SOLUTION EXPERIMENT I

PART A

1. **[Total 0.5 pts]**
   The experimental method chosen for the calibration of the arbitrary scale is a simple pendulum method [0.3 pts]

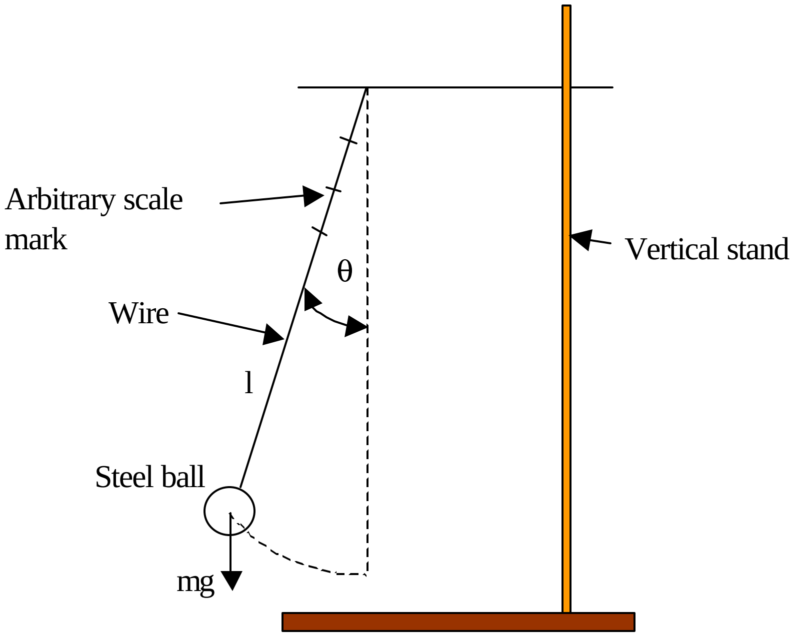


Figure 1. Sketch of the experimental set up [0.2 pts]

2. **[Total 1.5 pts]**
   The expression relating the measurable quantities: [0.5 pts]

$$T_{osc} = 2\pi\sqrt{\frac{l}{g}}\,;\; T_{osc}^{\;2} = 4\pi^2\frac{l}{g}$$

Approximations :

$\sin\theta \approx \theta$ [0.5 pts]

mathematical pendulum (mass of the wire << mass of the steel ball,
the radius of the steel ball << length of the wire [0.5 pts]
flexibility of the wire, air friction, etc [0.1 pts, only when one of the two major points above is not given]

3. **[Total 1.0 pts]** Data sample from simple pendulum experiment
   # of cycle ≥ 20 [0.2 pts.] , difference in T ≥ 0.01 s [0.4 pts], # of data ≥ 4 [0.4 pts]

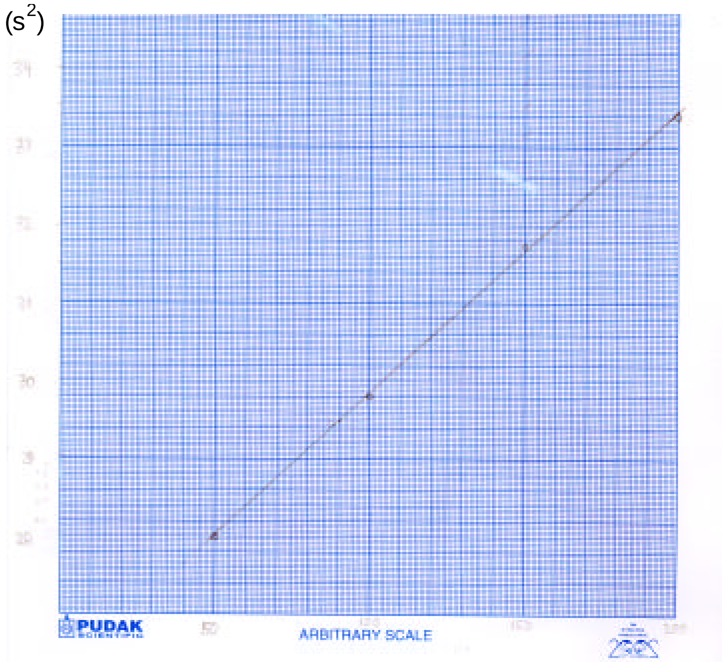
No.	t(s) for 50 cycles	Period, T (s)	Scale marked on the wire (arbitrary scale)
1	91.47	1.83	200
2	89.09	1.78	150
3	86.45	1.73	100
4	83.8	1.68	50

4. **[Total 0.5 pts]**

No.	Period, T (s)	Scale marked on the wire (arbitrary scale)	$T^2 (s^2)$
1	1.83	200	3.35
2	1.78	150	3.17
3	1.73	100	2.99
4	1.68	50	2.81

The plot of T^2 vs scale marked on the wire:

T^2 (s^2)



Scale marked on the wire (arbitrary scale)

5. Determination of the smallest unit of the arbitrary scale in term of mm **[Total 1.5 pts]**

$$T_{osc_1}^2 = \frac{4p^2}{g} L_1 \ , \qquad T_{osc_2}^2 = \frac{4p^2}{g} L_2$$

$$\left(T_{osc_1}^2 - T_{osc_2}^2\right) = \frac{4p^2}{g} L_1 - L_2 = \frac{4p^2}{g} \Delta L$$

$$\Delta L = \frac{g}{4\pi^2}\left(T_{osc_1}^2 - T_{osc_2}^2\right)$$ or other equivalent expression [0.5 pts]

No.		Calculated ΔL (m)	ΔL in arbitrary scale	Values of smallest unit of arbitrary scale (mm)
1.	T_1^2-T_2^2 = 0.171893 s^2	0.042626	50	0.85
2.	T_1^2-T_3^2 =0.357263 s^2	0.088595	100	0.89
3.	T_1^2-T_4^2 =0.537728 s^2	0.133347	150	0.89
4.	T_2^2-T_3^2 =0.18537 s^2	0.045968	50	0.92
5.	T_2^2-T_4^2 =0.365835 s^2	0.09072	100	0.91
6.	T_3^2-T_4^2 =0.180465 s^2	0.044752	50	0.90

The average value of smallest unit of arbitrary scale, $\bar{l}$ = 0.89 mm [0.5 pts]

The estimated error induced by the measurement: [0.5 pts]

No.	Values of smallest unit of arbitrary scale (mm)	$(l-\bar{l})$	$(l-\bar{l})^2$
1.	0.85	-0.04	0.0016
2.	0.89	0	0
3.	0.89	0	0
4.	0.92	0.03	0.0009
5.	0.91	0.02	0.0004
6.	0.90	0.01	0.0001

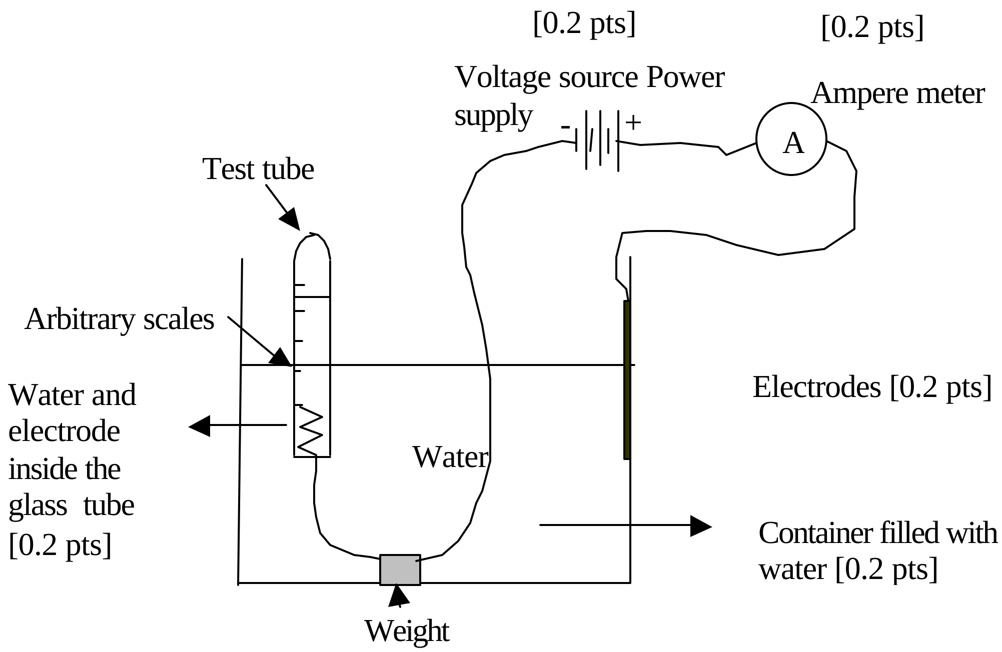
And the standard deviation is:

$$\Delta l = \sqrt{\frac{\sum_{i=1}^{6}(l-\bar{l})^2}{N-1}} = \sqrt{\frac{0.003}{5}} = 0.02 \text{ mm}$$

other legitimate methods may be used

PART B

1. The experimental set up:**[Total 1.0 pts]**



2. Derivation of equation relating the quantities time t, current I, and water level difference Δh: :**[Total 1.5 pts]**

$$I = \frac{\Delta Q}{\Delta t}$$

From the reaction: $2\,H^+ + 2\,e \longrightarrow H_2$, the number of molecules produced in the process (ΔN) requires the transfer of electric change is $\Delta Q = 2e\,\Delta N$: [0.2 pts]

$$I = \frac{\Delta N\, 2e}{\Delta t}$$ [0.5 pts]

$$P\,\Delta V = \Delta N\, k_B\, T$$ [0.5 pts]

$$= \frac{I\,\Delta t}{2e} k_B\, T$$

$$P\,\Delta h(\pi r^2) = \frac{I\,\Delta t}{2}\frac{k_B}{e} T$$ [0.2 pts]

$$I\,\Delta t = \frac{e}{k_B}\frac{2P(\pi r^2)}{T}\Delta h$$ [0.1 pts]

3. The experimental data: **[Total 1.0 pts]**

No.	Δh (arbitrary scale)	I (mA)	Δt (s)
1	12	4.00	1560.41
2	16	4.00	2280.61
3	20	4.00	2940.00
4	24	4.00	3600.13

- The circumference ϕ, of the test tube = 46 arbitrary scale [0.3 pts]
- The chosen values for Δh (≥ 4 scale unit) for acceptable error due to uncertainty of the water level reading and for I (≤ 4 mA) for acceptable disturbance [0.3 pts]
- # of data ≥ 4 [0.4 pts]

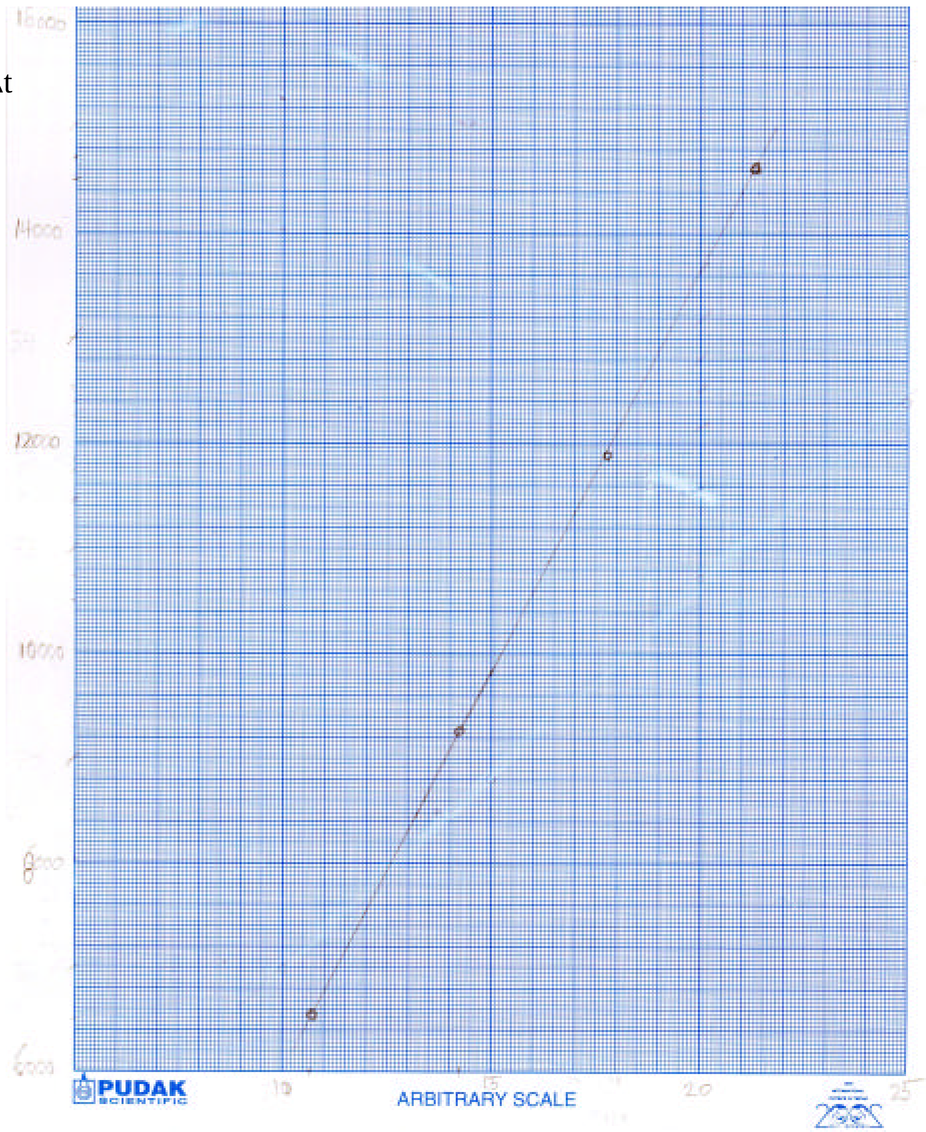
The surrounding condition (T,P) in which the experimental data given above taken:
T = 300 K
P = 1.00 10^5 Pa

4. Determination the value of e/k_B **[Total 1.5 pts]**

No.	Δh (arbitrary scale)	Δh (mm)	I (mA)	Δt (s)	I Δt (C)
1	12	10.68	4.00	1560.41	6241.64
2	16	14.24	4.00	2280.61	9120.48
3	20	17.80	4.00	2940.00	11760.00
4	24	21.36	4.00	3600.13	14400.52

Plot of $I\Delta t$ vs Δh from the data listed above

$I\,\Delta t$



Δh

The slope obtained from the plot is 763.94;

$$\frac{e}{k_B} = \frac{763.94\times 300\times \boldsymbol{p}}{2\times 10^5\times(23\times 0.89\times 10^{-3}\times 0.82)^2} = 1.28\times 10^4 \text{ Coulomb K/J}$$

[1.0 pts]

Alternatively [the same credit points]

No.	Δh (mm)	$I\,\Delta t$ (C)	Slope	e/k_b
1	10.68	6241.64	584.4232	9774.74
2	14.24	9120.48	640.4831	10712.37
3	17.80	11760.00	660.6742	11050.07
4	21.36	14400.52	674.1816	11275.99

Average of $e/k_b = 1.07 \times 10^4$ Coulomb K/J

[1.0 pts]

No.	e/k_b	difference	Square difference
1	9774.74	-928.55	862205.5
2	10712.37	9.077117	82.39405
3	11050.07	346.7808	120256.9
4	11275.99	572.6996	327984.9

Estimated error [0.5 pts]

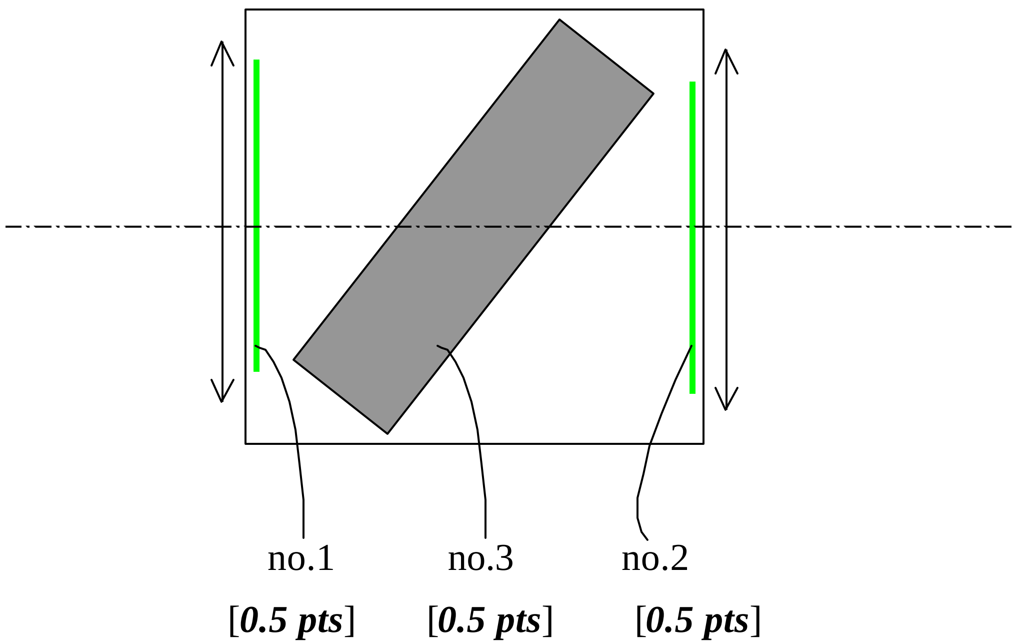
The standard deviation obtained is 0.66×10^3 Coulomb K/J,
Other legitimate measures of estimated error may be also used

SOLUTION OF EXPERIMENT PROBLEM 2

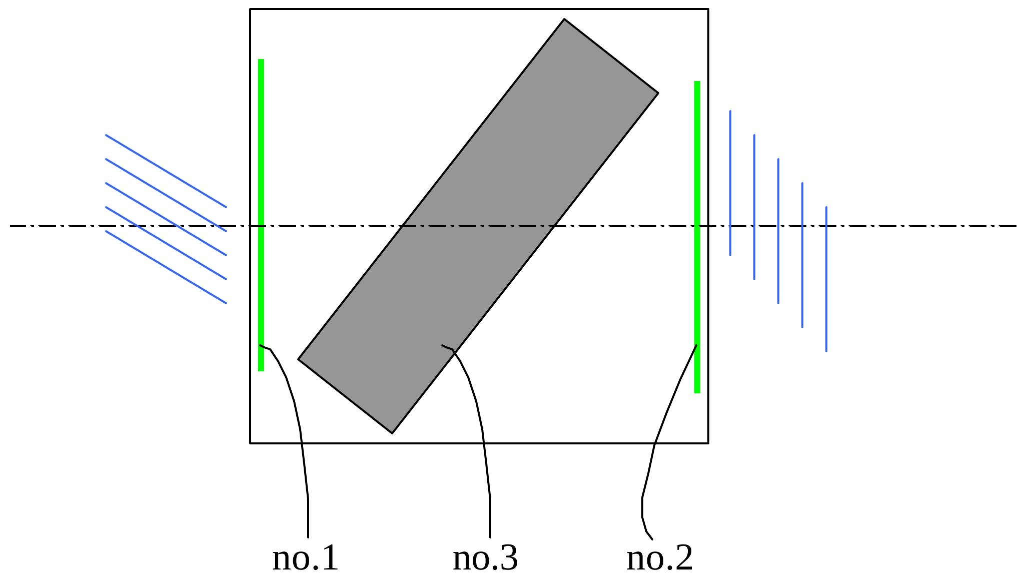
1. The optical components are **[total 1.5 pts]**:

no.1	Diffraction grating	[***0.5 pts***]
no.2	Diffraction grating	[***0.5 pts***]
no.3	Plan-parallel plate	[***0.5 pts***]

2. Cross section of the box **[total 1.5 pts]**:



3. Additional information **[total 1.0 pts]**:



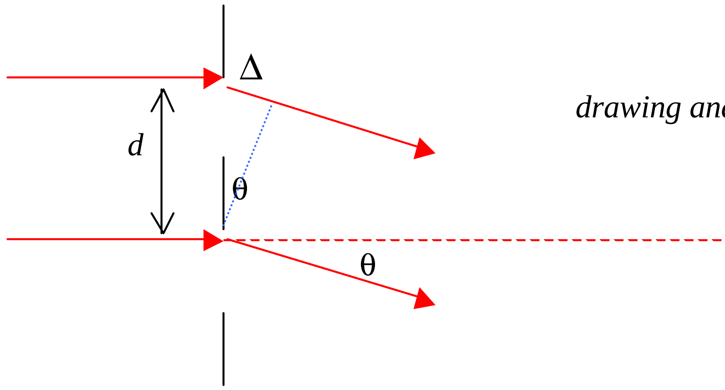
Distance of the grating (no.1) to the left wall is practically zero [***0.2 pts***]

Distance of the grating (no.2) to the right wall is practically zero [***0.2 pts***]

Lines of grating no.1 is at right angle to the slit [***0.3 pts***]

Lines of grating no. 2 is parallel to the slit [***0.3 pts***]

4. Diffraction grating **[total 2.0 pts]**:



drawing and labels should be complete **[*0.6 pts*]**

Path length difference:

$$\Delta = d \sin \theta \;,\qquad d = \text{spacing of the grating}$$

Diffraction order:

$$\Delta = m \lambda \;,\qquad m = \text{order number}$$

Hence, for the first order (m = 1):

$$\sin \theta = \lambda / d$$ [***0.4 pts***]

<u>Observation data:</u>

tan θ	θ	sin θ
0.34	18.78^0	0.3219
0.32	17.74^0	0.3048
0.32	17.74^0	0.3048

number of data ³ 3 [***0.5 pts***]

Name of component no.1	Specification
Diffraction grating	Spacing = 2.16 μm Lines at right angle to the slit

[*0.4 pts*]
[*0.1 pts*]

Note: true value of grating spacing is 2.0 μm, deviation of the result ≤ 10%

5. Diffraction grating **[total 2.0 pts]**:

For the derivation of the formula, see nr.4 above.

[***1.0 pts***]

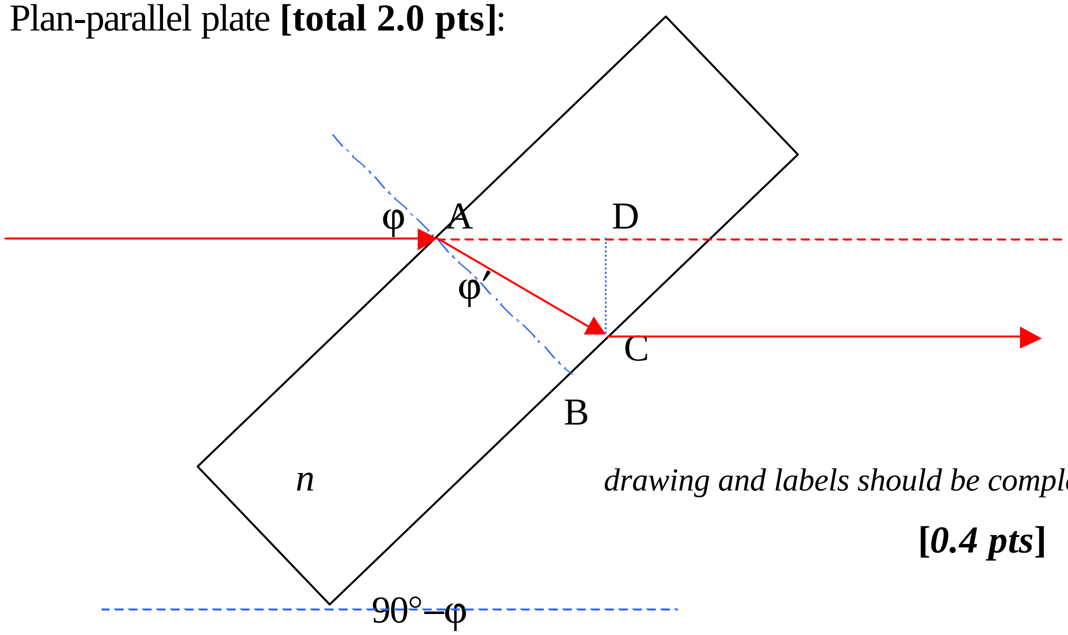
<u>Observation data:</u>

tanθ	θ	sinθ	
1.04	46.12^0	0.7208	
0.96	43.83^0	0.6925	*number of data ³ 3*
1.08	47.20^0	0.7330	[***0.5 pts***]

Name of component no.2	Specification	
Diffraction grating	Spacing = 0.936 μm	**[*0.4 pts*]**
	Lines parallel to the slit	**[*0.1 pts*]**

Note: true value of grating spacing is 1.0 μm, deviation of the result ≤ 10%

6. Plan-parallel plate **[total 2.0 pts]**:



drawing and labels should be complete

[*0.4 pts*]

Snell's law:

$\sin \varphi = n \sin \varphi'$, $\varphi' = \angle BAC$

Path length inside the plate:

$AC = AB / \cos \varphi'$, $AB = h =$ plate thickness

Beam displacement:

$CD = t = AC \sin \angle CAD$, $\angle CAD = \varphi - \varphi'$

Hence:

$t = h \sin \varphi \left[1 - \cos \varphi / (n^2 - \sin^2 \varphi)^{1/2} \right]$ [***0.6 pts***]

<u>Observation data:</u>

φ	t	
0	0	(angle between beam and axis 49°)
49^0	7.3 arbitrary scale	

[***0.5 pts***]

Name of component no.3	Specification
Plane-parallel plate	Thickness = 17.9 mm Angle to the axis of the box 49°

[*0.2 pts*]

[*0.3 pts*]

Note: - true value of plate thickness is 20 mm
- true value of angle to the axis of the box is 52°
- deviation of the results ≤ 20%.