Name: ____________ Date: ____________ Period: ____________

LAB: THE GREAT RAMP RACE

Physics in the Wild: Engineers choose wheel shapes, flywheels, and rolling stock based on exactly what you're about to discover. The shape of a rolling object determines how fast it moves — and mass doesn't matter at all.

THE CHALLENGE

Your Task: Four objects start from rest at the top of the same ramp. They all roll without slipping. Rank them from fastest to slowest at the bottom:

- Solid sphere
- Solid cylinder
- Hollow sphere (spherical shell)
- Hollow cylinder (hoop)

PREDICT the order BEFORE we derive anything.

My prediction: 1st _____ 2nd _____ 3rd _____ 4th _____

BACKGROUND: ENERGY CONSERVATION WITH ROTATION

ENERGY CONSERVATION

At the top, a rolling object has gravitational PE. At the bottom, all of it converts to translational and rotational KE:

$$mgh = \tfrac{1}{2}mv^2 + \tfrac{1}{2}I\omega^2$$

Using the rolling constraint $v = \omega R$, we substitute $\omega = v/R$:

$$mgh = \tfrac{1}{2}mv^2 + \tfrac{1}{2}I\tfrac{v^2}{R^2}$$

Factor out the speed terms:

$$mgh = \tfrac{1}{2}v^2\left(m + \tfrac{I}{R^2}\right)$$

Solve for the final speed:

$$v = \sqrt{\tfrac{2gh}{1+I/(mR^2)}}$$

REFERENCE: MOMENTS OF INERTIA

Shape	I	I/(mR²)	v at bottom
Solid sphere	$\frac{2}{5}mR^2$	2/5	$\sqrt{\frac{10gh}{7}}$
Solid cylinder	$\frac{1}{2}mR^2$	1/2	$\sqrt{\frac{4gh}{3}}$
Hollow sphere	$\frac{2}{3}mR^2$	2/3	$\sqrt{\frac{6gh}{[illegible]}}$

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EQUIPMENT

- Ramp (at least 1.0 m long)
- Set of rolling objects (solid sphere, solid cylinder, hollow sphere, hollow cylinder — ideally same radius ~2 cm)
- Meter stick
- Stopwatch
- Protractor or height measure

PROCEDURE

1. Set up the ramp at a consistent angle. Measure the vertical height h of the starting point above the table.
2. Release two objects simultaneously from the same starting line. Record which arrives first.
3. Run each pair at least 2 times to confirm consistency.
4. Complete the bracket: race all pairs to determine the full ranking.
5. For quantitative data: time each object individually over 3 trials. Record in the table below.

DATA TABLE 1: RACE RESULTS (BRACKET)

Race	Object A	Object B	Winner
1	Solid sphere	Solid cylinder	
2	Hollow sphere	Hollow cylinder	
3	Winner of Race 1	Winner of Race 2	
4	Loser of Race 1	Loser of Race 2	
5	Winner of Race 3	Winner of Race 4	
6	Loser of Race 3	Loser of Race 4	

DATA TABLE 2: TIMED RUNS

Object	Trial 1 (s)	Trial 2 (s)	Trial 3 (s)	Avg (s)	v_{avg} (m/s)
Solid sphere					
Solid cylinder					
Hollow sphere					
Hollow cylinder					

Ramp Data: Ramp height h = _____ m, Ramp length d = _____ m

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EXERCISE 1 Calculate Predicted Speed

(a) Using h from your ramp, calculate the predicted speed at the bottom for each shape using $v = \sqrt{\frac{2gh}{1+I/(mR^2)}}$. Fill in the table:

Shape	$I/(mR^2)$	Predicted v (m/s)	Measured v (m/s)	% Difference
Solid sphere	2/5			
Solid cylinder	1/2			
Hollow sphere	2/3			
Hollow cylinder	1			

(b) Did your experimental ranking match the theoretical prediction?

(c) Did a heavier object ever beat a lighter object of the same shape? Did a lighter object ever beat a heavier one of a different shape? What does this tell you?

EXERCISE 2 The Mass Cancellation

Show algebraically why mass cancels in the ramp race. Start from energy conservation, substitute $I = cmR^2$ where c is the shape factor, and show that m divides out.

EXERCISE 3 Where Did the Energy Go?

A sliding block (no rotation) would reach $v = \sqrt{2gh}$ at the bottom. Your rolling objects were all slower. What happened to the energy difference?

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EXTENSION 1 The Surprise Race

Your teacher has two cylinders that look identical but have different mass distributions (one is solid, one is hollow with a weighted rim). Predict which wins. Race them. Explain.

EXTENSION 2 Design Challenge

You're designing a vehicle to reach the bottom of a hill as fast as possible. The wheels must roll without slipping. Should you use solid wheels or hollow wheels? Should you make the wheels heavy or light? Should you make them big or small? Justify each choice using today's equation.

AP Connection: The AP loves this scenario. A typical prompt: "Two objects roll down a ramp. Derive an expression for the speed at the bottom in terms of g, h, and the shape factor." You just did this derivation. The key step is substituting $v = \omega R$ to eliminate ω and factor out the shape dependence.

CONCLUSION

In 2-3 sentences, state what determines the winner of a rolling race and explain why mass cancels.

Clean-Up: Return all rolling objects. Handle the glass/metal spheres carefully.