Torsional pendulum

We first saw this apparatus at the 2023 IOP Stirling physics teachers meeting. We were impressed by the thought that had gone into the design and the very reasonable cost. We received the apparatus for evaluation.

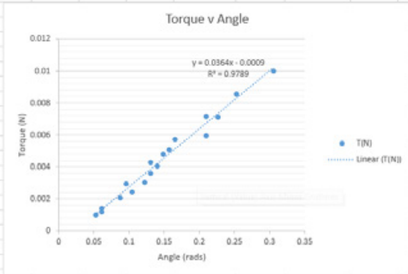
It arrived complete, well packaged and included a comprehensive manual detailing kit contents, assembly instructions and details of four suggested experiments (including some background theory).

The assembly instructions run to five pages. Assembly is not difficult but there is an order to assembly and some subtle features in the construction that are easily overlooked. Construction took about 90 minutes.

Experiment 1

Experiment 1 examines torque v angular displacement. This, in theory, was the simplest of the experiments. Provide a force (using thread, paperclips and a pulley wheel) at right angles to the suspended rod at a measured distance from the axis and measure the angle of rotation. This enables the torsional constant to be measured. This proved to be the least accurate of the experiments due to the poor quality of the cobbled together pulley wheel as no pulley wheel is provided (see Figure 1).

Expt 1					
R(mm)	m(g)	T(N)	θ(deg)	θ(rads)	T(N)
340	0.3	0.001001	3	0.05236	0.001001
340	0.62	0.002068	5	0.087266	0.002068
340	0.91	0.003035	7	0.122173	0.003035
340	1.22	0.004069	8	0.139626	0.004069
340	1.52	0.00507	9	0.15708	0.00507
400	0.3	0.001177	3.5	0.061087	0.001177
400	0.62	0.002433	6	0.10472	0.002433
400	0.91	0.003571	7.5	0.1309	0.003571
400	1.22	0.004787	8.5	0.148353	0.004787
400	1.52	0.005964	12	0.20944	0.005964
400	1.82	0.007142	13	0.226893	0.007142
480	0.3	0.001413	3.5	0.061087	0.001413
480	0.62	0.002919	5.5	0.095993	0.002919
480	0.91	0.004285	7.5	0.1309	0.004285
480	1.22	0.005745	9.5	0.165806	0.005745
480	1.52	0.007157	12	0.20944	0.007157
480	1.82	0.00857	14.5	0.253073	0.00857
480	2.12	0.009983	17.5	0.305433	0.009983



LINEST	
0.036402	-0.000916622
0.001335	0.000217472
0.978923	0.000386655
743.1207	16
0.000111	2.39204E-06

Figure 1 - Torque v angle rotation (Experiment 1).

Experiment 2

Experiment 2 examines the period of rotation v mass of the oscillating rod. The aim of this experiment is to show that the square of the period of oscillation is directly proportional to the moment of inertia of the tube/rod. The mass of the oscillating tube, and hence the moment of inertia, is altered by slotting lengths of copper wire into the tube (see Figure 2). Note the difference between the torsional constant calculated from the gradient of the graph in Figure 1 (0.036402N m rad^{-1}) with that obtained by calculation using the gradient in Figure 3 (0.031205N m rad^{-1}). As can be seen from Figure 3 the graph confirms the relationship.

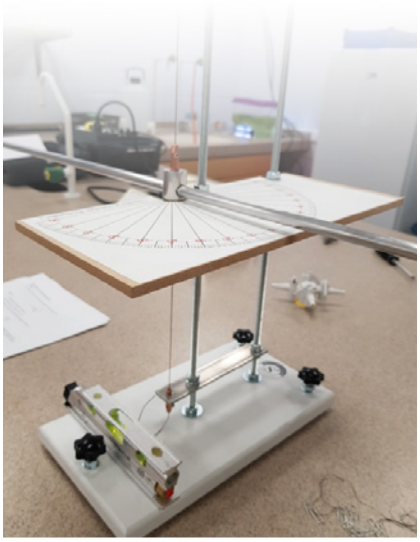
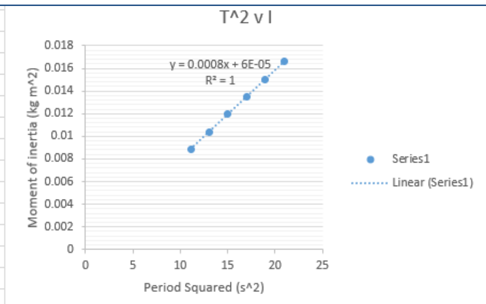


Figure 2

Expt 2						1 wire(g) :	18.4
	T20(s)	T(s)	T^2(s^2)	I(calctube	mass(g)		
tube	66.72	3.336	11.1289	0.008847	105.11		
tube+18.4	72.33	3.6165	13.07907	0.010396	123.51		
tube+36.8	77.5	3.875	15.01563	0.011944	141.91		
tube+55.2	82.43	4.1215	16.98676	0.013493	160.31		
tube+73.6	87.05	4.3525	18.94426	0.015042	178.71		
tube+92.0	91.5	4.575	20.93063	0.016591	197.11		
		c=	0.031205				



LINEST	
0.000790428	6.07E-05
1.52482E-06	2.49E-05
0.999985114	1.25E-05
268710.827	4
4.19729E-05	6.25E-10

Figure 3

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Expt 3						
	m(g)	L(mm)	id(mm)	od(mm)	I (tube)	I(rod)
tube	105.11	1005	7	9.5	0.008849	0.008847

m(g)	R(mm)	I(masses)	I(tot)	T20(s)	T(s)	T*T(s*s)	I(tot)	I(masses)	Isys from T^2
8.89	160	0.000455	0.009302	68.45	3.4225	11.71351	0.009302168	0.000455	0.009258744
8.89	180	0.000576	0.009423	68.83	3.4415	11.84392	0.009423072	0.000576	0.00936183
8.89	200	0.000711	0.009558	69.32	3.466	12.01316	0.0095582	0.000711	0.009495598
8.89	220	0.000861	0.009708	69.85	3.4925	12.19756	0.009707552	0.000861	0.009641354
8.89	240	0.001024	0.009871	70.55	3.5275	12.44326	0.009871128	0.001024	0.009835563
8.89	260	0.001202	0.010049	71.02	3.551	12.6096	0.010048928	0.001202	0.009967048
8.89	280	0.001394	0.010241	71.71	3.5855	12.85581	0.010240952	0.001394	0.010161659
8.89	300	0.0016	0.010447	72.56	3.628	13.16238	0.0104472	0.0016	0.010403986
8.89	320	0.001821	0.010668	73.06	3.653	13.34441	0.010667672	0.001821	0.010547864
8.89	340	0.002055	0.010902	74.05	3.7025	13.70851	0.010902368	0.002055	0.010835659
8.89	360	0.002304	0.011151	74.83	3.7415	13.99882	0.011151288	0.002304	0.011065134
8.89	380	0.002567	0.011414	75.74	3.787	14.34137	0.011414432	0.002567	0.011335894
8.89	400	0.002845	0.011692	76.65	3.8325	14.68806	0.0116918	0.002845	0.011609928
8.89	420	0.003136	0.011983	77.54	3.877	15.03113	0.011983392	0.003136	0.011881104
8.89	440	0.003442	0.012289	78.56	3.928	15.42918	0.012289208	0.003442	0.01219574
8.89	460	0.003762	0.012609	79.52	3.976	15.80858	0.012609248	0.003762	0.012495624
8.89	480	0.004097	0.012944	80.77	4.0385	16.30948	0.012943512	0.004097	0.012891557
8.89	500	0.004445	0.013292	81.56	4.078	16.63008	0.013292	0.004445	0.013144971

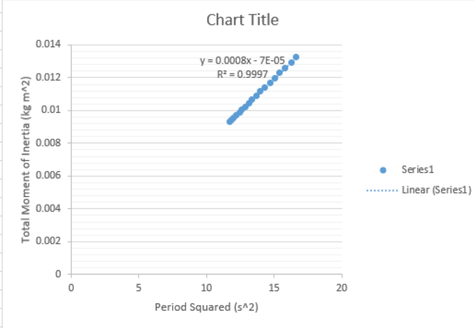

Figure 4

Experiment 3

Experiment 3 examines the relationship between period and mass distribution. Two collared masses are provided which slide over the suspended rod and are fixed at various distances from the axis of rotation using small grub screws. It is suggested that the moment of inertia of the system is plotted against the square of the period of oscillation. The value from the previous experiment is used for the moment of inertia of the tube to which we add the contribution of the two masses using mr^2.

We also calculated the moment of inertia of the tube and compared this with the assumption that the formula for a thin rod was valid.

We calculated I_{tube} = 0.008849kg m², I_{rod} = 0.008847kg m². Using the gradient this experiment gave a value for the torsional constant of (0.031643N m rad^{-1}).

Our results for this experiment are shown in Figure 4.

Experiment 3a

Not included as a suggested experiment in the instructions but we used the results from experiment 3 and plotted only the moment of inertia of the two masses against the period squared. The gradient (and hence torsional constant) was obviously the same but the offset gave a value for the moment of inertia of the rod which was 0.008921kg m²; very similar to that obtained in experiment 2 (see Figure 5).

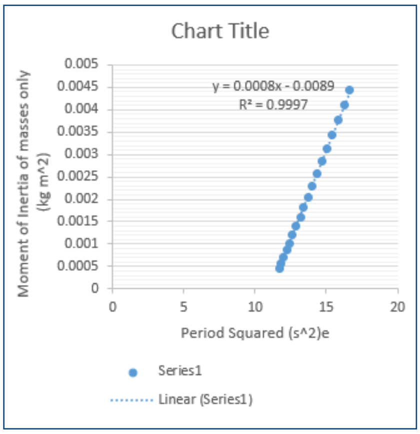

Figure 5

Experiment 3b

Again, not suggested in the supplied notes but an interesting alternative analysis of the collected data. We were, after all, starting to get carried away with ourselves. Again using the results from experiment 2 and 3 we plotted the logarithm of the moment of inertia of the masses (system moment of inertia calculated from the period of oscillation minus the rod moment of inertia) against the logarithm of the distance from the axis of rotation.

The gradient of this graph should be the power to which the moment of inertia depends on the radius and the offset should be the logarithm of the two masses combined (see Figure 6).

Exp 3c						
	R(mm)	Isys-Itube	LOG(R)	LOG(Im)		
	160	0.000412	-0.79588	-3.38535		
	180	0.000515	-0.744727	-3.28832		
	200	0.000649	-0.69897	-3.18801		
	220	0.000794	-0.657577	-3.09997		
	240	0.000989	-0.619789	-3.00499		
	260	0.00112	-0.585027	-2.95075		
	280	0.001315	-0.552842	-2.88118		
	300	0.001557	-0.522879	-2.80771		
	320	0.001701	-0.49485	-2.76932		
	340	0.001989	-0.468521	-2.70143		
	360	0.002218	-0.443697	-2.65401		
	380	0.002489	-0.420216	-2.60399		
	400	0.002763	-0.39794	-2.55863		
	420	0.003034	-0.376751	-2.51797		
	440	0.003349	-0.356547	-2.47512		
	460	0.003649	-0.337242	-2.43787	LINEST	
	480	0.004045	-0.318759	-2.39313	2.0734408	-1.735009
	500	0.004298	-0.30103	-2.36673	0.010193191	0.005365
					0.999613465	0.006381
	gradient=	power of R=	2.0734408		41377.37789	16
Total mass (g) =		18.40733			1.684983375	0.000652
calculated mass (g) =		9.203663				

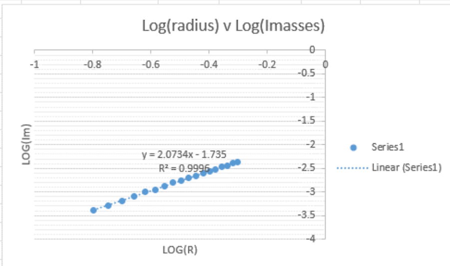

Figure 6

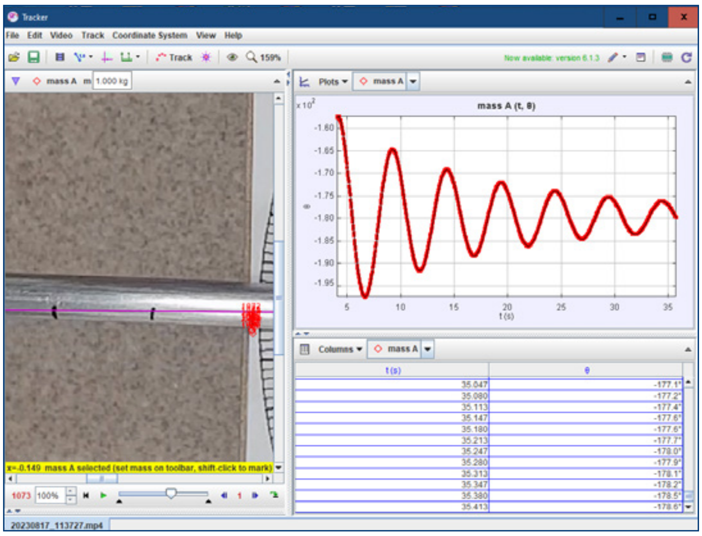

Figure 7

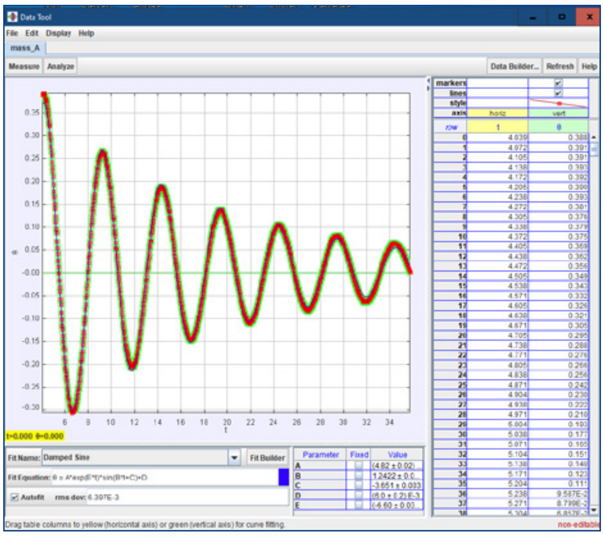

Figure 8

This yielded a value of 2.07 for the power of the radius and a value for each mass of 9.20g.

The measured value for each mass used in experiment 3 was 8.89g.

Experiment 4

In the instruction manual it is suggested that 'sails' can be added to each end of the oscillating rod and that the underdamped oscillation can be studied using tracker. We did this (Figure 7) and the results using the Tracker data analysis curve fitting tool are shown in Figure 8.

We published a a simple activity which shows under, critical and over damping in Bulletin 279. <<

References and resources

- A python article on data analysis and curve fitting can be found here https://www.sserc.org.uk/wp-content/uploads/2023/03/SSERC-bulletin-278-p2_5-Python-Pandas-Physics-Pendulums.pdf.
- The torsion pendulum used in this article can be found here: https://www.simplesciencesupplies.co.uk/shop/p/torsion-pendulum-ah-project.
- The current price of a torsion pendulum as at 18/08/2023 is £69.99.
- Critical damping demonstration can be found here: https://www.sserc.org.uk/wp-content/uploads/2023/10/SSERC-bulletin-279p5_6-Critical-damping-demonstration.pdf