SOLUTION

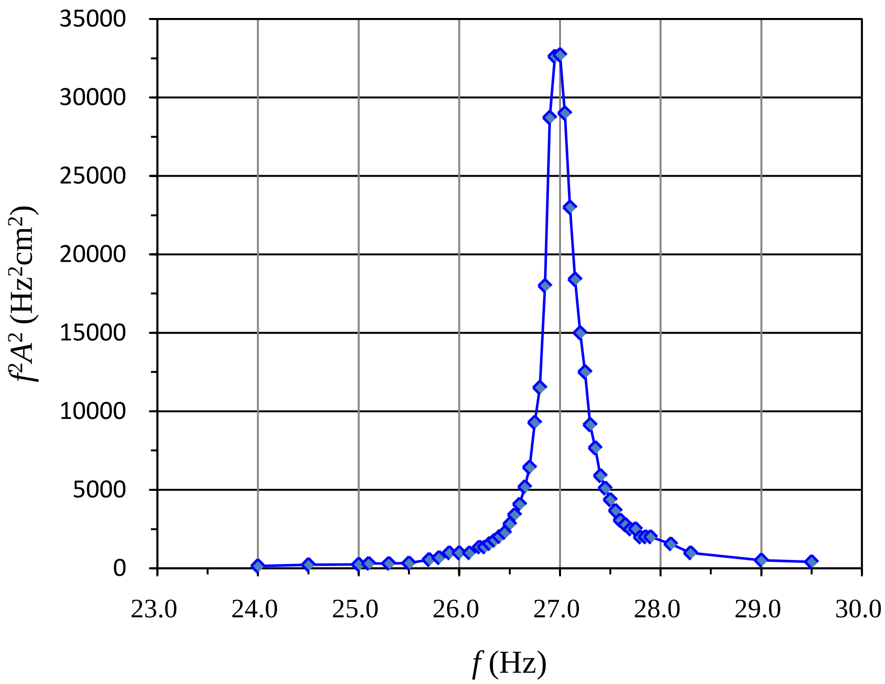
Exp. I-A、Measuring the resonance frequency

(1) Measure the amplitude A of the oscillating laser beam by tuning the frequency f of the sine wave generator. Record the measured data in the data table.

f(Hz)	A(cm)	f^2A^2(Hz^{2}cm^2)	f(Hz)	A(cm)	f^2A^2(Hz^{2}cm^2)
24.00	0.50	1.4×10^2	26.85	5.00	180×10^2
24.50	0.60	2.2×10^2	26.90	6.30	287×10^2
25.00	0.60	2.3×10^2	26.95	6.70	326×10^2
25.10	0.70	3.1×10^2	27.00	6.70	327×10^2
25.30	0.70	3.1×10^2	27.05	6.30	290×10^2
25.50	0.70	3.2×10^2	27.10	5.60	230×10^2
25.70	0.90	5.4×10^2	27.15	5.00	184×10^2
25.80	1.00	6.66×10^2	27.20	4.50	150×10^2
25.90	1.20	9.66×10^2	27.25	4.10	125×10^2
26.00	1.20	9.73×10^2	27.30	3.50	91.3×10^2
26.10	1.20	9.81×10^2	27.35	3.20	76.6×10^2
26.20	1.40	13.5×10^2	27.40	2.80	58.9×10^2
26.25	1.40	13.5×10^2	27.45	2.60	50.9×10^2
26.30	1.50	15.6×10^2	27.50	2.40	43.6×10^2
26.35	1.60	17.8×10^2	27.55	2.20	36.7×10^2
26.40	1.70	20.1×10^2	27.60	2.00	30.5×10^2
26.45	1.80	22.7×10^2	27.65	1.90	27.6×10^2
26.50	2.00	28.1×10^2	27.70	1.80	24.9×10^2
26.55	2.20	34.1×10^2	27.75	1.80	25.0×10^2
26.60	2.40	40.8×10^2	27.80	1.60	19.8×10^2
26.65	2.70	51.8×10^2	27.85	1.60	19.9×10^2
26.70	3.00	64.2×10^2	27.90	1.60	19.9×10^2
26.75	3.60	92.7×10^2	28.10	1.40	15.5×10^2
26.80	4.00	115×10^2	28.30	1.10	9.69×10^2

SOLUTION

(2) Plot a proper data in the graph paper to determine the resonance frequency f_{RO} and the quality factor Q. Record f_{RO} and Q in the following blank.



$$Q = \frac{f_{RO}}{f_2 - f_1} = \frac{27.0}{27.17 - 26.84} = 81.8$$

f_{RO} = 27.0 Hz	Q = 81.8

SOLUTION

Exp. I-B、Resonance frequency versus the external force.

(1) Measure and record the measured data z_0 in the data table.

z_0 = 6.40 cm

(2) Determine the position z of the top plane of the N-pole of M_C. Calculate the nominal distance d by defining $d = z_0 - z$. Record z and d in the data table.

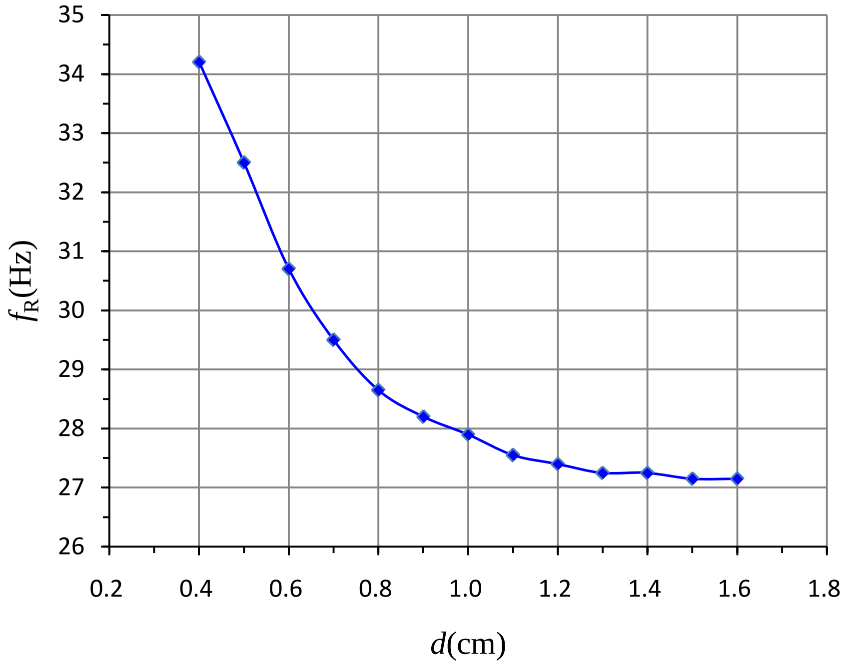
(3) Determine the resonance frequency f_R for the distance d by tuning the frequency of the sine wave generator until the maximum amplitude is reached. Record the determined resonance frequency f_R in the data table.

(4) Change the vertical position of the magnet M_C and repeat the steps (2) and (3) for a number of measurements of different distance d and the corresponding resonance frequency f_R.

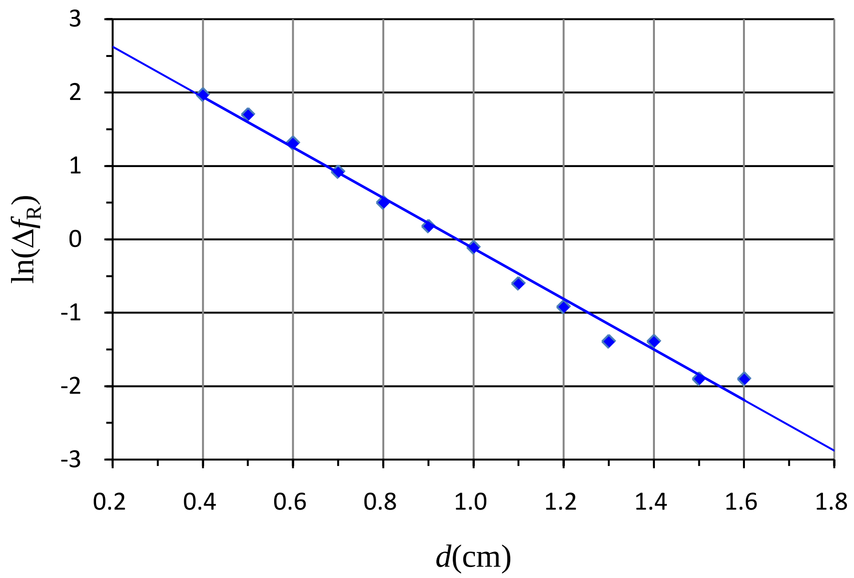
z(cm)	d (cm)	f_R(Hz)	Δf_R(Hz)	ln(Δf_R)
4.80	1.60	27.15	0.15	-1.90
4.90	1.50	27.15	0.15	-1.90
5.00	1.40	27.25	0.25	-1.39
5.10	1.30	27.25	0.25	-1.39
5.20	1.20	27.40	0.40	-0.92
5.30	1.10	27.55	0.55	-0.60
5.40	1.00	27.90	0.90	-0.11
5.50	0.90	28.20	1.20	0.18
5.60	0.80	28.65	1.65	0.50
5.70	0.70	29.50	2.50	0.92
5.80	0.60	30.70	3.70	1.31
5.90	0.50	32.50	5.50	1.70
6.00	0.40	34.20	7.20	1.97

SOLUTION

(5) Plot a graph of f_R as a function of distance d using a graph paper.



(6) Define $\Delta f_R = f_R - f_{RO}$, and plot $\ln(\Delta f_R)$ as a function of d using another graph paper.



SOLUTION

Exp. I-C、Find the positions and depths of magnets in a black box.

(1) Record z_0 and z_{box} on the answer sheet.

z_0 = 5.37 cm $\qquad$ z_{box} = 4.97 cm

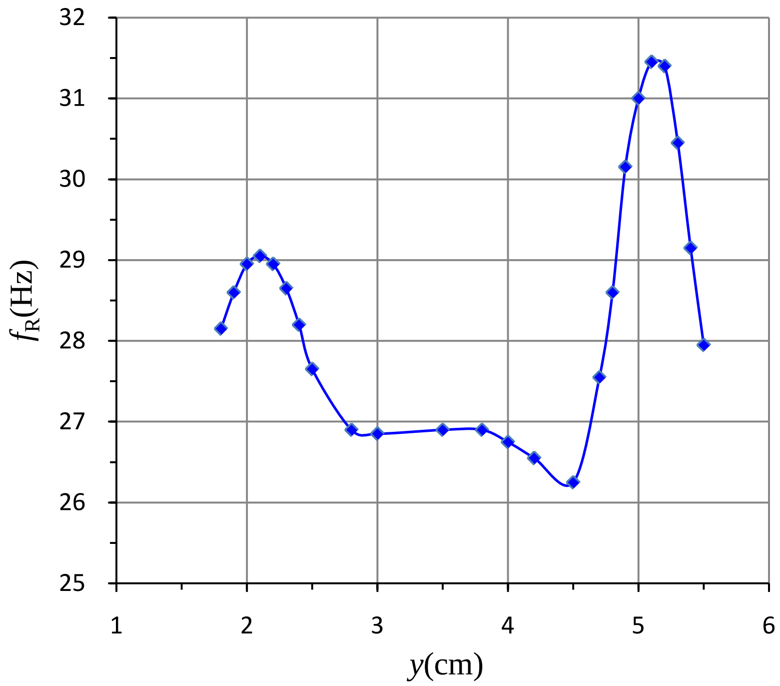
(2) Move the black box along the longer line and observe the variation in resonance frequency f_R of the reed to find the position of M_B. Record the measured distances y and their corresponding resonance frequencies f_R in the data table.

y(cm)	f_R(Hz)
5.50	27.95
5.40	29.15
5.30	30.45
5.20	31.40
5.10	31.45
5.00	31.00
4.90	30.15
4.80	28.60
4.70	27.55
4.50	26.25
4.20	26.55
4.00	26.75
3.80	26.90
3.50	26.90
3.00	26.85

y(cm)	f_R(Hz)
2.80	26.90
2.50	27.65
2.40	28.20
2.30	28.65
2.20	28.95
2.10	29.05
2.00	28.95
1.90	28.60
1.80	28.15

SOLUTION

(3) Plot f_R as a function of y on a graph paper to determine the position of magnet M_B. Mark the positions of magnets M_A and M_B on the y-axis of your graph, and write down the value of $\overline{AB}$ on the answer sheet.

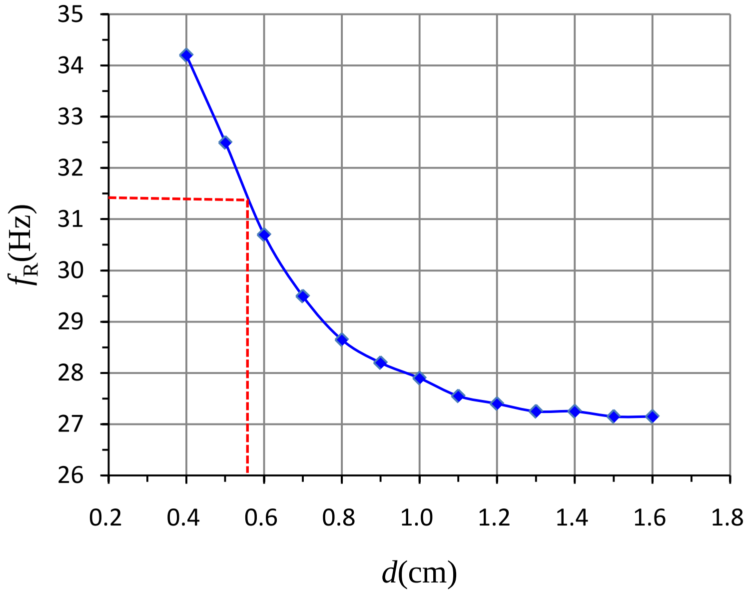


The distance between the two maximum points is 5.1-2.1=3.0 cm.

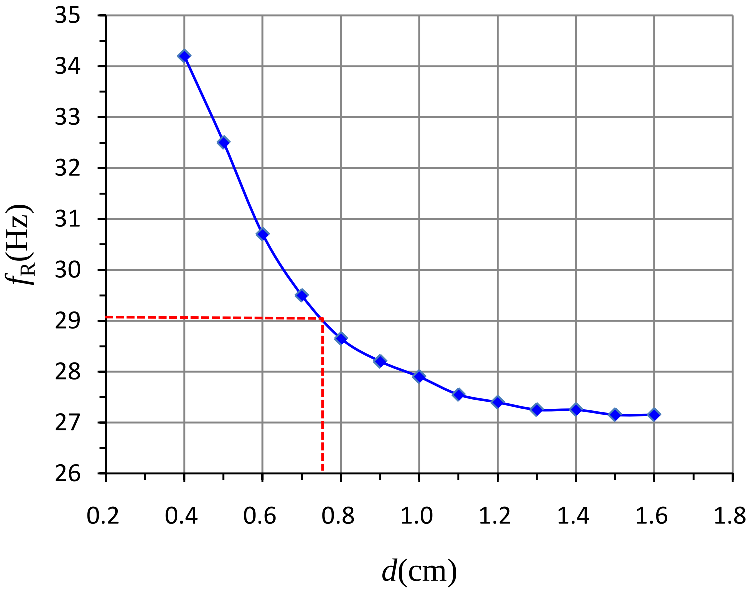
$\overline{AB}$ = 3.0 cm

SOLUTION

(4) Determine the depths d_A and d_B of the magnets M_A and M_B from the top surface of the black box using the results in Exp. I-B. Write down the values of d_A and d_B on the answer sheet.



$$\begin{aligned} d_A &= d - (z_0 - z_{box}) \\ &= 0.56 - 0.40 \\ &= 0.16 \text{ cm} \end{aligned}$$

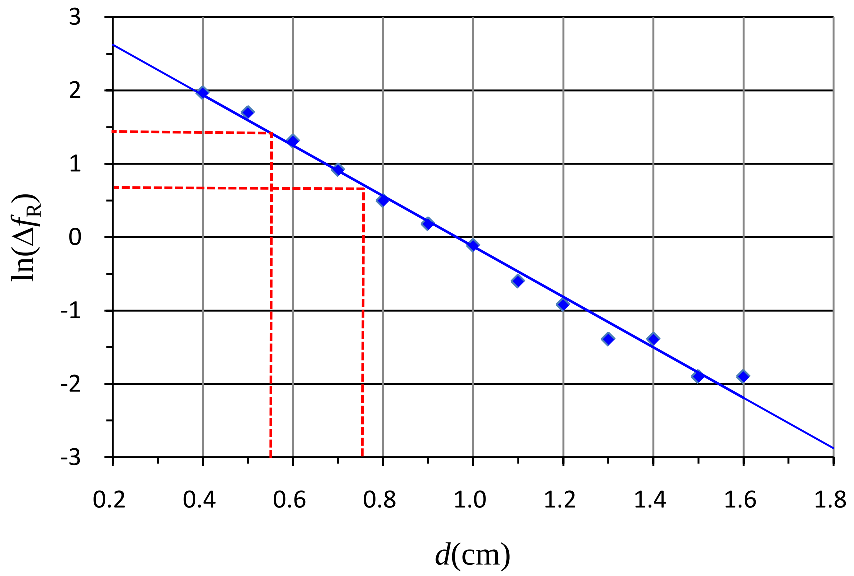


$$\begin{aligned} d_B &= d - (z_0 - z_{box}) \\ &= 0.75 - 0.40 \\ &= 0.35 \text{ cm} \end{aligned}$$

d_A = 0.16 cm	d_B = 0.35 cm

SOLUTION

Alternatively,



M_A :

$$\ln(\Delta f_R) = \ln(31.4 - 27.0) = 1.48$$
$$\Rightarrow d = 0.56 \text{ cm}$$
$$\Rightarrow d_A = d - (z_0 - z_{box}) = 0.56 - 0.40 = 0.16 \text{ cm}$$

M_B :

$$\ln(\Delta f_R) = \ln(29.1 - 27.0) = 0.74$$
$$\Rightarrow d = 0.75 \text{ cm}$$
$$\Rightarrow d_A = d - (z_0 - z_{box}) = 0.75 - 0.40 = 0.35 \text{ cm}$$

SOLUTION

Exp. II-A：Light Response of the Photoconductor

(1) Record the measured PC resistance (R) and θ_P in the data table. Transform the measured R values into conductance (C) values and record them in the data table.

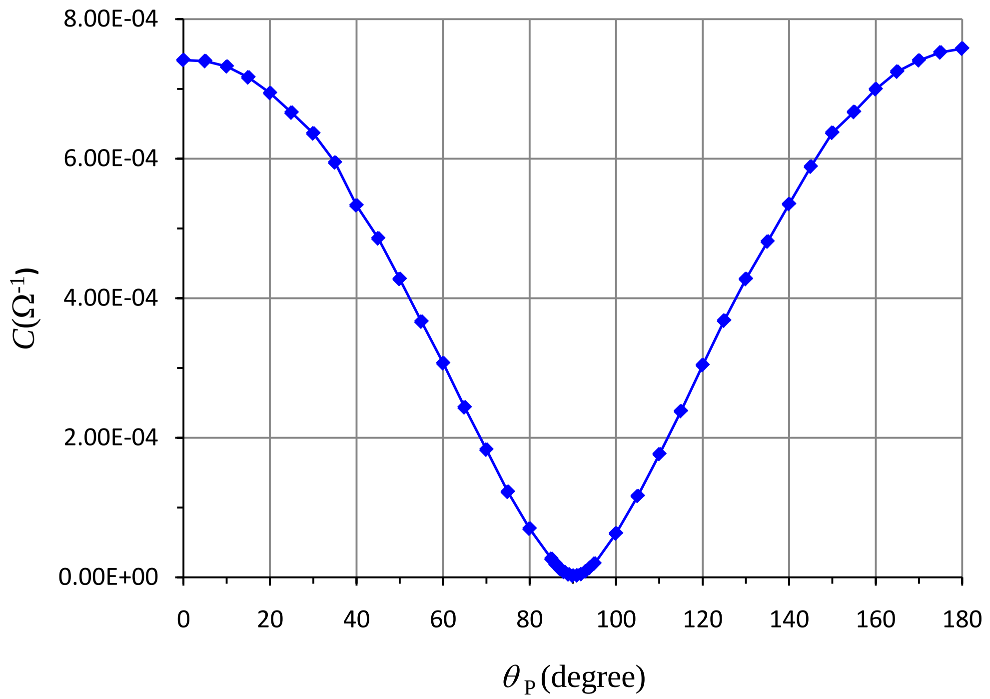
θ_P (degree)	$R(\Omega)$	$C(1/\Omega)$	$J=\cos^2\theta_P$	
0.0	1349	7.413E-04	1.00	
5.0	1352	7.396E-04	0.992	
10.0	1366	7.321E-04	0.970	
15.0	1396	7.163E-04	0.933	
20.0	1441	6.940E-04	0.883	
25.0	1502	6.658E-04	0.821	
30.0	1572	6.361E-04	0.750	
35.0	1682	5.945E-04	0.671	
40.0	1876	5.330E-04	0.587	
45.0	2060	4.854E-04	0.500	
50.0	2340	4.274E-04	0.413	
55.0	2730	3.663E-04	0.329	
60.0	3260	3.067E-04	0.250	
65.0	4110	2.433E-04	0.179	
70.0	5470	1.828E-04	0.117	
75.0	8180	1.222E-04	0.0670	
80.0	14410	6.944E-05	0.0302	
85.0	37900	2.639E-05	0.00760	
86.0	52200	1.916E-05	0.00487	
87.0	82000	1.220E-05	0.00274	
88.0	130300	7.674E-06	0.00122	
89.0	254000	3.937E-06	3.05E-04	
90.0	450000	2.222E-06	0	
91.0	393000	2.544E-06	3.05E-04	

SOLUTION

92.0	219000	4.566E-06	0.00122	
93.0	118900	8.410E-06	0.00274	
94.0	73700	1.357E-05	0.00487	
95.0	51300	1.949E-05	0.00760	
100.0	15960	6.266E-05	0.0302	
105.0	8580	1.166E-04	0.0670	
110.0	5660	1.767E-04	0.117	
115.0	4200	2.381E-04	0.179	
120.0	3290	3.040E-04	0.250	
125.0	2720	3.676E-04	0.329	
130.0	2340	4.274E-04	0.413	
135.0	2080	4.808E-04	0.500	
140.0	1870	5.348E-04	0.587	
145.0	1700	5.882E-04	0.671	
150.0	1570	6.369E-04	0.750	
155.0	1500	6.667E-04	0.821	
160.0	1430	6.993E-04	0.883	
165.0	1380	7.246E-04	0.933	
170.0	1350	7.407E-04	0.970	
175.0	1330	7.519E-04	0.992	
180.0	1320	7.576E-04	1.00	

SOLUTION

(2) Plot the PC conductance values as a function of θ_P on a graph paper.



SOLUTION

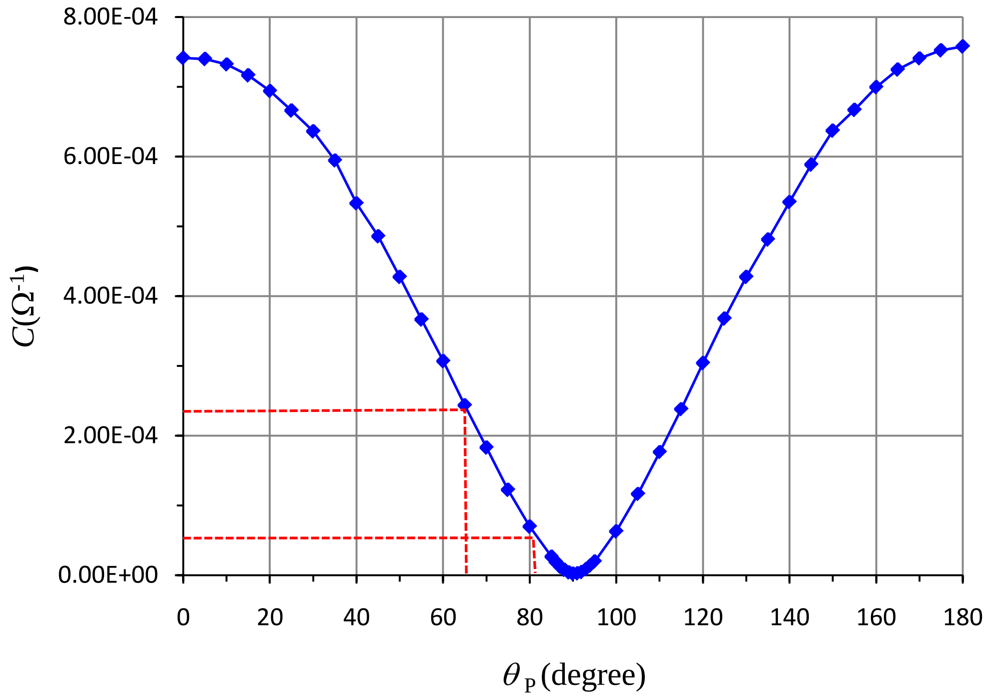
Exp. II-B：The Fraction of Linearly Polarized Laser Light

(1) Find the maximum and minimum values of PC resistance (R_{max} and R_{min}) by rotating P1 360 °. Transform R_{max} and R_{min} into the minimum and maximum values of PC conductance C_{min} and C_{max}. Record the data in the data table.

R_{min} (kΩ)	R_{max} (kΩ)	C_{max} (1/kΩ)	C_{min} (1/kΩ)		
4.30	19.40	0.233	0.0515		
4.28	19.42	0.234	0.0515		
4.31	19.41	0.232	0.0515		
	Average	0.233	0.0515		

SOLUTION

(2) Utilizing the conductance versus θ_P graph in Exp. II-A-(2) to determine the relative intensities J_{max} and J_{min} corresponding to C_{max} and C_{min}. Write down the result.



$$C_{\min} = 0.0515\ \Omega^{-1} \Rightarrow \theta_P = 81^\circ \Rightarrow J_{\min} = \cos^2 81^\circ = 0.025$$

$$C_{\max} = 0.233\ \Omega^{-1} \Rightarrow \theta_P = 65^\circ \Rightarrow J_{\min} = \cos^2 65^\circ = 0.18$$

$J_{\min} = 0.025$	$J_{\max} = 0.18$

SOLUTION

(3) Calculate β and write down the result on the answer sheet.

$$\beta = \frac{J_{\max} - J_{\min}}{J_{\max} + J_{\min}} = \frac{0.18 - 0.025}{0.18 + 0.025} = 0.76$$

β = 0.76

SOLUTION

Exp. II-C： The Differential Quantum Efficiency of the Collimated Laser Diode

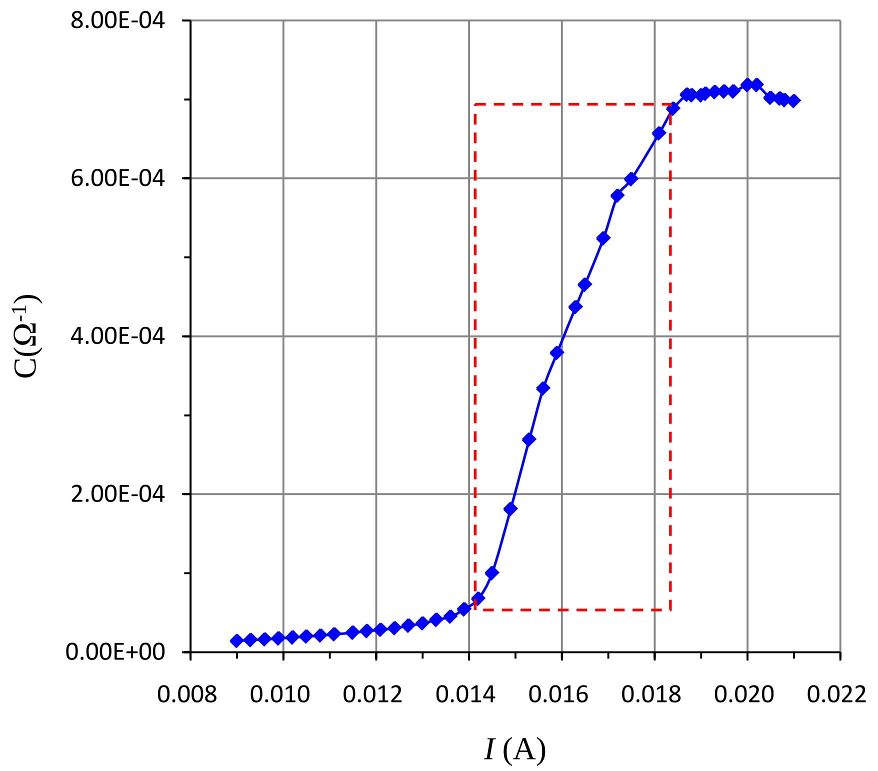
(1) Control the CLD current (I) and measure the corresponding PC resistance (R) values. Record the data in the data table. Transform your data and plot the PC conductance (C) versus CLD current on a graph paper.

I (A)	R (Ω)	C (1/Ω)	J	
0.0090	70600	1.42E-05	0.00335	
0.0093	66000	1.52E-05	0.00365	
0.0096	61600	1.62E-05	0.00396	
0.0099	58200	1.72E-05	0.00426	
0.0102	54200	1.85E-05	0.00466	
0.0105	50300	1.99E-05	0.00514	
0.0108	47400	2.11E-05	0.00559	
0.0111	44100	2.27E-05	0.00620	
0.0115	40600	2.46E-05	0.00692	
0.0118	37500	2.67E-05	0.00776	
0.0121	35200	2.84E-05	0.00865	
0.0124	32900	3.04E-05	0.00970	
0.0127	29900	3.34E-05	0.0112	
0.0130	27400	3.65E-05	0.0129	
0.0133	24600	4.07E-05	0.0151	
0.0136	22200	4.50E-05	0.0174	
0.0139	18500	5.41E-05	0.0221	
0.0142	14800	6.76E-05	0.0292	
0.0145	10000	1.00E-04	0.0516	
0.0149	5510	1.81E-04	0.115	
0.0153	3720	2.69E-04	0.208	
0.0156	2990	3.34E-04	0.286	
0.0159	2640	3.79E-04	0.351	
0.0163	2290	4.37E-04	0.428	
0.0165	2150	4.65E-04	0.470	

SOLUTION

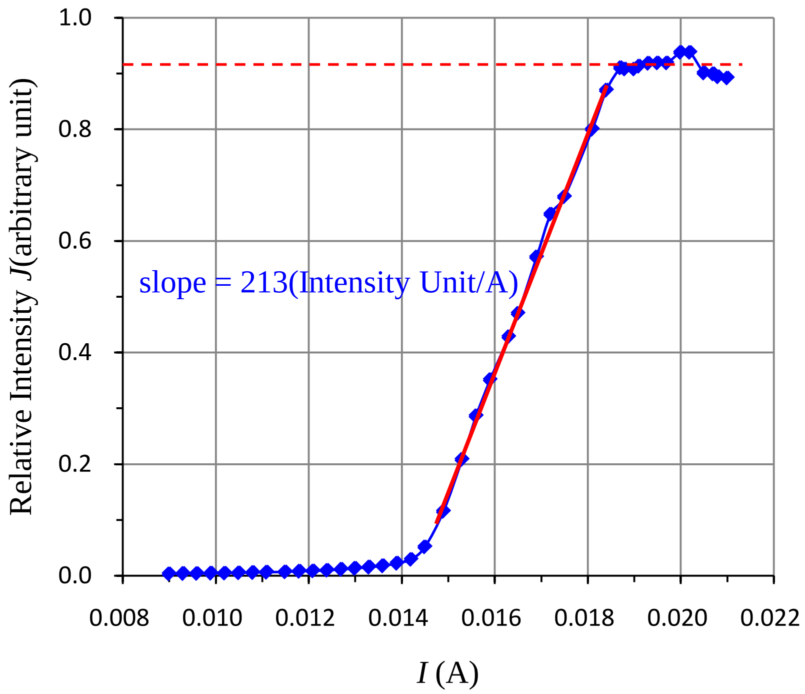
0.0169	1910	5.24E-04	0.571	
0.0172	1730	5.78E-04	0.648	
0.0175	1670	5.99E-04	0.679	
0.0181	1523	6.57E-04	0.800	
0.0184	1454	6.88E-04	0.870	
0.0187	1417	7.06E-04	0.910	
0.0188	1418	7.05E-04	0.908	
0.0190	1419	7.05E-04	0.908	
0.0191	1414	7.07E-04	0.913	
0.0193	1411	7.09E-04	0.918	
0.0195	1409	7.10E-04	0.919	
0.0197	1409	7.10E-04	0.919	
0.0200	1393	7.18E-04	0.938	
0.0202	1392	7.18E-04	0.938	
0.0205	1425	7.02E-04	0.901	
0.0207	1426	7.01E-04	0.899	
0.0208	1430	6.99E-04	0.894	
0.0210	1432	6.98E-04	0.892	

SOLUTION


8.00E-04
6.00E-04
4.00E-04
2.00E-04
0.00E+00
C(Ω-1)
0.008
0.010
0.012
0.014
0.016
0.018
0.020
0.022
I (A)

SOLUTION

(2)Based on the graph of step (1), choose a region (ΔI ~ 3 mA) centered around the maximum slope. By using the conductance versus θ_P graph in Part II-A-(2), transform and record the data of this region in the table of step (1) into the relative light intensity (J). Plot the relative light intensity (J) versus CLD current (I) in a graph paper.



SOLUTION

(3) The maximum radiating power of the CLD is assumed to be exactly $P_{\max} = 3.0$ mW. Extract the maximum slope from the graph in step (3) and transfer it to the value of $G \equiv \left.\frac{\Delta P}{\Delta I}\right|_{Max}$, which is the maximum ratio of the increased amount of radiating power and the increase amount of input ampere. Write down your analysis and the calculated value G on the answer sheet. Estimate the error of G. Do not include the error of the P_{max}. Write down your analysis and the calculated value ΔG on the answer sheet.

$G = \left.\frac{\Delta P}{\Delta I}\right|_{Max} = 0.69$ W/A $\Delta G = 0.02$ W/A

By linear regression analysis,

slope S = 213 (Intensity Unit /A) , uncertainty of slope ΔS = 3 (Intensity Unit /A).

$P_{\max}$ = 3.0 mW $\Rightarrow$ $J_{\max}$ = 0.92 (Intensity Unit)

$$\because\ P \propto J \quad \Rightarrow \quad P = kJ$$

$$\therefore\ G = \left.\frac{\Delta P}{\Delta I}\right|_{\max} = \left.\frac{k\Delta J}{\Delta I}\right|_{\max} = \frac{P_{\max}}{J_{\max}} \cdot \left.\frac{\Delta J}{\Delta I}\right|_{\max} = \frac{3.0\times 10^{-3}}{0.92}\times 213 = 0.69 \text{ W/A}$$

From the measured data, uncertainty of $J_{\max}$: $\Delta J_{\max}$ = 0.02 (Intensity Unit)

Uncertainty Analysis: by using the formula of error propagation

$$G = G(S, J_{\max}) = \frac{P_{\max}}{J_{\max}} \cdot \left.\frac{\Delta J}{\Delta I}\right|_{\max} = (3.0\times 10^{-3})\frac{S}{J_{\max}}$$

$$\Delta G = \sqrt{\left(\frac{\partial G}{\partial S}\right)^2 (\Delta S)^2 + \left(\frac{\partial G}{\partial J_{\max}}\right)^2 (\Delta J_{\max})^2} = \sqrt{\left(\frac{3.0\times 10^{-3}}{J_{\max}}\right)^2 (\Delta S)^2 + \left(-\frac{3.0\times 10^{-3} S}{J_{\max}^2}\right)^2 (\Delta J_{\max})^2}$$

$$= \sqrt{\left(\frac{3.0\times 10^{-3}}{0.92}\right)^2 (3)^2 + \left(-\frac{3.0\times 10^{-3}\times 213}{0.92^2}\right)^2 (0.02)^2}$$

$$= 0.02$$

Alternatively,

$$\frac{\Delta G}{G} = \sqrt{\left(\frac{\Delta S}{S}\right)^2 + \left(\frac{\Delta J_{\max}}{J_{\max}}\right)^2} \quad \Rightarrow \quad \Delta G = 0.69\sqrt{\left(\frac{3}{213}\right)^2 + \left(\frac{0.02}{0.92}\right)^2} = 0.02$$

SOLUTION

(4) The **Quantum Efficiency** equals the probability of one photon being generated per electron injected. From a particular bias current of the laser, a small increment of electrons injected would cause a corresponding increment of photons. The **Differential Quantum Efficiency** $\boldsymbol{\eta}$ is defined as the ratio of the increased number of photons and the increased number of injected electrons. Determine $\boldsymbol{\eta}$ of your CLD by using the value of G obtained in step (4). Write down your analysis and the calculated value $\boldsymbol{\eta}$ on the answer sheet. Estimate the error of $\boldsymbol{\eta}$. Write down your analysis and the calculated value $\Delta\boldsymbol{\eta}$ on the answer sheet. (Laser wavelength = 650 nm. Planck's constant = $6.63\times10^{-34}\,J\cdot s$. Light speed $=3.0\times10^{8}\,m/s$)

$\eta = 0.36$	$\Delta\eta = 0.01$

$$\eta = \frac{\Delta N_{photon}}{\Delta N_{electron}} = \frac{\Delta P / E_{photon}}{\Delta I / e} = \frac{\Delta P}{\Delta I}\cdot\frac{e}{E_{photon}} = G\cdot\frac{e}{hc/\lambda} = \frac{Ge\lambda}{hc}$$

$$= \frac{0.69\times1.6\times10^{-19}\times650\times10^{-9}}{6.63\times10^{-34}\times3.0\times10^{8}} = 0.36$$

$$\Delta\eta = \Delta G\frac{e\lambda}{hc} \quad\Rightarrow\quad \frac{\Delta\eta}{\eta} = \frac{\Delta G}{G} \quad\Rightarrow\quad \Delta\eta = \eta\left(\frac{\Delta G}{G}\right) = 0.36\times\left(\frac{0.02}{0.69}\right) = 0.01$$