

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]

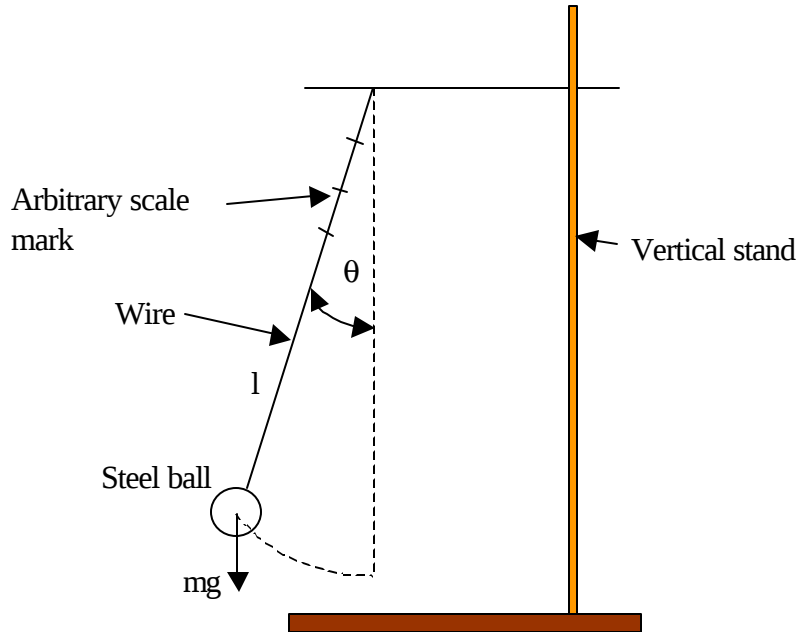


Figure 1. Sketch of the experimental set up [0.2 pts]

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 :

$$\sin \theta \approx \theta \quad [0.5 \text{ pts}]$$

mathematical pendulum (mass of the wire $\ll$ mass of the steel ball,
the radius of the steel ball $\ll$ 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]

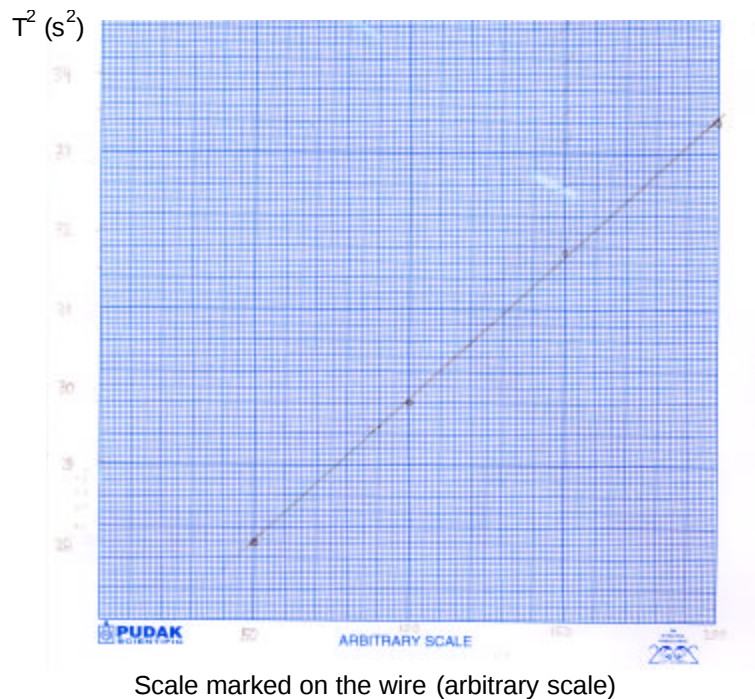
3. **[Total 1.0 pts]** Data sample from simple pendulum experiment
 # of cycle ≥ 20 [0.2 pts.] , difference in $T \geq 0.01$ s [0.4 pts], # of data ≥ 4 [0.4 pts]

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:



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

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

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

$$\Delta L = \frac{g}{4p^2} (T_{osc1}^2 - T_{osc2}^2) \text{ or other equivalent expression} \quad [0.5 \text{ pts}]$$

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

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

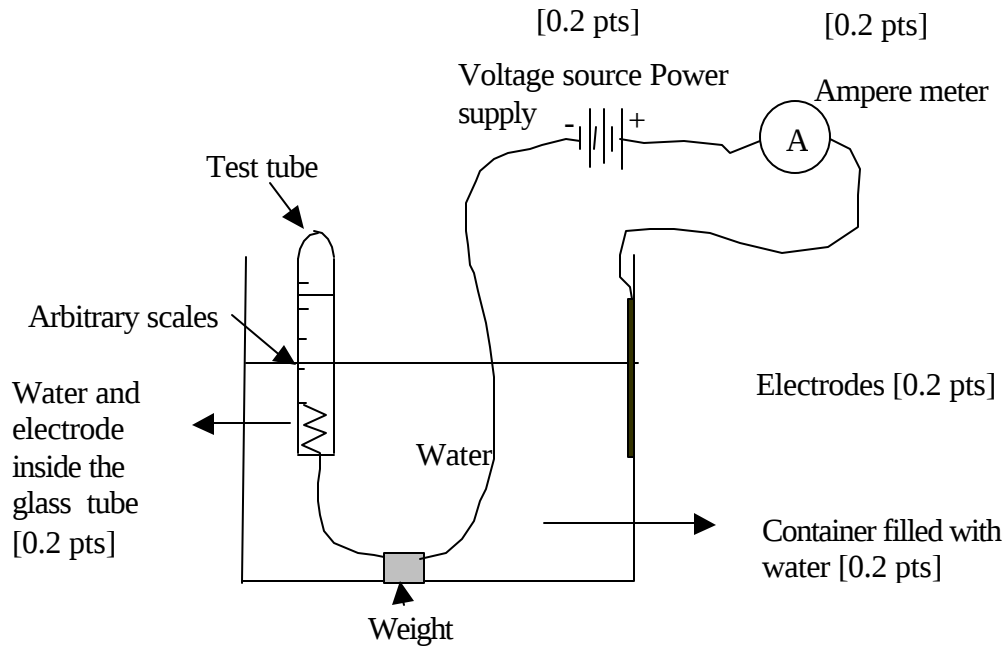
And the standard deviation is:

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

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: $2 \text{H}^+ + 2 \text{e}^- \longrightarrow \text{H}_2$, the number of molecules produced in the process (ΔN) requires the transfer of electric charge is $\Delta Q = 2e \Delta N$: [0.2 pts]

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

$$P \Delta V = \Delta N k_B T \quad [0.5 \text{ pts}]$$

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

$$P \Delta h (pr^2) = \frac{I \Delta t}{2} \frac{k_B}{e} T \quad [0.2 \text{ pts}]$$

$$I \Delta t = \frac{e}{k_B} \frac{2P(pr^2)}{T} \Delta h \quad [0.1 \text{ pts}]$$

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:

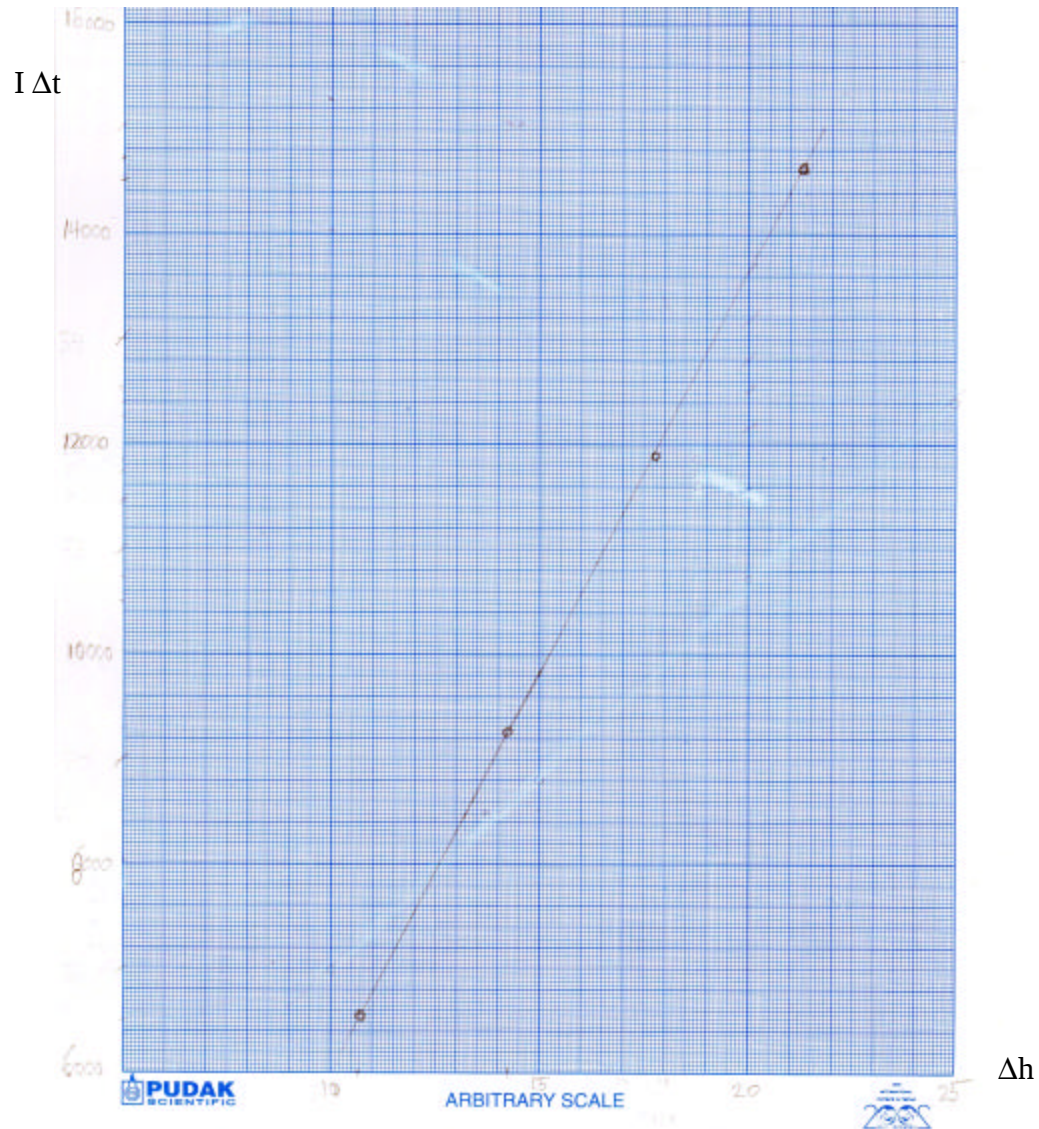
$$T = 300 \text{ K}$$

$$P = 1.00 \cdot 10^5 \text{ Pa}$$

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

No.	Δh (arbitrary scale)	Δh (mm)	I (mA)	Δt (s)	$I \Delta t$ (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



The slope obtained from the plot is 763.94;

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

[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]

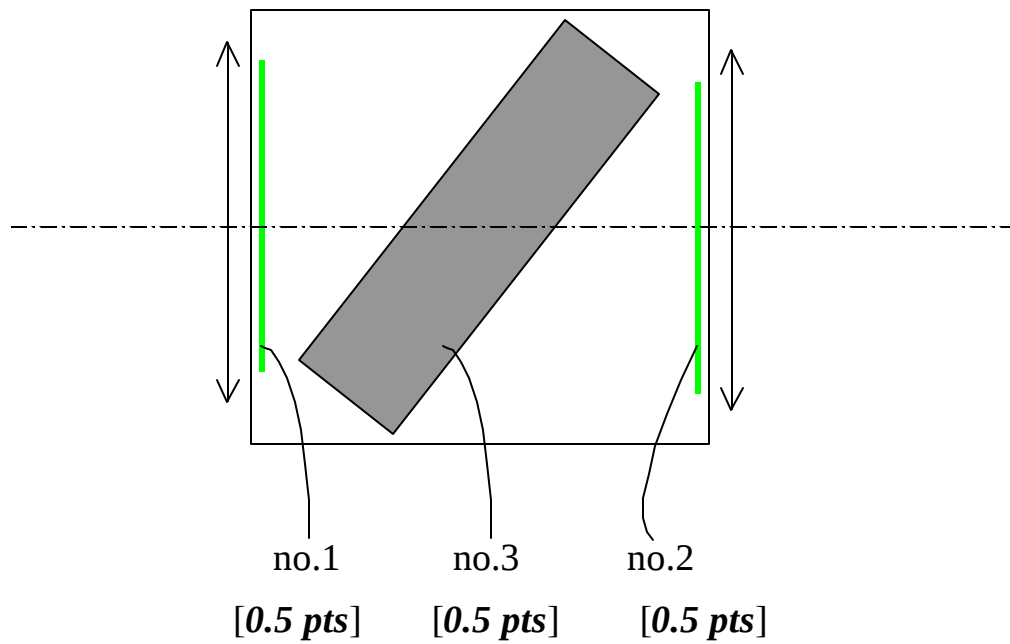
The standard deviation obtained is 0.66×10^3 Coulomb K/J,
Other legitimate measures of estimated error may be also used

SOLUTION OF EXPERIMENT PROBLEM 2

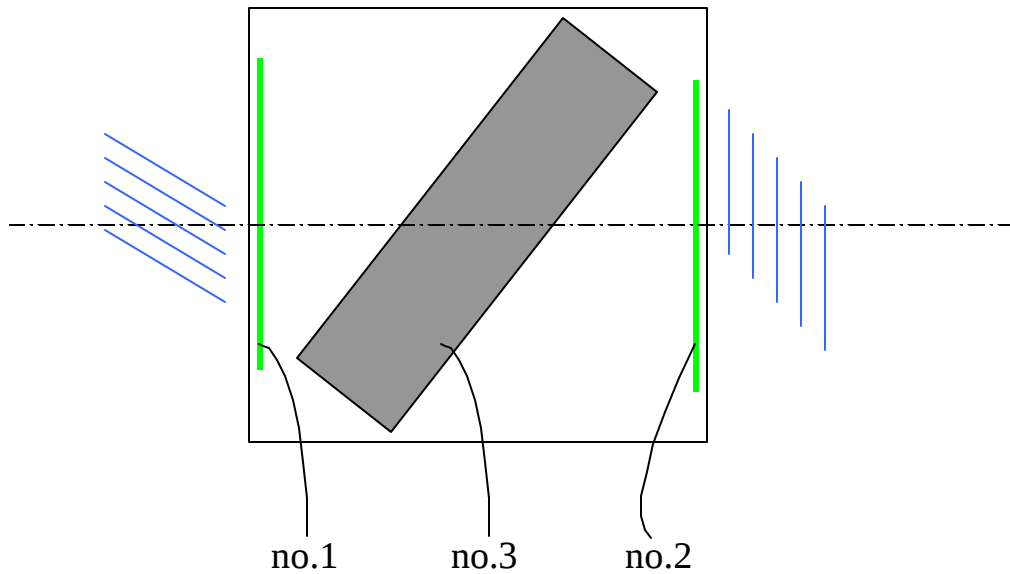
1. The optical components are **[total 1.5 pts]**:

- 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]**:



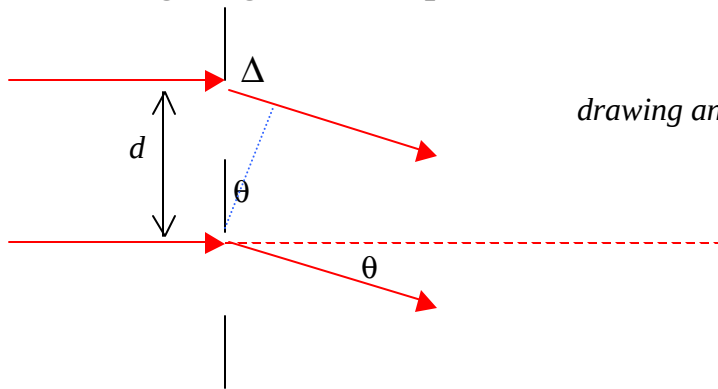
Distance of the grating (no.1)
to the left wall is practically zero
[0.2 pts]

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:

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

Diffraction order:

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

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

$$\sin \theta = \lambda / d \quad [0.4 \text{ pts}]$$

Observation data:

$\tan \theta$	θ	$\sin \theta$
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 = $2.16 \mu\text{m}$ Lines at right angle to the slit

[0.4 pts]

[0.1 pts]

Note: true value of grating spacing is $2.0 \mu\text{m}$, deviation of the result $\leq 10\%$

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

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

[1.0 pts]

Observation data:

$\tan\theta$	θ	$\sin\theta$
1.04	46.12^0	0.7208
0.96	43.83^0	0.6925
1.08	47.20^0	0.7330

number of data ³ 3

[0.5 pts]

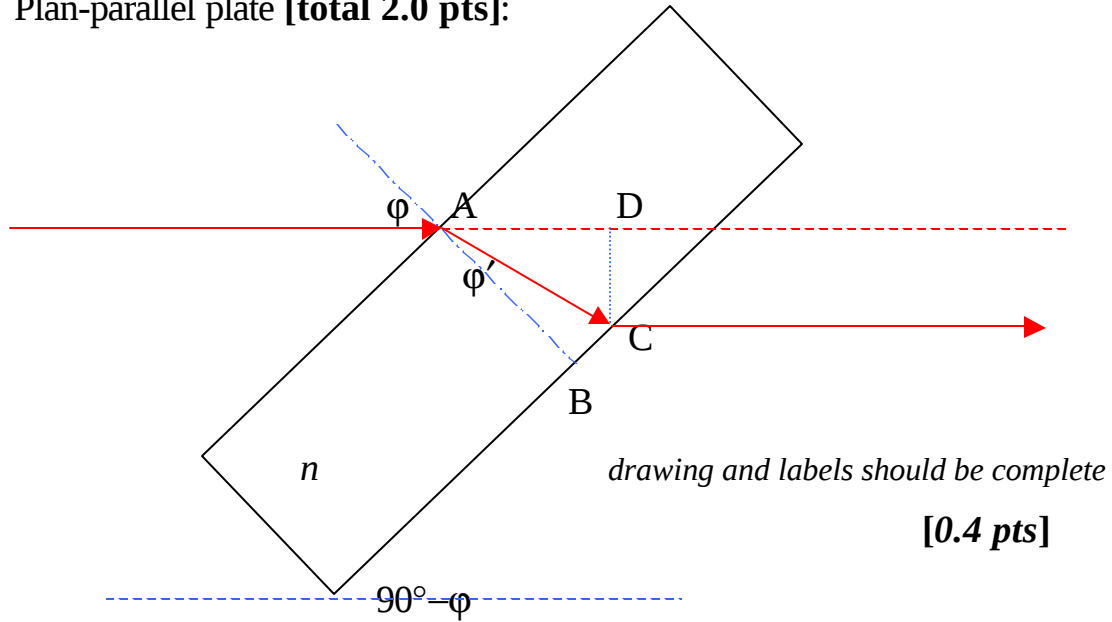
Name of component no.2	Specification
Diffraction grating	Spacing = $0.936 \mu\text{m}$ Lines parallel to the slit

[0.4 pts]

[0.1 pts]

Note: true value of grating spacing is $1.0 \mu\text{m}$, deviation of the result $\leq 10\%$

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



Snell's law:

$$\sin \phi = n \sin \phi' , \quad \phi' = \angle BAC$$

Path length inside the plate:

$$AC = AB / \cos \phi' , \quad AB = h = \text{plate thickness}$$

Beam displacement:

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

Hence:

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

Observation data:

ϕ	t	
0	0	(angle between beam and axis 49°)
49°	7.3 arbitrary scale	[0.5 pts]

Name of component no.3	Specification	
Plane-parallel plate	Thickness = 17.9 mm	[0.2 pts]
	Angle to the axis of the box 49°	[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 $\leq 20\%$.