Having a ball with science:

Leveraging Sports for Science Education

Professor Adedeji Badiru

Air Force Institute of Technology (AFIT)

Wright-Patterson Air Force Base

Purpose of Workshop

- Shows how teaching science can be made fun
- Shows how simple examples of ball-based sports can be used to spark the interest of students
  - "When curiosity is established, the urge to learn develops." – Deji Badiru
- Uses soccer to illustrate "FUN-damentals" of STEM
- Uses hands-on and legs-on examples

Curiosity and the Urge to Learn

"I would get a Ph.D. in physics even if I made minimum wage afterwards. It's what I want to do."

- Zach Gault, Physics major at Wright State University, 2009

Workshop Activities

- Illustrate specific examples of the applications of Physics in Soccer
  - Gravity
  - Friction, etc.

- Video demo of Paris street soccer juggling illustrating interplay of gravity and friction

- Physic of Soccer book and t-shirt door prizes

Soccer fun for kids

Learn Science While Having Fun.

The science behind championships and jubilation

2010 Demo at TechFest

AFRL Commander MajGen Ellen Pawlikowski at PhysicsofSoccer demo - TechFest2010

2011 Legs-on Demos at TechFest

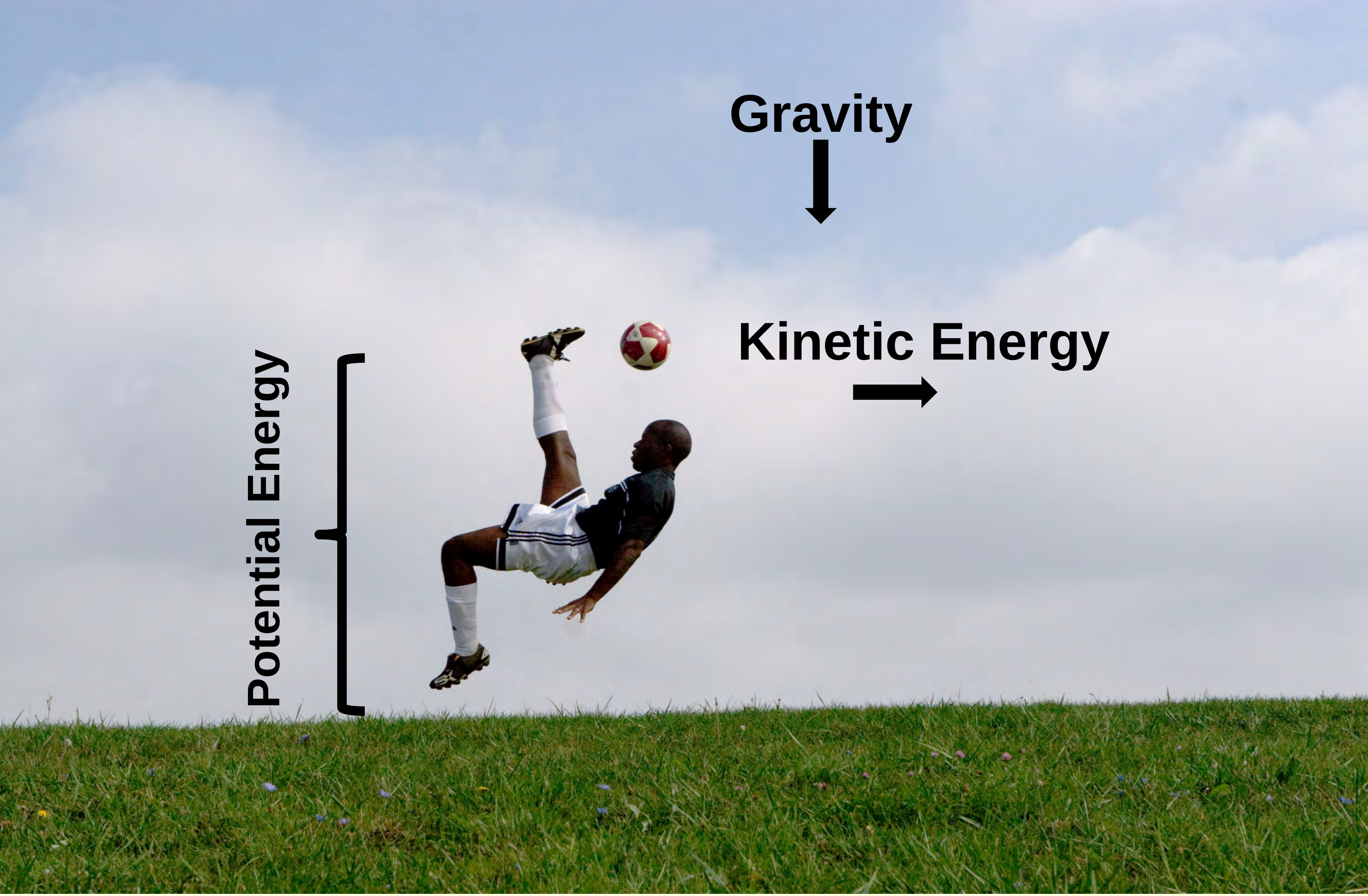
DAYTON DAILY NEWS | SUNDAY, FEBRUARY 20, 2011 | A9

TechFest at Sinclair

Ben Roseberry, 10, of Springfield tries to win a T-shirt from the PhysicsOfSoccer.com booth during the 9th annual Dayton/Miami Valley TechFest at the Sinclair Community College David Ponitz Center in Dayton

Linking Science and Sports for STEM Education

Soccer ball, Gravity, and Friction


Gravity
Kinetic Energy
Potential Energy

Leveraging Newton's Laws of Motion

First Law:

An object at rest tends to stay at **rest** and an object in motion tends to stay in **motion** with the same speed and in the same direction unless acted upon by an unbalanced force.

If the resultant force is zero, then the velocity of the object is constant.

$$\sum \mathbf{F} = 0 \Rightarrow \frac{d\mathbf{v}}{dt} = 0$$

No action, no force.
No force, no motion.

Reflections on the First Law

The first law is, perhaps, the most readily observable on the soccer field. A player already in motion will more easily continue to be in motion and be able to "spring" into action in response to events on the playing field.

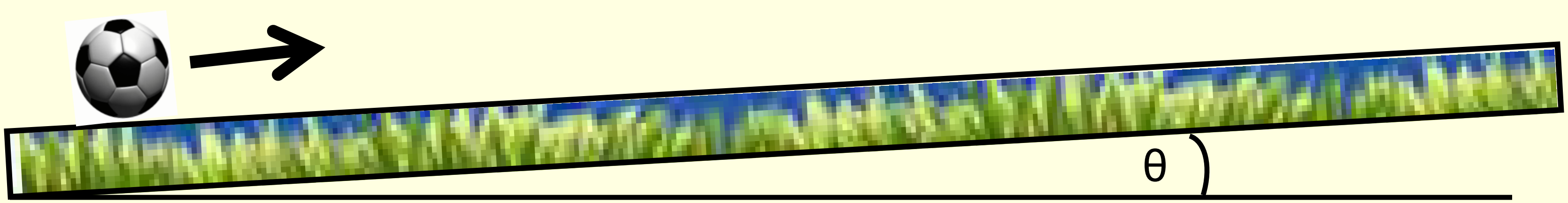
A player who is stationary will have a more difficult time responding to the soccer ball. The basic lesson here is that players will do better by staying in motion on the soccer field as much as possible.

- The best world class players are always on their toes, even when they don't have the ball.

Motion → Force → Impact

Friction on an inclined soccer field

Height of grass creates an increase in friction even on a level playing fields.



Angle of incline of a soccer field creates additional frictional force to overcome when kicking the ball uphill.

Second Law:

The **acceleration** of an object, as produced by a net force, is directly proportional to the magnitude of the net force, in the same direction as the net force, and inversely proportional to the mass of the object.

$$F = ma$$

$$F = ma$$

Third Law:

For every **action**, there is an equal and opposite **reaction**.

Consider a collision between two objects (e.g., head and soccer ball):

For such a collision, the forces acting between the two objects are equal in magnitude and opposite in direction. This statement can be expressed in equation form as follows.

$$F_1 = -F_2$$

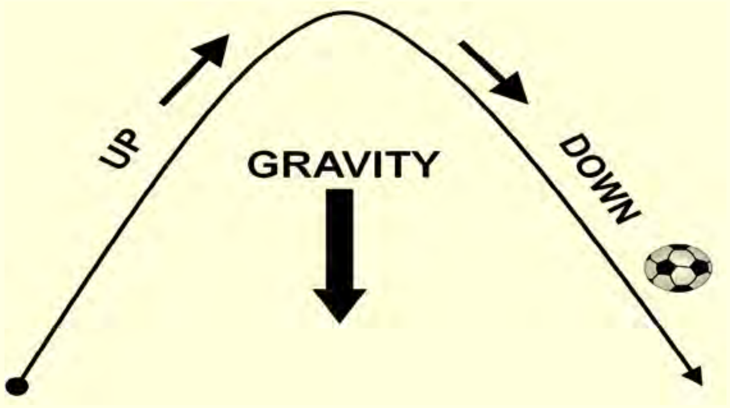
The forces are equal in magnitude and opposite in direction.

The Role of Gravity

. . . . on a ball kicked upward

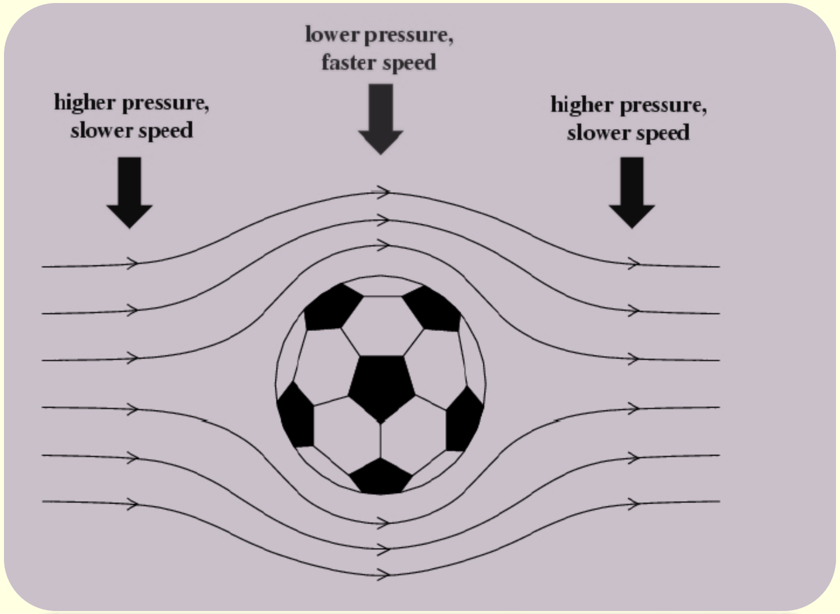
During the first part of the ball's flight, it has enough Kinetic Energy to fly against the downward pull of gravity.

After the first part, the ball falls downwards, pulled by gravity.



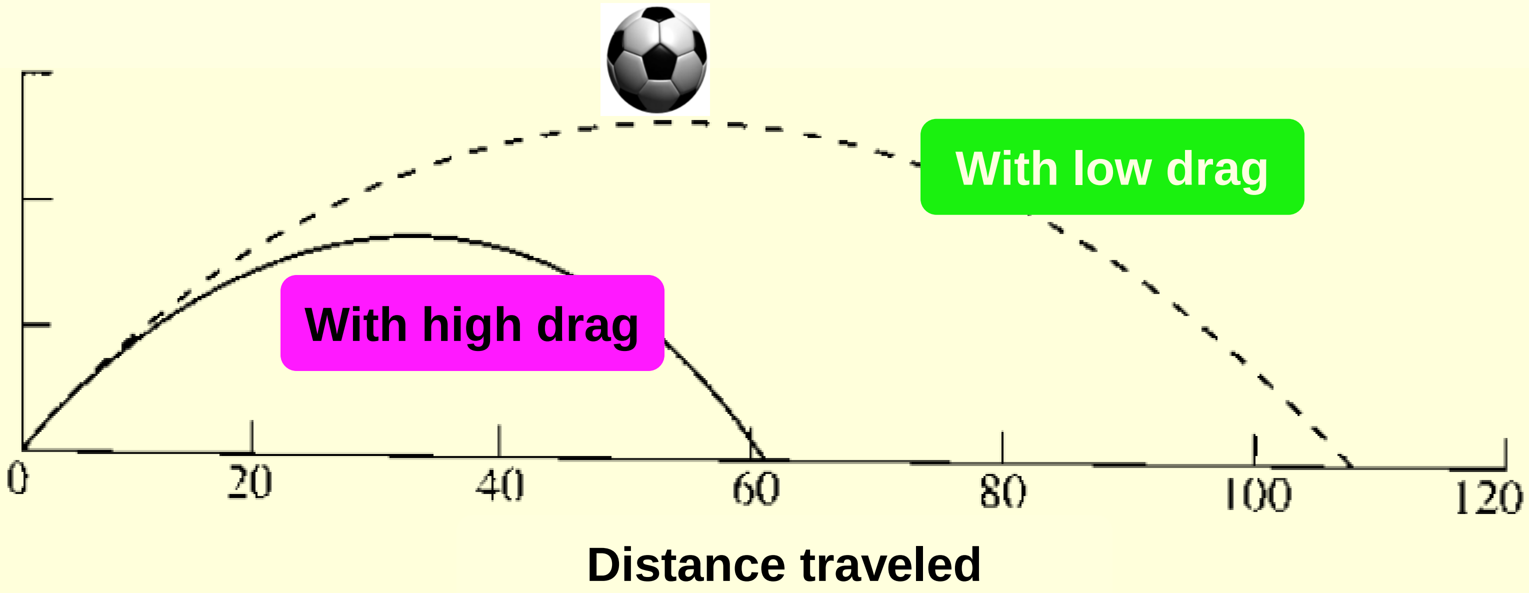
The Role of Friction

Drag is a friction-like force that has a slowing effect on the horizontal velocity of a ball. It is also the force of air on objects moving through it. At higher speeds, drag has larger effects on the speed of the ball.

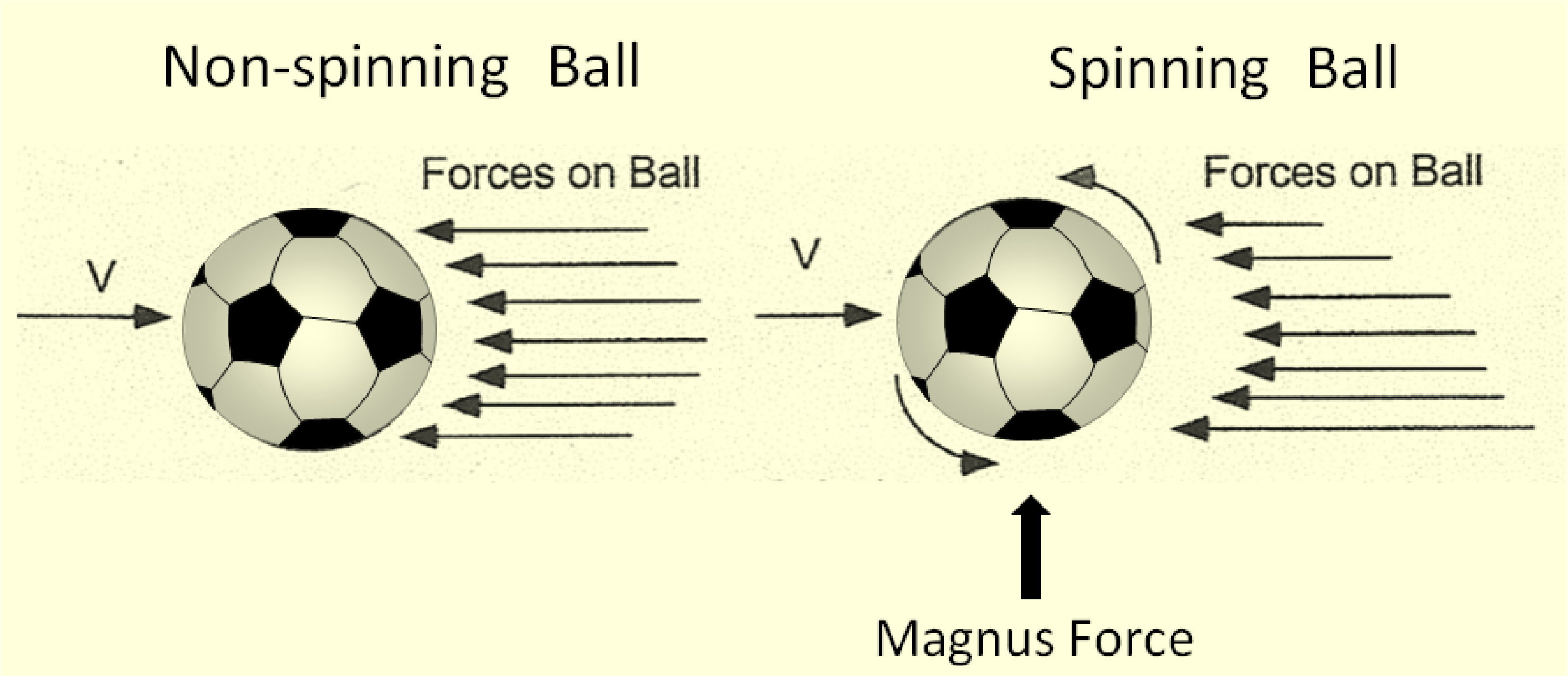


The air moving over the surface of the soccer ball is going faster than the air around the ball, creating decreased air pressure on the ball (Bernoulli's principle).

Frictional impedance on ball travel distance



Magnus Force and Ball Spin



Conservation of Energy and Conservation of Angular Momentum

- Momentum is always conserved in a collision of two bodies
- The sum of momentum before the collision must equal the sum of momenta after the collision

$$\frac{1}{2}m_1u_1^2 + \frac{1}{2}m_2u_2^2 = \frac{1}{2}m_1v_1^2 + \frac{1}{2}m_2v_2^2$$

Transfer of momentum from foot to ball

$$v_{\text{ball}} = v_0 \frac{1+e}{1+(ml^2 / I)}$$

Kinetic Energy: $\text{KE} = \frac{1}{2}mv^2$

Potential Energy: $\text{PE} = mgh$

Initial and Final Velocities

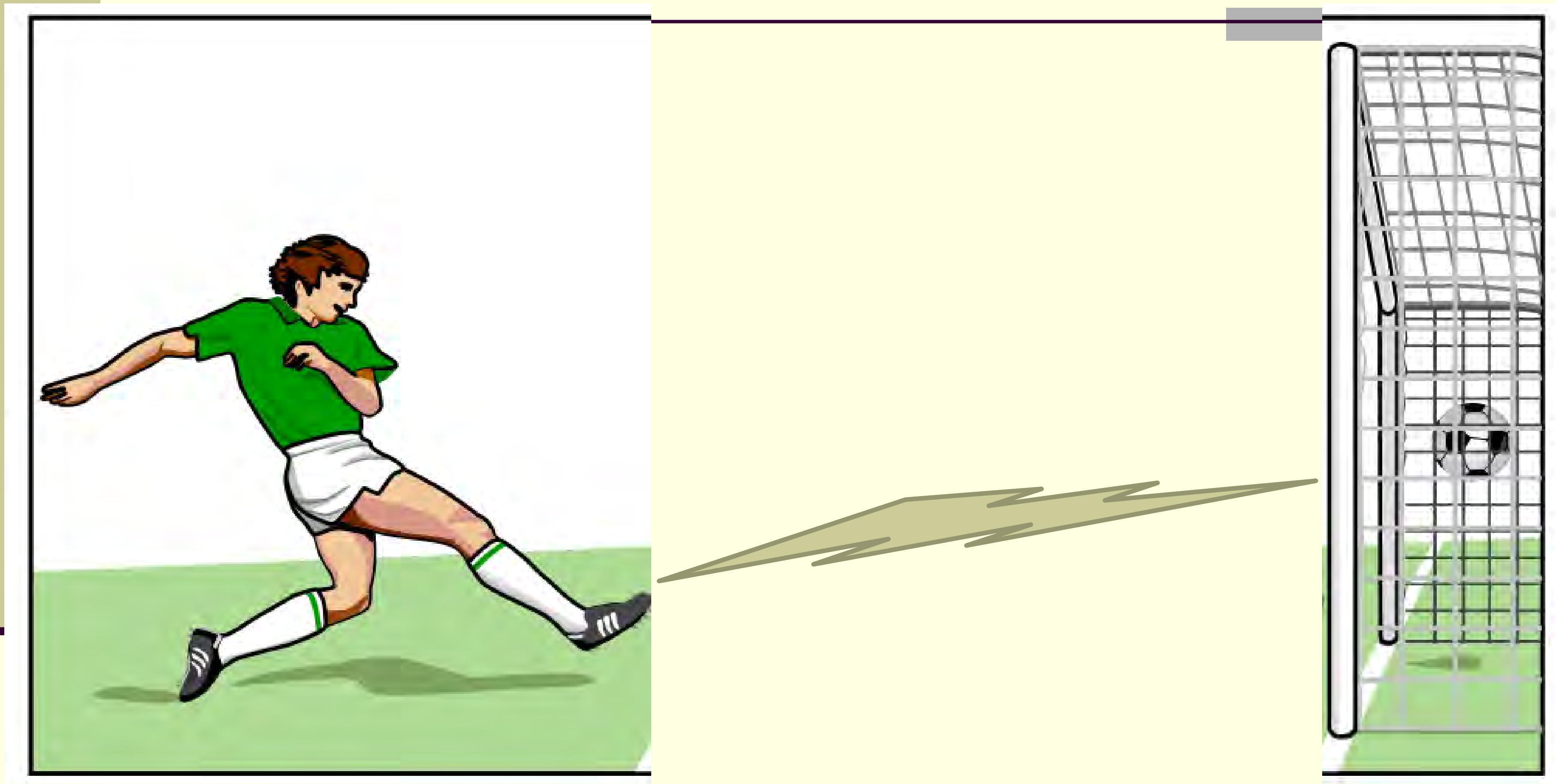
When the initial velocities are known, the final velocities for a head-on collision (foot and ball) are given by:

$$\mathbf{v}_1 = \left(\frac{m_1 - m_2}{m_1 + m_2}\right)\mathbf{u}_1 + \left(\frac{2m_2}{m_1 + m_2}\right)\mathbf{u}_2$$

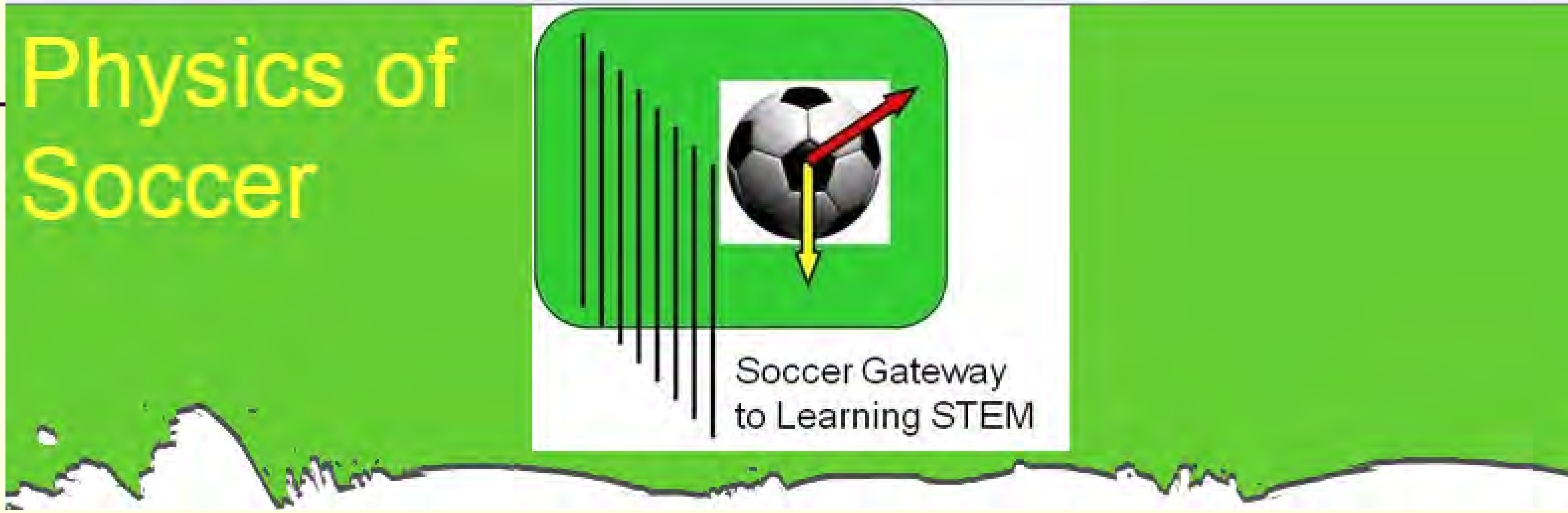
$$\mathbf{v}_2 = \left(\frac{m_2 - m_1}{m_1 + m_2}\right)\mathbf{u}_2 + \left(\frac{2m_1}{m_1 + m_2}\right)\mathbf{u}_1$$

Consider the velocity of the soccer ball after it is kicked by a certain level of force by the foot.

From foot to goal



Physics of Soccer Website

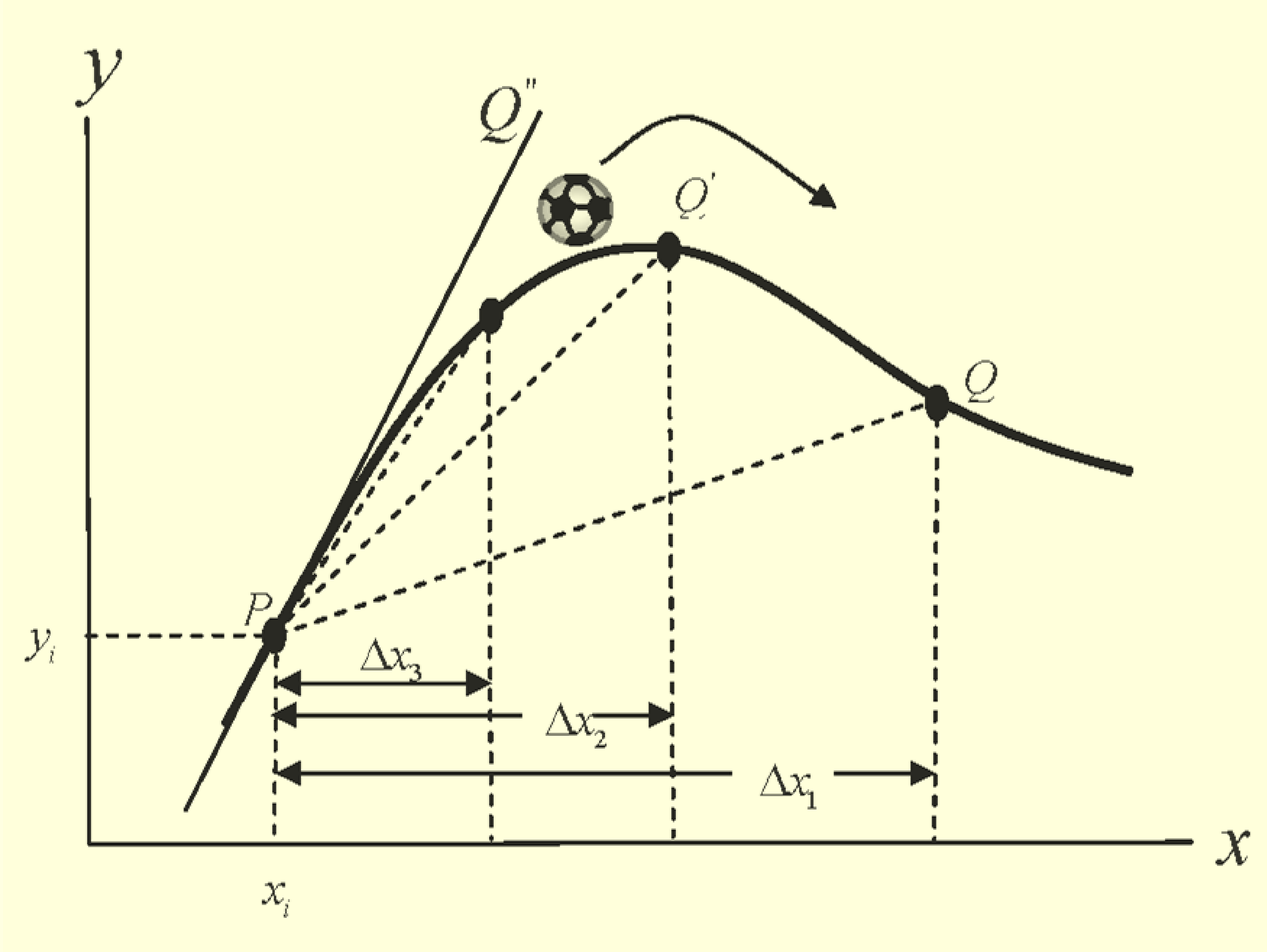


www.PhysicsOfSoccer.com

Using physics reasoning in soccer gives an edge in

- analyzing angles
- estimating geometric dimensions
- anticipating opponents' actions and reactions

Experiment: Ball Path Trajectory



Questions of Interest
- What makes a ball bounce?

A ball bounces due to the **pressure differential** between the inside of the ball and the outside of the ball opposite to the point of impact. When a ball hits a hard surface, it **momentarily deforms.** This means that the inside of the ball now has less space to contain the air particles contained inside the ball. This compression increases the pressure inside the ball beyond the initial balancing pressure on the outside of the ball. This causes the ball to take off in the direction of the lower pressure.

Deformation and the Bounce

A hard surface creates more deformation at the point of contact. So, a ball bounces more off a hard surface compared to a soft surface.

The following three properties determine the performance and reaction of the ball to externally applied forces:

1. Ball size (circumference, radius, diameter): Typically, 27 to 28 inches
2. Ball weight (mass): Typically, 14 to 16 oz
3. Ball pressure: Typically, 8.8 to 16.2 pounds per inch

Take-away Points:

Soccer players should be attentive to the following STEM factors that can, from a scientific standpoint, alter the state of play during a soccer game:

- **Wind** direction and speed as they affect ball movement
- **Friction** as it affects slippery playing surface and ball ground roll
- Humidity as it affects air **moisture** on and around the soccer ball
- **Gravity** as it affects downward motion of the ball
- **Evaporation** as it affects player comfort and health
- **Force** of collision as it may affect player motion and stability
- Ball inside **pressure** (inflation) level as it affects bounce and mobility of the ball

Homework

What is the terminal speed of a 0.47 kg soccer ball that has a radius of 0.12 m and a drag coefficient of 2.6? The density of the air through which the ball falls is 1.2 kg/m^3.

<u>Given equation:</u>

$$f_{\text{drag}} = -\frac{1}{2} C \rho A v^2$$

C = drag coefficient
ρ = air density
A = cross-sectional area
v = velocity

References

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Concluding Remarks

- STEM is good for Soccer as Soccer is good for STEM

Thank you.