## Post-IGCSE Physics Course: Experimental Physics using Data Loggers and Computers

aser Differencie

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Waves

Last updated April/May 2017

#### **Experimental setup**



2V DC power supply for potential divider which enables rotation angle of laser and grating to be measured

Laser on turntable. Turntable is mounted on a potentiometer.

PASCO light sensor (with black tape covering and pinhole)

This was removed for several experiments to allow in more light

Laser beam will be diffracted by the grating. Turning the turntable enables one to measure the light intensity vs angle from normal to grating. 100 HAW ASLEY EDI CITION

Black tape covering light sensor aperture with pinhole

Rotate laser mounting to enable light sensor to 'scan' diffraction pattern (i.e. light intensity vs angle)



The small aperture did not absorb sufficient light at modest angles from normal incidence. The cap and tape were removed, and the sensor was placed at an appropriate distance such that the distances between the main lobes would be greater than the width of the light sensor



Diffraction grating: 100, 300 or 600 lines per mm



[Graph title here]

## **CAPSTONE** recordings of turntable voltage vs light level

11000	title herel															
		<b>V</b> Run #6	🗙 Run #6	]		1600-						1				
	Time (s)	Light Level (lx)	Voltage (V)									1			Run	#6
776	155.000	0.120163	0.88932	•								11#7¥A				
777	155.200	0.140182	0.88932	1		1200										
778	155.400	0.140182	0.89419									WWAA				
779	155.600	0.180237	0.89906	1	×											
780	155.800	0.160217	0.90393	1	eve							fi in A				
781	156.000	0.240326	0.90393	1	ht L	800-						A HAAN				
782	156.200	1.241684	0.90880	1	o ≘											
783	156.400	4.345886	0.90880	1								/////				
784	156.600	50.949097	0.91367	1												
785	156.800	95.529556	0.92828	1		400-					- #L	/ <b>1/</b> /   NAN				
786	157.000	98.473541	0.93802	1							H	<i>x</i> + <i>x</i> +	N I			
787	157.200	99.755280	0.94289	1									1		******	
788	157.400	100.756638	0.95263	1		0		1 AL	1							
789	157.600	99.695206	0.95263				0.	90 0.9	95	1.00	1.05	1.10	1.15	1.20	1.25	1.3
790	157.800	89.341156	0.95263								V	oltage (V)	)			
701	158.000	69.794647	0.94776		10.00	ما مافنه ما م										

Principal maxima of diffraction pattern plus secondary lobes.

(600 lines per mm grating)

#### Calibration – determining the voltage vs angle of turn relationship



100 lines /mm is a slit spacing of 10,000nm. For red light of wavelength 650nm this means a spacing of about 15.4 wavelengths.



MATLAB model of expected diffraction pattern vs angle. Note due to the large number of lines in the grating (probably more than 10 in the beam), one expects each maxima to be sharper than indicated here.

Expect main lobes when:

$$\theta = \sin^{-1} \left( \frac{n\lambda}{d} \right)$$
  
$$\frac{\lambda}{d} \approx \frac{1}{15.4}$$
  
$$\therefore \theta = 0^{\circ}, 3.7^{\circ}, 7.5^{\circ}$$
  
$$11.2^{\circ}, 15.1^{\circ}, 18.9^{\circ}$$
  
$$22.9^{\circ}, 27.0^{\circ}, 31.3^{\circ}, 35.8^{\circ}, 40.5^{\circ}$$
  
$$45.6^{\circ}, 51.2^{\circ}, 57.6^{\circ}, 65.4^{\circ}, 76.9^{\circ}$$

Unlikely individual peaks will be resolved by lux sensor



Time (s)	Light Level (lx)	Voltage (V)	Angle /degrees						<i>c</i>						
0	987.399109	1.09386	-0.0878128			Diff	raction	1 pattern	for grat	ting wit	h 100 línes	per mm	. Red las	ser light	
0.2	986.658081	1.09386	-0.0878128							(650	nm)				
0.4	986.077332	1.09386	-0.0878128							1600					
0.6	986.477844	1.09386	-0.0878128												
0.8	985.116028	1.09386	-0.0878128												
1	1023.788452	1.09386	-0.0878128												
1.2	1012.573242	1.09386	-0.0878128							1400					
1.4	1017.720215	1.09386	-0.0878128							1400	*				
1.6	1017.359741	1.09386	-0.0878128								••				
1.8	1018.661499	1.09386	-0.0878128							•	•				
2	1020.423889	1.09386	-0.0878128							1200	* <sup>**</sup>				
2.2	1007.806763	1.09386	-0.0878128							1200					
2.4	1007.546448	1.09386	-0.0878128												
2.6	1006.104492	1.09386	-0.0878128												
2.8	1006.865479	1.09386	-0.0878128								-				
3	996.351257	1.09386	-0.0878128							1000					
3.2	1035.284058	1.09386	-0.0878128						×		•				
3.4	1119.778687	1.09386	-0.0878128						Ţ		••				
3.6	1260.229126	1.09386	-0.0878128								1				
3.8	1305.170044	1.09873	0.5624296						Š	800	•				
4	1294.635742	1.09873	0.5624296						L L						
4.2	1291.371338	1.09873	0.5624296						闧		+				
4.4	1152.983643	1.09873	0.5624296												
4.6	218.255997	1.1036	1.212672							600					
4.8	31.182281	1.1036	1.212672								•		v diff	icult to	<b>`</b>
5	56.616776	1.1036	1.212672									VCI	y uni		,
5.2	278.197296	1.10847	1.8629144							:	•	reso	olve I	ohes	
5.4	274.051666	1.10847	1.8629144							400	1	1000			
5.6	271.307953	1.10847	1.8629144							400	•.				
5.8	269.525543	1.11334	2.5131568								20				
6	60.702316	1.12795	4.463884												
6.2	34.306519	1.12795	4.463884												
6.4	3.064148	1.12795	4.463884							200	K				
6.6	4.425995	1.13282	5.1141264								•••				
6.8	8.010864	1.13282	5.1141264												
7	18.064499	1.13769	5.7643688							• ••••••••••••••••••••••••••••••••••••	11.4				
7.2	24.072647	1.14256	6.4146112							21808 · O' 80		1000.2000			• •••••
7.4	23.231506	1.14256	6.4146112	-40	)	-30		-20	-10		0 1	10	20	30	40
7.6	22.690765	1.14743	7.0648536						Ar	ngle /de	g				
7.8	3.124237	1.1523	7.715096												
0	2 204246	1 15717	0 2652204												

300 lines /mm is a slit spacing of 3330nm. For red light of wavelength 650nm this means a spacing of about 5.1 wavelengths.



MATLAB model of expected diffraction pattern vs angle. Note due to the large number of lines in the grating (probably more than 10 in the beam), one expects each maxima to be sharper than indicated here.

Expect main lobes when:

$$\theta = \sin^{-1} \left( \frac{n\lambda}{d} \right)$$

 $\frac{\lambda}{d} \approx \frac{1}{5.1}$ :.  $\theta = 0^{\circ}, 11.3^{\circ}, 23.1^{\circ}$ 36.0°, 51.7°, 78.6°



Time (s)	Light Level (lx)	Voltage (V)	Angle /degrees		D1//				200 !!		D U			
0	30.481339	1.0549	-5.289752		Diffi	raction patter	rn for grat	ting with	300 line	s per mm.	Red lase	r light		
0.2	633.118652	1.08412	-1.3882976					(650r	חm)					
0.4	1285.94397	1.09873	0.5624296					1800						
0.6	27.577393	1.11334	2.5131568							1 ohas	at			
0.8	158.274658	1.17178	10.3160656								a			
1	147.159576	1.16204	9.0155808					1.000		around	110 :	as		
1.2	138.768204	1.15717	8.3653384					1600				40		
1.4	158.47493	1.16691	9.6658232					•	•	predict	ted.			
1.6	100.516312	1.16204	9.0155808					· · · ·						
1.8	110.029221	1.16691	9.6658232					1400 •	1					
2	84.234238	1.16691	9.6658232					1400	•	Thala	haa a	t high	<b>~</b> <i>r</i>	
2.2	87.118149	1.16204	9.0155808					•	••	111610	nes g	i ngne	51	
2.4	80.529205	1.15717	8.3653384					•	•	analas		o too		
2.6	82.732193	1.15717	8.3653384					1200	•	angies				
2.8	96.250534	1.16204	9.0155808				×			small t	o me	asure	or	
3	76.964371	1.16691	9.6658232				Ę					uouro,		
3.2	28.078079	1.15717	8.3653384					•	•*	possib	lv rec	luced	bV	
3.4	28.378479	1.1523	7.715096				- Sa	1000	•				Ĵ	
3.6	76.764099	1.16204	9.0155808				Ľ t		•	the ap	erture	<b>;</b>		
3.8	82.772247	1.16204	9.0155808				g			مامىرمام	no (o		طلالم	
4	87.03804	1.15717	8.3653384					800 <sup>°</sup>		enveio	pe (a	SIIL WI	ain	
4.2	95.509521	1.15717	8.3653384					800		of abo	ut 2			
4.4	53.292267	1.15717	8.3653384					••	•		ul S			
4.6	65.428726	1.15717	8.3653384					• •	•	wavele	nath	s was		
4.8	69.574356	1.15717	8.3653384					600 <sup>°</sup>	•		Jingui	5 1143		
5	73.119156	1.16204	9.0155808							auesse	ed).			
5.2	72.838776	1.16204	9.0155808							34000				
5.4	73.179245	1.16204	9.0155808											
5.6	54.473877	1.15717	8.3653384					400 *						
5.8	16.101837	1.1523	7.715096						••••					
6	252.682693	1.13769	5.7643688					•						
6.2	473.88269	1.12795	4.463884					200						
6.4	390.189178	1.12308	3.8136416					200	• •	12012****				
6.6	1320.130371	1.11334	2.5131568					1 · .	•••					
6.8	1494.266479	1.10847	1.8629144				••	•						
/	1400.279053	1.10847	1.8629144						•					
7.2	1318.888672	1.10847	1.8629144				4.0	0		10	20	20	10	
7.4	1399.538086	1.1036	1.212672	-40	-30	-20	-10 Ar	0 Jale /dea		10	20	30	40	
7.6	1432.803101	1.1036	1.212672					isic / ucg						
7.8	1437.5896	1.10847	1.8629144											

600 lines /mm is a slit spacing of 1667nm. For red light of wavelength 650nm this means a spacing of about 2.6 wavelengths.



MATLAB model of expected diffraction pattern vs angle. Note due to the large number of lines in the grating (probably more than 10 in the beam), one expects each maxima to be sharper than indicated here.

Expect main lobes when:

$$\theta = \sin^{-1} \left( \frac{n\lambda}{d} \right)$$
$$\frac{\lambda}{d} \approx \frac{1}{2.6}$$
$$\therefore \theta = 0^{\circ}, 22.6^{\circ}, 50.3^{\circ}$$



Iou       Voite       Angle /degrees         666.10054       1.08899       0.780552         666.100554       1.08899       0.7380552         666.100554       1.08899       0.7380552         665.5407244       1.09386       0.0878128         665.5407245       1.09386       0.0878128         665.350755       1.09386       0.0878128         665.350755       1.09386       0.0878128         692.40553       1.09386       0.0878128         250.159271       1.09386       0.0878128         35.448       1.12275         24.1189736       1.104971       1.862914         1.1382733       1.104971       1.862914         1.1382731       1.136204       9.0155808         1.222736       1.16152       11.615504         1.862738       1.19126       1.216679         1.862738       1.19126       1.216679         1.822531       1.2064       9.0155808         1.2226986       1.36204       9.0155808         1.822531       1.2067       4.81844         1.822531       1.2067       4.81849         6.638374       1.32027       1.8116155504         1.842758       1		Light Level	Voltage		
666.2077         1.0336         -0.0878128           665.30755         1.08899         -0.738052           665.590256         1.08899         -0.738052           665.590256         1.09386         -0.0878128           665.590275         1.09386         -0.0878128           665.590275         1.09386         -0.0878128           665.590275         1.09386         -0.0878128           655.348755         1.09386         -0.0878128           250.159271         1.09386         -0.0878128           250.159271         1.09386         -0.0878128           250.159271         1.09386         -0.0878128           250.159271         1.09386         -0.0878128           250.159271         1.09386         -0.0878128           250.159271         1.09386         -0.0878128           25.70733         1.146274         -1.06279           1.133373         1.10947         1.862914           1.902573         1.1669504         -1.005504           1.902573         1.1669504         -0.07828           1.902574         1.18152         1.6165504           1.822518         1.19126         1.291792           1.862518         1.291679	ïme (s)	(lux)	(volts)	Angle /degrees	Diffraction pattern for grating with 600 lines per mm. Red laser light
666.13054         1.08899         0.738052           667.19959         1.08899         0.738052           685.990356         1.09386         0.0878128           667.292737         1.08899         0.738052           663.1957031         1.09386         0.0878128           673.195703         1.09386         0.0878128           631.957031         1.09386         0.0878128           7.90138         1.09376         0.0878128           250.139271         1.09386         0.0878128           250.139273         1.66091         1.6001           11.13337         1.08471         1.6679144           7.490158         1.12795         4.63884           1.902573         1.16691         9.658942           1.902573         1.16691         9.658942           1.902573         1.1669504         1.620144           1.22144         1.81523         1.165504           1.822518         1.19126         1.917952           1.820578         1.22049         16.8184896           6.502818         1.22049         16.8184896           6.028158         1.22049         16.8184896           6.302357         1.23994         2.2004288		686.290771	1.09386	-0.0878128	(650nm)
686.10053         108899         -0730052           685.549744         109386         -0.0878128           685.90226         1.09386         -0.0878128           685.90273         1.08366         -0.0878128           655.348755         1.09386         -0.0878128           651.970733         1.09386         -0.0878128           250.159271         1.09386         -0.0878128           250.159271         1.09386         -0.0878128           250.159271         1.09386         -0.0878128           250.159271         1.09386         -0.0878128           250.159271         1.09386         -0.0878128           25.411         1.01365         1.10477           21.188754         1.10877         1.667914           11.133373         1.10847         1.8679144           11.133373         1.10469         9.658232           2.027373         1.1669504         -0.015504           1.221649         1.18152         1.16165504           1.622192         1.201         1.217952           1.882533         1.20687         1.29048           2.83061         1.202048         1.8189744           1.822158         1.8189744	2	686.130554	1.08899	-0.7380552	2000
685.990356         1.08899         0.7380552           685.990356         1.08899         0.7380552           685.950256         1.03386         0.0878128           653.950256         1.03386         0.0878128           653.950256         1.03386         0.0878128           633.957031         1.03386         0.0878128           250.159271         1.09386         0.0878128           343.13731         1.08673         0.5382144           11.335735         1.10847         1.8629144           7.490158         1.12795         4.463884           5.707733         1.14256         6.4446112           3.5448         1.15237         1.08673           2.022736         1.18152         1.0165504           1.221649         1.18152         1.0165504           1.221649         1.8152         1.6105504           1.8622138         1.913552         1.6015506           1.8622138         1.91352         1.6105504           1.8622158         1.91352         1.6105504           1.8622158         1.91352         1.8119724           1.8622192         1.811924         1.6105504           1.8622193         1.8119126         4.4073286 <td>4</td> <td>686.170593</td> <td>1.08899</td> <td>-0.7380552</td> <td></td>	4	686.170593	1.08899	-0.7380552	
685:54974         1.00386         0.0878128           685:54974         1.00386         0.0878128           655:348755         1.00386         0.0878128           655:338755         1.00386         0.0878128           650:95731         1.00386         0.0878128           250:159271         1.00386         0.0878128           250:159271         1.00386         0.0878128           250:159271         1.00386         0.0878128           250:159271         1.00386         0.0878128           250:159271         1.00386         0.0878128           250:159271         1.00386         1.28725           1.1335373         1.10364         1.2820744           11335373         1.10847         1.8829144           7:490158         1.12795         4.48384           3:5448         1.15323         7.715096           2:022736         1.18152         11.6165504           1:021573         1.6691         9.055808           1:02254         1.011         14.21752           1:862518         1.19126         12.917052           1:862518         1.2014         14.81752           1:862518         1.2014         14.81752	6	685.990356	1.08899	-0.7380552	
885.950256       1.09386       -0.0287128         675.992737       1.08999       -0.780552         653.94755       1.09385       -0.0878128         653.95031       1.09385       -0.0878128         250.159271       1.09385       -0.0878128         250.159273       1.09385       -0.0878128         250.159271       1.09385       -0.0878128         250.159273       1.09873       0.5674296         21138733       1.10847       1.8629144         7.490158       1.12795       4.43884         5.707733       1.16605         1.902573       1.16616504         1.902573       1.16615504         1.80253       1.2165504         1.80253       1.2165504         1.80253       1.2165504         1.80253       1.20582         1.80253       1.2056764         2.839911       1.21074         1.8424988       1.814896         6.548874       1.23020         1.8424988       1.23904         2.848779       1.56444         2.84874       1.23020         1.8424988       1.2390436         3.9305576       1.24483         2.843778	8	685.549744	1.09386	-0.0878128	1000
672.992737       1.08899       -0.0780552         655.348755       1.09386       -0.0878128         53.1037031       1.09386       -0.0878128         54.513931       1.09873       0.5624296         29.319763       1.1036       1.112672         11.1335373       1.10847       1.8629144         11.1335373       1.10847       1.8629144         13.33373       1.10472       1.8629144         13.33373       1.10472       1.8629144         13.33373       1.10691       9.658232         2.022736       1.18152       11.6165504         1.222649       1.8152       11.6165504         1.222736       1.882753       1.3165504         1.222736       1.8152       11.6165504         1.222736       1.8152       11.6165504         1.822533       1.20587       14.8877624         2.833911       1.10174       15.5180048         6.0202158       1.2204       600       The 50° lobes were too small to measure         95420578       1.5944       22.004288         47.844879       12.5948       23.00136         0.508051       1.3944       22.004288         23.31778       1.2643		685.950256	1.09386	-0.0878128	1800
655.348755         1.09386         0.0878128           631.957031         1.09386         0.0878128           520.159271         1.09386         0.0878128           252.159271         1.09386         0.0878128           253.3131         1.09873         0.6824296           29.319763         1.10867         1.8629144           11.1353731         1.10847         1.8629144           7.490158         1.12795         4.463884           5.707733         1.16691         9.665823           2.823965         1.1604         9.0155808           1.902573         1.168519         9.665823           1.825253         1.16165504           1.825253         1.20587         1.848756           6.028168         1.22048         16.8184896           6.028168         1.22048         16.8184896           6.548874         1.23096         18.418974           1.822573         1.24848         2.0097016           5.948874         1.23096         18.418974           1.842577         1.29448         2.2004288           47.844879         1.2996         3.908901           1.230913         1.28483         2.0097016           5.	2	672.992737	1.08899	-0.7380552	•
631.95701         1.09386         -0.0878128           609.46653         1.09386         -0.0878128           520.159271         1.09386         -0.0878128           54.513931         1.09873         0.5624296           24.319763         1.1038         1.21272           21.188736         1.00477         1.8629144           11.335373         1.10447         1.8629144           11.335373         1.10447         1.8629144           11.335373         1.10447         1.8629144           12.923965         1.16204         9.015508           1.902573         1.16691         9.0658822           2.023965         1.16604         9.015508           1.82253         1.20564         1.21049           1.862518         1.19126         1.917352           1.882533         1.2087         1.884896           6.028481         1.231649         1.8189744           1.822578         1.2396         1.917352           1.842593         1.2396         1.94194592           6.028488         1.23996         1.94194592           6.3105576         1.24843         2.00697016           5.948874         1.23996         1.94194592	4	655.348755	1.09386	-0.0878128	
609.46553         1.09386         -0.0878128           250.15921         1.09386         -0.0878128           25.31331         1.09873         0.5624956           29.319763         1.10364         1.8229144           11.335373         1.10847         1.8629144           7.490158         1.12755         4.463884           5.707733         1.14256         6.4146112           3.5448         1.1523         7.710906           2.923955         1.16019         9.658232           2.022736         1.18152         11.6165504           1.862531         1.20158         1.20158           1.20269         1.201         14.21752           1.882531         1.20587         1.48677624           1.8825531         1.2022         1.81189744           1.8425531         1.2022         1.81189744           1.8425531         1.20298         194194592           63.005761         1.23996         194194592           63.105576         1.24848         2.2004288           47.844879         1.20996         194194592           63.005761         1.23944         2.2004288           47.844879         1.20936         1.9461182	6	631.957031	1.09386	-0.0878128	1600
250.159271       1.09366       -0.0878128         54.513931       1.08873       0.5624296         29.3159761       1.036       1.12672         21.188736       1.0847       1.8629144         11.335373       1.0847       1.8629144         1.335373       1.10847       1.8629144         7.490158       1.2725       4.463884         5.707733       1.14256       6.4146112         3.5448       1.523       7.71506         1.902573       1.16691       9.655822         2.022736       1.18152       11.6165504         1.221649       1.81523       1.16165504         1.221649       1.81752       1.20165504         1.82533       1.20587       14.8677624         2.883911       1.21074       15.5180048         6.028168       1.20483       20.697016         35.908691       1.23996       18.7692168         47.844679       1.2897016       23.907166         59.420578       1.28944       22.0204288         47.844679       1.2984       22.0204288         47.844679       1.2984       22.0204288         40       -30       -20       -10       10       20 <td>8</td> <td>609.466553</td> <td>1.09386</td> <td>-0.0878128</td> <td>•</td>	8	609.466553	1.09386	-0.0878128	•
54.513931       1.09873       0.5624296         29.319763       1.1036       1.212672         21.188726       1.0047       1.8629144         7.490158       1.12755       4.463884         7.490158       1.12755       6.4146112         3.5448       1.1523       7.715096         2.923965       1.16165904         1.902731       1.6165504         1.221649       1.8152         1.862518       1.91126       1.91752         1.862531       1.20174       15.818044         6.628168       1.22048       18.818744         1.882553       1.20587       1.48677624         2.88371       1.23009       18.789744         2.848371       1.23009       18.789744         2.848371       1.23096       18.484896         6.502818       1.921842       20.097016         3.908691       1.23092       18.189744         2.848171       1.23094       2.0204288         47.844879       1.23944       2.0204288         47.844879       1.23944       2.0204288         0.28038       1.27892       2.8671256         0.02002       1.2984       2.722368		250.159271	1.09386	-0.0878128	
29.319763       1.1036       1.212672         21.188736       1.10847       1.8629144         11.335373       1.0047       1.8629144         7.490158       1.12795       4.463884         5.707733       1.14256       6.4146112         2.35448       1.523       7.750966         2.923965       1.16204       9.055808         1.902573       1.1615504         1.221649       1.8152       11.6165504         1.221523       1.2017       15.81504         1.622192       1.201       14.21752         1.882535       1.20287       1.48477624         2.883911       1.2074       15.5180048         6.028168       1.22048       16.8184996         6.54874       1.23020       18.189744         1.8424988       1.23090       18.7692168         3.5444879       1.23909       18.7692168         3.5444874       2.20204288         47.844879       1.23944       2.20204288         47.844879       1.23952       2.6571852         0.800231       1.27892       2.613984         0.02002       1.29353       2.65721256         0.040054       1.2984       2.722368	.2	54.513931	1.09873	0.5624296	1400
21.188736       1.10847       1.8629144         1.1335373       1.10847       1.8629144         7.490158       1.12795       4.63844         5.707733       1.14256       6.4146112         3.5448       1.1523       7.715096         2.923965       1.16601       9.0658232         2.022736       1.18152       11.6165504         1.82523       1.16519       1.65504         1.82523       1.1026       1.29170352         1.622192       1.201       14.21752         1.882553       1.20264       16.818486         6.028168       1.22048       16.818486         6.028168       1.22048       16.818486         6.548874       1.3399       18.7692168         1.33991       1.2048       16.818486         6.026901       1.2399       12.9944         2.8431778       1.26918       23.309136         0.680923       1.27894       22.0204288         2.24.431894       2.3209136       -40         0.100202       1.2984       27.22388	.4	29.319763	1.1036	1.212672	1400
11.335373       1.10847       1.8629144         7.490158       1.12795       4.463884         5.70773       1.14256       6.4146112         3.5448       1.1523       7.715096         2.2923965       1.16204       9.0155808         1.902573       1.1661594         1.862518       1.19126       12.0170352         1.162192       1.201       14.21752         1.882553       1.20587       14.8677624         2.883911       1.20174       15.5180048         6.6248874       1.23022       18.189744         18.424988       1.23996       18.7692168         6.3.05576       1.24483       20.0697016         59.420578       1.25944       22.0204288         47.844879       1.25944       22.0204288         7.844879       1.25944       22.0204288         0.02002       1.2984       27.222368	.6	21.188736	1.10847	1.8629144	
7.490158       1.12795       4.463884         5.707733       1.14256       6.4146112         3.5448       1.1523       7.715096         2.923955       1.16204       9.0155808         1.902573       1.16204       9.0155808         1.902573       1.161691       9.6658322         2.022736       1.8152       11.6165504         1.2121649       1.8152       11.6165504         1.82518       1.19126       12.9170352         1.622192       1.2011       14.21752         1.882553       1.20587       14.8677624         2.883911       1.21074       15.5180048         6.028168       1.22099       18.189744         3.5908691       1.23996       19.4194592         63.105576       1.25444       2.0204288         2.3431778       1.25944       2.0204288         2.3431778       1.26918       2.3209136         0.02002       1.29844       2.722368	.8	11.335373	1.10847	1.8629144	× .
5.707733       1.14256       6.4146112         3.5448       1.1523       7.715096         2.923965       1.16204       9.0155080         2.022736       1.16619       9.6658232         2.022736       1.18152       11.6165504         1.221649       1.18152       11.6165504         1.622192       1.201       14.21752         1.882513       1.20587       14.8677624         2.883911       1.21074       15.5180048         6.028168       1.22022       18.1189744         1.8424988       1.23209       18.7692168         6.5.94874       1.23096       19.4194592         6.3.105576       1.24843       20.0007016         5.9.420578       1.25944       22.0204288         2.3.431778       1.26918       23.3209136         0.28038       1.27892       24.62139844         0.180237       1.28866       25.9218832         0.040054       1.29844       27.222368		7.490158	1.12795	4.463884	₹ 1200
3.5448       1.1523       7.715096         2.923965       1.16204       9.0155808         1.902573       1.16691       9.6658232         2.022736       1.18152       11.6165504         1.221649       1.18152       11.6165504         1.862518       1.19126       12.9170352         1.622192       1.201       14.21752         1.882553       1.20587       14.8677624         2.883911       1.21074       15.5180048         6.028168       1.23020       18.1189744         6.548874       1.23020       18.1189744         6.348874       1.23096       19.4194592         6.3105576       1.24483       20.0697016         59.4020788       1.25944       22.0204288         23.431778       1.26918       23.309136         0.680923       1.27405       23.971156         0.28038       1.27892       4.6213984         0.180237       1.2866       25.9218832         0.02002       1.29348       27.222368	.2	5.707733	1.14256	6.4146112	
<ul> <li>2.923965</li> <li>1.16204</li> <li>9.0155808</li> <li>1.902573</li> <li>1.16691</li> <li>9.6658232</li> <li>1.2012</li> <li>1.6165504</li> <li>1.862518</li> <li>1.19126</li> <li>1.2014</li> <li>1.862518</li> <li>1.2014</li> <li>1.2014</li> <li>1.20174</li> <li>1.5180048</li> <li>6.528168</li> <li>1.20148</li> <li>1.20148</li> <li>1.20144</li> <li>1.882533</li> <li>1.2014</li> <li>1.5180048</li> <li>6.548874</li> <li>1.23020</li> <li>18.189744</li> <li>18.424988</li> <li>1.23090</li> <li>1.72592</li> <li>1.23996</li> <li>1.24483</li> <li>2.00697016</li> <li>5.9.420578</li> <li>1.25944</li> <li>2.00012</li> <li>1.28866</li> <li>2.5918832</li> <li>0.02002</li> <li>1.2984</li> <li>27.22368</li> <li>0.02002</li> <li>1.2984</li> <li>27.22368</li> </ul>	4	3.5448	1.1523	7.715096	e e
<ul> <li>1.902573</li> <li>1.16691</li> <li>9.6658232</li> <li>2.022736</li> <li>1.18152</li> <li>1.16165504</li> <li>1.221649</li> <li>1.18152</li> <li>1.16165504</li> <li>1.2014</li> <li>1.21616</li> <li>1.2016</li> <li>1.20174</li> <li>1.5180048</li> <li>6.028168</li> <li>1.20202</li> <li>1.88774</li> <li>1.23022</li> <li>18.189744</li> <li>6.548874</li> <li>1.23022</li> <li>18.189744</li> <li>1.23022</li> <li>18.189744</li> <li>1.23022</li> <li>18.189744</li> <li>2.20204288</li> <li>35.908691</li> <li>1.23996</li> <li>19.4194592</li> <li>63.105576</li> <li>1.24483</li> <li>2.00697016</li> <li>59.420578</li> <li>1.25944</li> <li>2.20204288</li> <li>47.844879</li> <li>1.25944</li> <li>2.20204288</li> <li>47.844879</li> <li>1.25944</li> <li>2.20204288</li> <li>2.3209136</li> <li>0.880923</li> <li>1.27405</li> <li>2.3209136</li> <li>0.28038</li> <li>1.27892</li> <li>2.46213984</li> <li>0.180237</li> <li>1.28866</li> <li>25.9218832</li> <li>0.02002</li> <li>1.2984</li> <li>27.222368</li> <li>0.02002</li> <li>1.2984</li> <li>27.222368</li> </ul>	6	2.923965	1.16204	9.0155808	
2.022736       1.18152       11.6165504         1.221649       1.18152       11.6165504         1.862518       1.19126       12.9170352         1.622192       1.201       14.21752         1.882553       1.20587       14.8677624         2.883911       1.21074       15.5180048         6.028168       1.22048       16.8184896         6.548874       1.23020       18.1189744         1.8424988       1.23090       18.7692168         3.5908691       1.23090       18.7692168         43.05576       1.24483       20.0697016         53.420578       1.25944       22.0204288         47.844879       1.25944       22.0204288         23.431778       1.26918       23.309136         0.680923       1.27405       23.971156         0.02002       1.2984       27.22368	8	1.902573	1.16691	9.6658232	
1.221649       1.18152       11.6165504         1.862518       1.19126       12.9170352         1.622192       1.201       14.21752         1.882553       1.20587       14.8677624         2.883911       1.21074       15.5180048         6.028168       1.22048       16.8184896         6.548874       1.23022       18.1189744         1.8424988       1.23509       18.7692168         35.908691       1.23996       19.4194592         6.3.105576       1.24843       20.0697016         59.420578       1.25944       22.0204288         2.3.309136       2.0204288         0.680923       1.27405       23.971156         0.680923       1.27892       24.6213984         0.02002       1.29384       27.222368		2.022736	1.18152	11.6165504	around 23° as
1.862518       1.19126       12.9170352         1.622192       1.201       14.21752         1.882553       1.20587       14.8677624         2.883911       1.21074       15.5180048         6.028168       1.22048       16.8184896         6.534874       1.23022       18.1189744         1.8424988       1.23509       18.7692168         35.908691       1.23996       19.4194592         63.105576       1.24483       20.0697016         59.420578       1.25944       22.0204288         47.844879       1.25944       22.0204288         47.844879       1.25944       22.0204288         0.680923       1.27405       23.971156         0.28038       1.27892       24.6213984         0.180237       1.28866       25.9218832         0.02002       1.2983       26.5721256         0.040054       1.2984       27.222368	2	1.221649	1.18152	11.6165504	
1.622192       1.201       14.21752         1.882553       1.20587       14.8677624         2.883911       1.21074       15.5180048         6.028168       1.22048       16.8184896         6.548874       1.23022       18.1189744         18.424988       1.23950       18.7692168         35.908691       1.23965       19.4194592         63.105576       1.2448       20.0697016         59.420578       1.25944       22.0204288         47.844879       1.25944       22.0204288         0.680923       1.27405       23.309136         0.02002       1.29353       26.5721256         0.02002       1.29353       26.5721256         0.02002       1.2984       27.222368	4	1.862518	1.19126	12.9170352	<sup>800</sup> predicted
1.882533       1.20587       14.8677624         2.883911       1.21074       15.5180048         6.028168       1.22048       16.8184896         6.548874       1.23022       18.1189744         18.424988       1.23509       18.7692168         35.908691       1.23996       19.4194592         63.105576       1.24483       20.0697016         59.420578       1.25944       22.0204288         47.844879       1.25944       22.0204288         23.431778       1.26918       23.3209136         0.680923       1.27405       23.971156         0.28038       1.27892       24.6213984         0.180237       1.28866       25.9218832         0.02002       1.29834       27.222368	6	1.622192	1.201	14.21752	prodictour
2.883911       1.21074       15.5180048         6.028168       1.22048       16.8184896         6.548874       1.23022       18.1189744         18.424988       1.23509       18.7692168         35.908691       1.23996       19.4194592         63.105576       1.24483       20.0697016         59.420578       1.25944       22.0204288         47.844879       1.25944       22.0204288         23.431778       1.26918       23.3209136         0.680923       1.27405       23.971156         0.28038       1.27892       24.62139844         0.180237       1.28866       25.9218832         0.040054       1.2984       27.222368	8	1.882553	1.20587	14.8677624	***
6.028168       1.2048       16.8184896       Ine 50° lobes         6.548874       1.23022       18.1189744       were too small to         18.424988       1.23509       18.7692168       400       measure         63.105576       1.24483       20.0697016       400       measure         59.420578       1.25944       22.0204288       200       10       10       10         23.431778       1.26918       23.309136       10       20       30         0.080923       1.27405       23.971156       200       10       20       30         0.180237       1.28866       25.9218832       -40       -30       -20       -10       0       10       20       30         0.040054       1.2984       27.222368       1.2984       27.222368       -20       -10       0       Angle /deg       10       20       30		2.883911	1.21074	15.5180048	
6.548874       1.23022       18.1189744         18.424988       1.23509       18.7692168         35.908691       1.23996       19.4194592         63.105576       1.24483       20.0697016         59.420578       1.25944       22.0204288         47.844879       1.25944       22.0204288         23.431778       1.26918       23.3209136         0.680923       1.27405       23.971156         0.28038       1.27892       24.6213984         0.180237       1.28866       25.9218832         -40       -30       -20       -10       0         Angle /deg       10       20       30	.2	6.028168	1.22048	16.8184896	· I he 50° lobes
18.424988       1.23509       18.7692168       were too small to measure         35.908691       1.23996       19.4194592       400       measure         63.105576       1.24483       20.0697016       20.04288       20.014288         47.844879       1.25944       22.0204288       200       200       10         23.431778       1.26918       23.3209136       200       10       20         0.680923       1.27405       23.971156       10       20       30         0.180237       1.28866       25.9218832       -40       -30       -20       -10       0       10       20       30         0.02002       1.2984       27.222368       27.222368       -40       -30       -20       -10       0       Angle /deg       20       30	4	6.548874	1.23022	18.1189744	ware too small to
35.908691       1.23996       19.4194592         63.105576       1.24483       20.0697016         59.420578       1.25944       22.0204288         47.844879       1.25944       22.0204288         23.431778       1.26918       23.3209136         0.680923       1.27405       23.971156         0.28038       1.27892       24.6213984         0.180237       1.28866       25.9218832         0.02002       1.29353       26.5721256         0.040054       1.2984       27.222368	6	18.424988	1.23509	18.7692168	
63.105576       1.24483       20.0697016         59.420578       1.25944       22.0204288         47.844879       1.25944       22.0204288         23.431778       1.26918       23.3209136         0.680923       1.27405       23.971156         0.180237       1.28866       25.9218832         0.02002       1.29353       26.5721256         0.040054       1.2984       27.222368	8	35.908691	1.23996	19.4194592	
59.420578       1.25944       22.0204288         47.844879       1.25944       22.0204288         23.431778       1.26918       23.3209136         0.680923       1.27405       23.971156         0.28038       1.27892       24.6213984         0.180237       1.28866       25.9218832         0.02002       1.29353       26.5721256         0.040054       1.2984       27.222368		63.105576	1.24483	20.0697016	
47.844879       1.25944       22.0204288         23.431778       1.26918       23.3209136         0.680923       1.27405       23.971156         0.28038       1.27892       24.6213984         0.180237       1.28866       25.9218832         0.02002       1.29353       26.5721256         0.040054       1.2984       27.222368	2	59.420578	1.25944	22.0204288	• •
23.431778       1.26918       23.3209136         0.680923       1.27405       23.971156         0.28038       1.27892       24.6213984         0.180237       1.28866       25.9218832         0.02002       1.29353       26.5721256         0.040054       1.2984       27.222368         0.02002       1.2984       27.222368	4	47.844879	1.25944	22.0204288	200
0.680923       1.27405       23.971156         0.28038       1.27892       24.6213984         0.180237       1.28866       25.9218832         0.02002       1.29353       26.5721256         0.040054       1.2984       27.222368         0.02002       1.2984       27.222368	6	23.431778	1.26918	23.3209136	
0.28038       1.27892       24.6213984         0.180237       1.28866       25.9218832         0.02002       1.29353       26.5721256         0.040054       1.2984       27.222368         0.02002       1.2984       27.222368	8	0.680923	1.27405	23.971156	
0.180237       1.28866       25.9218832         0.02002       1.29353       26.5721256         0.040054       1.2984       27.222368         0.02002       1.2984       27.222368		0.28038	1.27892	24.6213984	
0.02002         1.29353         26.5721256         -40         -30         -20         -10         0         10         20         30           0.040054         1.2984         27.222368         -40         -30         -20         -10         0         Angle /deg         30         -30         -30         -20         -10         0         10         20         30           0.02002         1.2984         27.222368         -40         -30         -20         -10         0         10         20         30	2	0.180237	1.28866	25.9218832	· ·· · · ·· ·· ·· ·· ·· ·· ···········
0.040054         1.2984         27.222368         Angle /deg           0.02002         1.2984         27.222368         Angle /deg	4	0.02002	1.29353	26.5721256	-40 -30 -20 -10 0 10 20 30
0.02002 1.2984 27.222368	6	0.040054	1.2984	27.222368	Angle /deg
	8	0.02002	1.2984	27.222368	

## Diffraction pattern for 100 lines/mm grating



## Diffraction pattern for 300 lines/mm grating



