M-8: HINGED STICK (FALLING CHIMNEY)

ABSTRACT: A ball is held at a height lower than the lip of a plastic cup which is firmly attached to a hinged board held at an angle of about 30° by a small stick. When the stick is snatched away the ball falls into the cup proving that the end of the stick must have fallen with an acceleration greater than that of gravity. An excellent, nearly foolproof, demonstration useful in both 110 and 100A.

EQUIPMENT: 1) Hinged board with attached cup and golf tee and stick separator.
2) Steel ball.

DEMONSTRATION: The hinged boards are separated by inserting the small stick separator between them making certain that the two ends are placed on the dots marked on the boards. Then twist the plastic golf tee so that it is vertical and put the ball on it. Point out to the class that the ball is slightly lower than the lip of the cup. Quickly snatch the stick away and observe that (a) the end of the hinged board falls away from the ball (Acceleration greater than g) and (b) the ball falls into the cup (again showing that the end must have accelerated at a rate larger than g). The effect is accompanied by a rather loud and dramatic sound when the boards collide. The demonstration is quite well received and evokes a considerable amount of comment. The equation of motion of the hinged stick is

\[ \ddot{\theta} = - \frac{mgL}{2} \cos \theta \]

If we use \( I = \frac{1}{3} mL^2 \) then

\[ \ddot{\theta} = - \frac{3g}{2L} \cos \theta \]

and the linear acceleration of the end of the stick near where the cup is located is:

\[ a = - \frac{3}{2} g \cos \theta. \]

This acceleration has a component in the downward direction.

\[ a_D = \frac{3}{2} g \cos^2 \theta. \]

Thus, so long as \( \frac{3}{2} \cos^2 \theta \) is larger than 1 then \( a_D \) is larger than g. Thus we require \( \cos^2 \theta > \frac{2}{3} \) or \( \cos \theta > \frac{\sqrt{2}}{3} \) so that \( \theta < 35^\circ \).
Comment: Many of the students may have seen movies of tall chimneys falling and have observed that they do not fall as rigid bodies but appear to curve upwards. Now they can understand the reason. In order to fall as a rigid body, the tip of the chimney would have to acquire an acceleration larger than g and would thus need a force component in the vertical direction in addition to gravity. The only source for such a force is the chimney itself and since the mortar holding the bricks together can supply only a small shear force the chimney breaks apart rather than doing the rigid body rotation.

The same phenomenon can also be demonstrated using a meter stick and a small block of wood. Rest the meter stick on two horizontally held fingers placed near the ends of the stick. On one end of the stick place the wood block. Suddenly remove the finger under the end of the stick holding the block. Surprisingly the end of the meter stick falls away from the block. (Same explanation as above.)

DIFFICULTIES: 1) This is not really a difficulty, but remember to snatch the separating stick out quickly and perpendicularly to the boards.

2) Be sure to put the stick on the dots marked on the hinged boards or else the ball will fail to go into the cup.