

Moment of inertia by integration and torque

AP Physics C (Mechanics and E&M, calculus-based) · Lab

Name: _____ Date: _____ Class: _____

A rod swinging about a pivot has period $T = 2\pi\sqrt{[(I_{\text{cm}} + Md^2)/(Mgd)]}$. Rearranged, T^2d is linear in d^2 , with a gradient $4\pi^2/g$. Measuring T for several pivot positions tests the parallel axis theorem and gives g and the radius of gyration without needing to know the mass.

Level: AP Physics C (Mechanics and E&M, calculus-based) · **Curriculum:** AP PC:M Unit 5

Aim

Check the parallel axis theorem by timing a metre rule that swings as a pendulum about pivots at different distances d from its centre of mass, and use the graph to find g and the radius of gyration.

Equipment

- Wooden metre rule with small holes drilled at 5, 10, 20, 30 and 40 cm (teacher prepared)
- Pin or small bolt as pivot, in a clamp on a stand
- Phone stopwatch
- Second metre rule
- Card marker for the equilibrium position

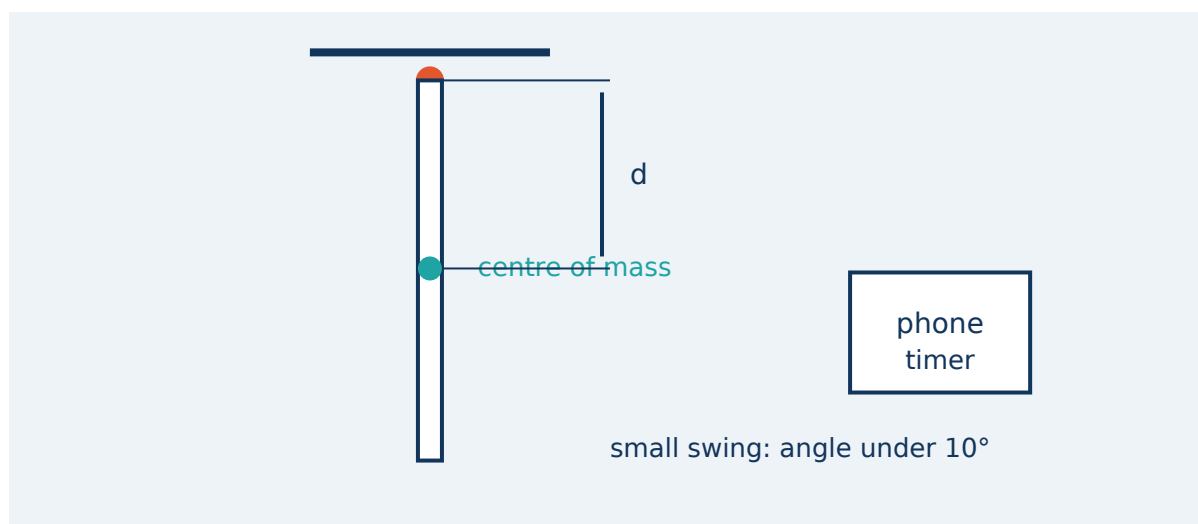
Safety

Safety

Use a short, blunt bolt rather than a sharp pin, and clamp the stand to the bench or weigh it down. Stay clear of the swinging end, and wear goggles in case the rule slips off the pivot.

Method

1. Hang the rule from the pivot at the 40 cm hole, so $d = 0.10$ m from the centre at 50 cm.
2. Pull the lower end aside by a small angle (under 10°) and release it without twisting.
3. Time 20 complete oscillations from the equilibrium mark and record t_{20} .
4. Repeat with holes at 30, 20, 10 and 5 cm ($d = 0.20, 0.30, 0.40$ and 0.45 m).
5. Calculate $T = t_{20}/20$, then T^2d and d^2 for each position.



The rule swings as a physical pendulum about a pivot at distance d from its centre.

Results

d (m)	t_{20} (s)	T (s)	T^2d ($s^2 \cdot m$)	d^2 (m^2)
0.10	38.8	1.94	0.376	0.0100
0.20	31.5	1.58	0.496	0.0400
0.30	30.6	1.53	0.702	0.0900
0.40	31.2	1.56	0.973	0.1600
0.45	32.0	1.60	1.152	0.2025

Analysis questions

Question 1 Period equation

Show that $T^2d = (4\pi^2/g)(k^2 + d^2)$, where $I_{cm} = Mk^2$.

Question 2 Plot the graph

Plot T^2d against d^2 and find the gradient and intercept from the sample data.

Question 3 Find g

Use the gradient to calculate g .

Question 4 Radius of gyration

Use the intercept and gradient to find k , and compare with $L/\sqrt{12}$ for a rod of length 1.00 m.

Question 5 Why small angles

Explain why the amplitude must be small.

Question 6 Uncertainty

Timing 20 oscillations gives t_{20} with an uncertainty of ± 0.2 s. Calculate the percentage uncertainty in T .

Question 7 Evaluation

State two sources of error and one improvement.