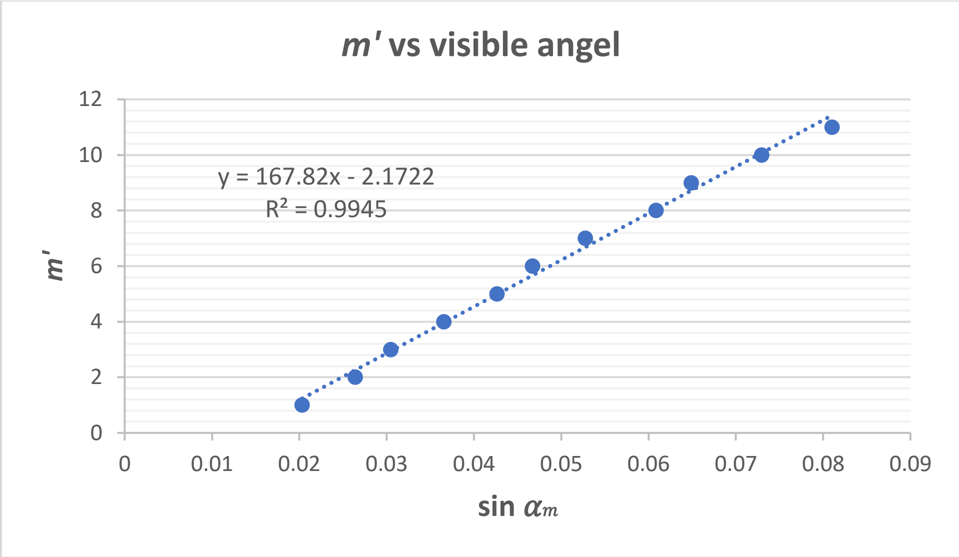
$$\Delta s_m \approx 2h - OA = n\lambda - R\ \sin\alpha_m = n\lambda - m\lambda$$

$$R\sin\alpha_m = m\lambda\ \Rightarrow R = \frac{m\lambda}{\sin\alpha_m}$$

Data obtained in Part C.1 were used.

m'	R, cm	L, cm	$\tan\alpha_m$	$\sin\alpha_m$
1	1.0	49.2	0.0203	0.0203
2	1.3		0.0264	0.0264
3	1.5		0.0305	0.0305
4	1.8		0.0366	0.0366
5	2.1		0.0427	0.0426
6	2.3		0.0467	0.0467
7	2.6		0.0528	0.0528
8	3.0		0.0610	0.0609
9	3.2		0.0650	0.0649
10	3.6		0.0732	0.0730
11	4.0		0.0813	0.0810
12	4.5		0.0915	0.0911
13	5.0		0.1016	0.1011

Here, m' and m are observed and real number of fringes, respectively.



$$m' = 167.82 \cdot \sin \alpha_m - 2.1722$$

From the above equation, it shows that difference between m' and m is 2.1722≈2 which is the number of fringes hidden in the central circle. From our data, $m = m^{'} + 2 = 15$.

From the experiment, height of the bump is calculated to be 7.5λ and the base radius is $R_{base} \approx 167.82\lambda$.