INTERNATIONAL
TENNIS HALL OF FAME

The Physics of Tennis

Lesson 3: Trajectories and a parabolic motion of a ball in the rally

Unit Overview: In this unit students continue to develop understanding of what can be at first glance a complicated system, the game of tennis. In this activity we have taken two components of the game of tennis, the ball and court, to see if we can model the interactions between them.

Objectives:
Students will be able to-

- Determine the curved/parabolic trajectory of a tennis ball in flight.
- Understand that the two dimensional motion of a tennis ball in flight can be thought of as two separate motions. Motion in the horizontal direction ("X") and motion in the vertical direction ("y")
- Demonstrate that in the horizontal direction, Newton's First Law-the Law of Inertia holds (neglecting air resistance) and a ball moves forward after being hit at a constant velocity (almost.)
- Demonstrate that in the vertical direction the ball, as it falls, accelerates throughout its path or trajectory at the acceleration due to gravity ($9.8 m/s^2$).
- You will understand that when the ball is hit by a racquet it accelerates forward only while the racquet is in contact with the ball.
- If you are a high school student you also will understand that Newton's Third Law, the Law of Interaction is related to the impact of the ball and racquet. i.e. Impulse = Change in Momentum.

Lesson Time Required: 1 class period

Next Generation Science/Common Core Standards:

CCSS.MATH.CONTENT.HSG.GPE.A.2 Derive the equation of a parabola given a focus and directrix (This activity supports in part this Common Core Math Standard)

NGSS.MS.PS2- Apply Newton's Third Law to design a solution to a problem by involving the motion of two colliding objects. (This activity sets up stduents for prior knowledge when the third law is introduced.)

- PS2-A1- Plan and conduct an investigation to provide evidence of the effects of balanced and unbalanced forces on the motion of an object.
  PS2.A: Forces and Motion: Each force acts on one particular object and has both strength and a direction. An object at rest typically has multiple forces acting on it, but they add to give zero net force on the object. Forces that do not sum to zero can cause changes in the object's speed or direction of motion. (Boundary: Qualitative and conceptual, but not quantitative addition of forces are used at this level)
- PS2B: Types of Interactions: Objects in contact exert forces on each other
  [Clarification Statement: Examples could include an unbalanced force on one side of a ball can make it start moving; and, balanced forces pushing on a box from both sides will not produce any motion at all.]
  [Assessment Boundary: Assessment is limited to one variable at a time: number, size, or direction of forces. Assessment does not include quantitative force size, only qualitative and relative. Assessment is limited to gravity being addressed as a force that pulls objects down.

Possible Sources:

- video of a tennis rally

Materials Needed:

- tennis ball
- painter's tape
- table

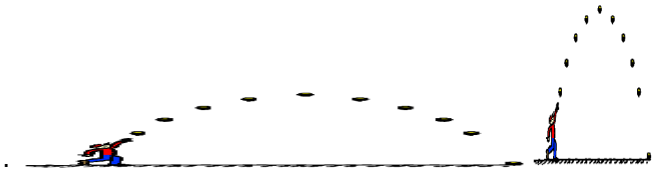
Vocabulary:

- Parabola- a symmetrical open plane curve formed by the intersection of a cone with a plane parallel to its side. The path of a projectile under the influence of gravity ideally follows a curve of this shape.
- Momentum- the quantity of motion of a moving body, measured as a product of its mass and velocity.
- Impulse- is the integral of a force, F, over the time interval, t, for which it acts.

Lesson & Activity

The path that the ball follows after being hit by the racquet is called a parabola. Parabolas occur in many places. Some examples are radio telescopes, light reflectors, bridges and even the golden arches of McDonald's. By performing

this experiment you will find out if the path of a thrown tennis ball also travels in a parabolic path.



Focus Question: What is the path of a projectile?

Part A

1) This experiment requires a few trial and error attempts, but you and your partners can illustrate the parabolic path of a tennis ball when launched.

2) Place painter's tape on the whiteboard in the classroom or on a wall. Be sure that it is horizontal. It will provide the "X" axis of a graph of the motion of the ball.

3) Then, at every .5 meters (1/2 meter) interval from the starting point end or origin, place a vertical piece of the same tape to provide vertical frames of reference.

4) Your team will stand in front of the board at each vertical marking and observe the ball's flight path, focusing just on their vertical line, and then place a dot on the line where each person observes the thrown ball moving past it.

5) One of your partners will stand or sits at the origin location and launch the ball forward and upward. Try this several times. Each time you launch the ball every student will mark the vertical lines where they see the ball pass. Each time before you launch the ball again draw a smooth curve connecting the dots.

Part B

6) Roll a tennis ball off the edge of a table. Observe the path of the ball and sketch what you observed below.

7) Roll the ball faster this time off the edge of the table. What do you observe and how does it compare to step #5.

8) If you are a high school student discuss the role of momentum and impulse for the racquet as it hits a tennis ball.