7 Bull's Eye

Purpose

To investigate the independence of horizontal and vertical components of motion. To predict the landing point of a projectile.

Required Equipment/Supplies

ramp or Hot Wheels® track
1/2-inch (or larger) steel ball
empty soup can
meterstick
plumb line
stopwatch, ticker-tape timer, or
  computer
  light probes with interface
  light sources

Discussion

Imagine a universe without gravity. In this universe, if you tossed a rock where there was no air, it would just keep going—forever. Because the rock would be going at a constant speed, it would cover the same amount of distance in each second (Figure A). The equation for distance traveled when motion is uniform is

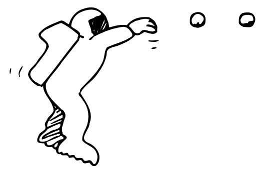

Fig. A

$$x = vt$$

The speed is

$$v = \frac{x}{t}$$

Coming back to earth, what happens when you drop a rock? It falls to the ground and the distance it covers in each second increases (Figure B). Gravity is constantly increasing its speed. The equation of the vertical distance y fallen after any time t is

Fig. B

$$y = \frac{1}{2}gt^2$$

where g is the acceleration of gravity. The falling speed v after time t is

$$v = gt$$

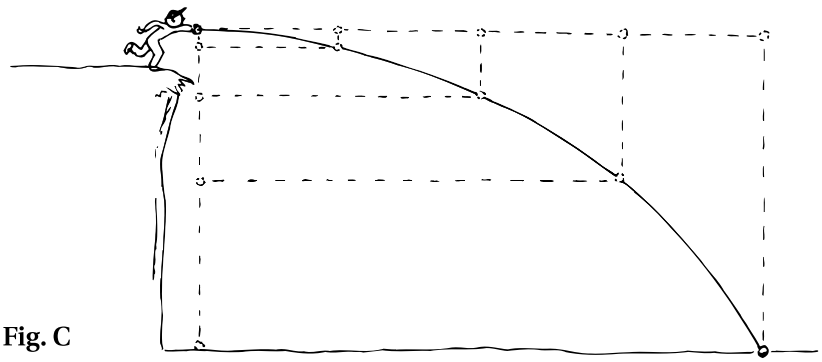

Fig. C

What happens when you toss the rock sideways (Figure C)? The curved motion that results can be described as the combination of two straight-line motions: one vertical and the other horizontal. The vertical motion undergoes the acceleration due to gravity, while the horizontal motion does not. The secret to analyzing projectile motion is to keep two separate sets of "books": one that treats the horizontal motion according to

$$x = vt$$

and the other that treats the vertical motion according to

$$y = \frac{1}{2}gt^2$$

Horizontal motion

- When thinking about how *far*, think about $x = vt$.
- When thinking about how *fast*, think about $v = x/t$.

Vertical motion

- When thinking about how *far*, think about $y = (1/2)\,gt^2$
- When thinking about how *fast*, think about $v = gt$.

Your goal in this experiment is to predict where a steel ball will land when released from a certain height on an incline. The final test of your measurements and computations will be to position an empty soup can so that the ball lands in the can the *first* time!

Procedure

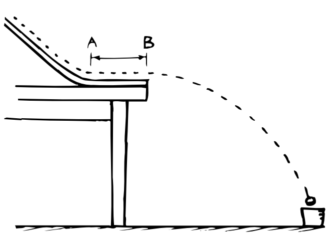

Fig. D

Step 1: Assemble your ramp. Make it as sturdy as possible so the steel balls roll smoothly and reproducibly, as shown in Figure D. The ramp should not sway or bend. The ball must leave the table *horizontally*. Make the horizontal part of the ramp at least 20 cm long. The vertical height of the ramp should be at least 30 cm.

Compute the horizontal speed.

Step 2: Use a stopwatch or light probe to measure the time it takes the ball to travel, from the first moment it reaches the level of the tabletop (point A in Figure D) to the time it leaves the tabletop (point B in Figure D). Divide this time interval into the horizontal distance on the ramp (from point A to point B) to find the horizontal speed. Release the ball from the same point (marked with tape) on the ramp for each of three runs.

Do *not* permit the ball to strike the floor! Record the average horizontal speed of the three runs.

horizontal speed = _______________

Measure the vertical distance.

Step 3: Using a plumb line and a string, measure the vertical distance h the ball must drop from the bottom end of the ramp in order to land in an empty soup can on the floor.

1. Should the height of the can be taken into account when measuring the vertical distance h? If so, make your measurements accordingly.

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h = ______________

Step 4: Using the appropriate equation from the discussion, find the time t it takes the ball to fall from the bottom end of the ramp and land in the can. Write the equation that relates h and t.

equation for vertical distance: ______________

Show your work in the following space.

t = ______________

Predict the range.

Step 5: The range is the horizontal distance of travel for a projectile. Predict the range of the ball. Write the equation you used and your predicted range.

equation for range: ______________

predicted range R = ______________

Place the can on the floor where you predict it will catch the ball.

Analysis

2. Compare the actual range of the ball with your predicted range. Compute the percentage error. (See Appendix 1 on how to compute percentage error.)

3. What may cause the ball to miss the target?

4. You probably noticed that the range of the ball increased in direct proportion to the speed at which it left the ramp. The speed depends on the release point of the ball on the ramp. What role do you think air resistance had in this experiment?

Going Further

Horizontally launch ball.

Suppose you don't know the firing speed of the steel ball. If you go ahead and fire it, and then measure its range rather than predicting it, you can work backward and calculate the ball's initial speed. This is a good way to calculate speeds in general! Do this for one or two fired balls whose initial speeds you don't know.