Day 3

Physics of Sports

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http://pages.jh.edu/~maliyou1/Physics_of_Sports/

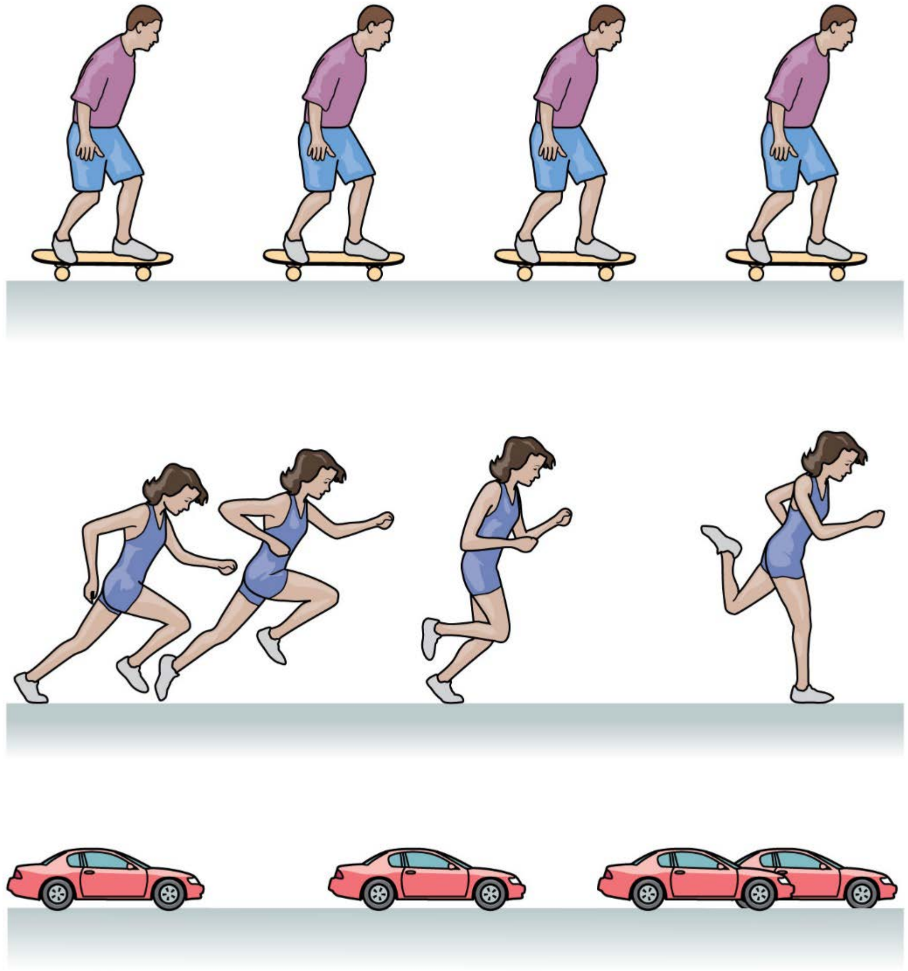
Image https://www.disneyclips.com/imagesnewb/skating.html

Copyright

Plan for Today

- Motion diagrams
- Video analysis using Tracker
- Optimum shot-put launch angle
- Human Projectiles
- Curveballs, Foul Shots, and Bent Kicks

Making a Motion Diagram

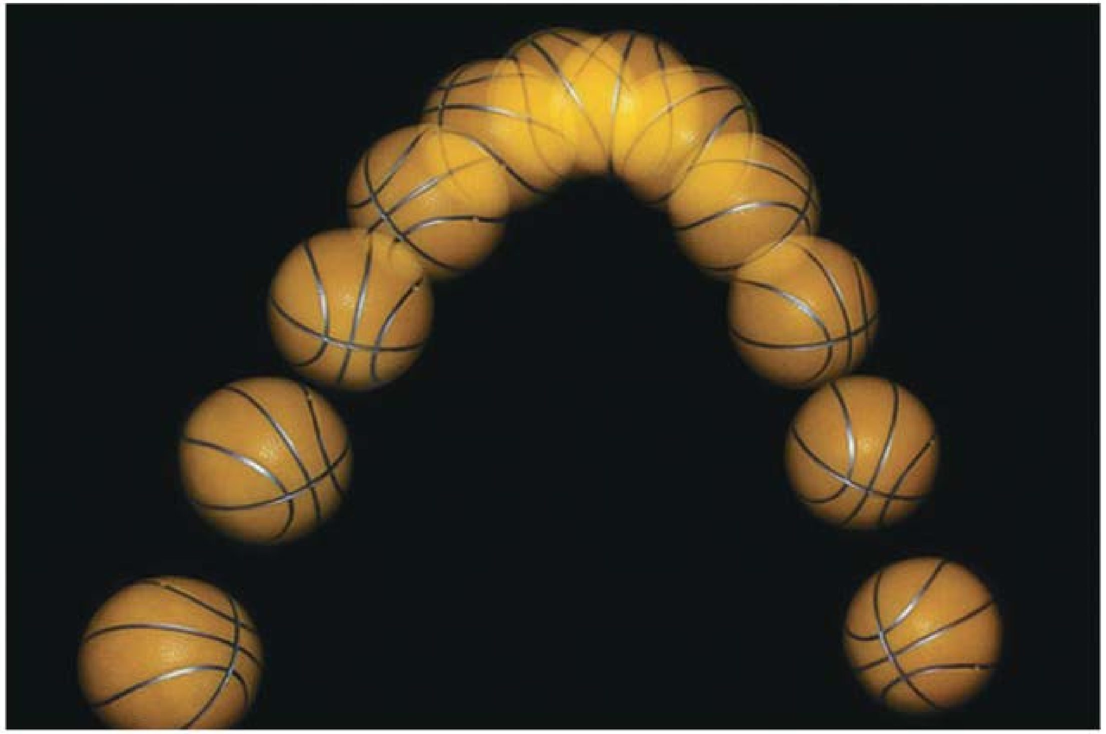


- These motion diagrams in one dimension show objects moving at constant speed (skateboarder), speeding up (runner) and slowing down (car).

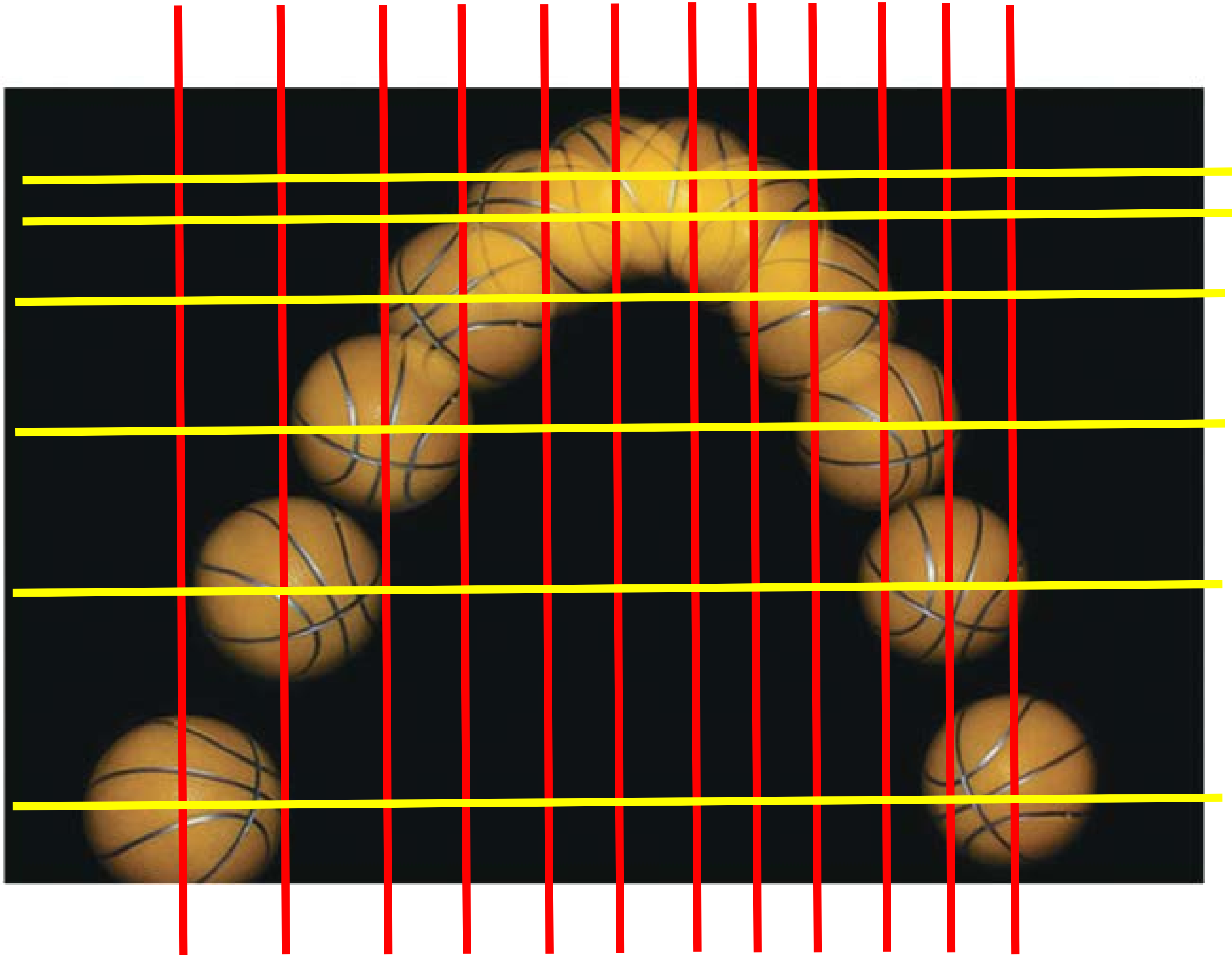
http://www.pxleyes.com/blog/2012/03/50-brilliant-examples-of-sequence-photography/

Describing Motion

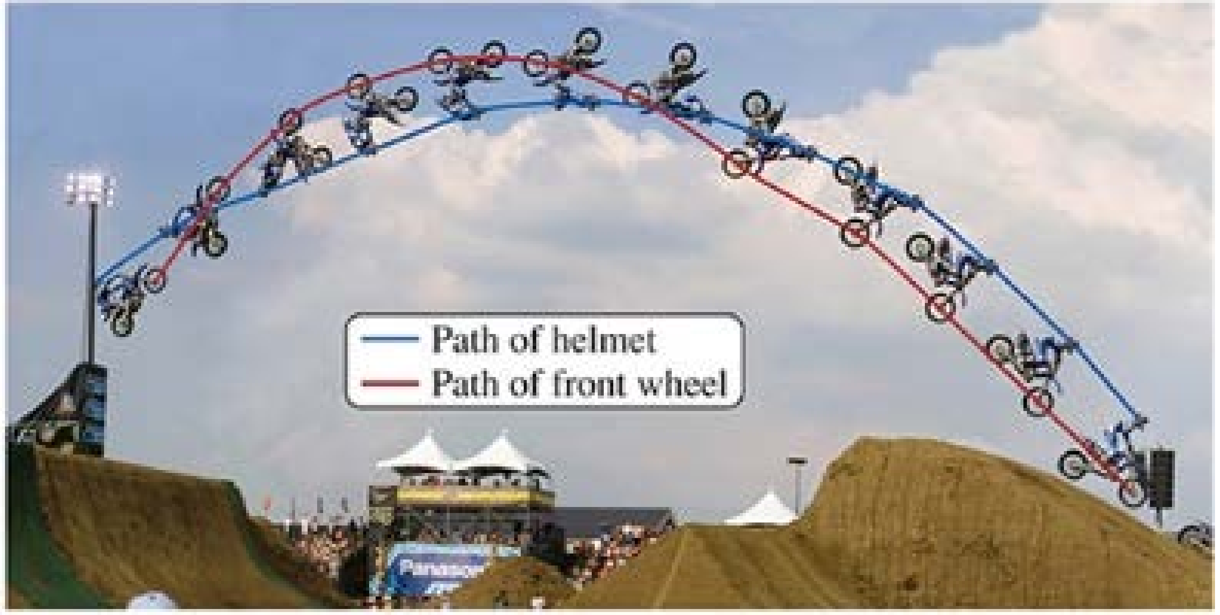
- This series of images of a skier clearly shows his motion. Such visual depictions are a good first step in describing motion in sports.



Projectile motion



Once again, time stamps
here appear funky
so we can't use for speed
measurements but
we can still use it to see the
center of mass
motion.



Top and Bottom: © Bo Bridges/Corbis

Optimum shot-put launch angle

- We saw earlier, equations for the maximum height reached and range:

Maximum at theta=45 for **ANY** value of v_0

- Sometimes equation above are not appropriate for figuring out the range of a projectile, because the starting and ending heights are not the same.

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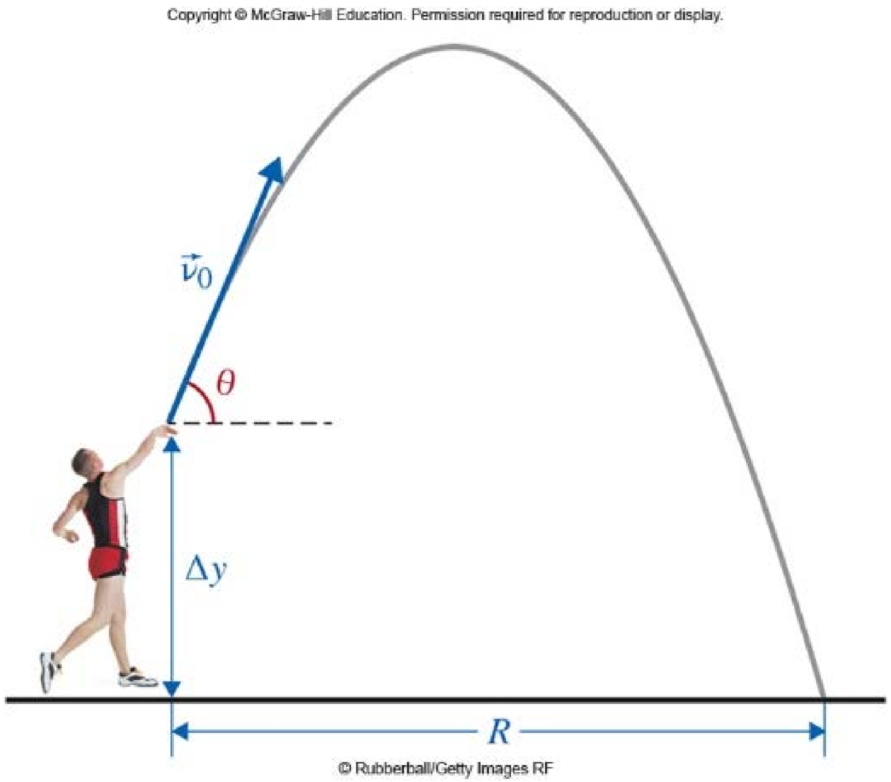
Optimum shot-put launch angle

- In these cases, the range formula is a bit more complicated:

Note: for the shot-put, Del_y is a negative number



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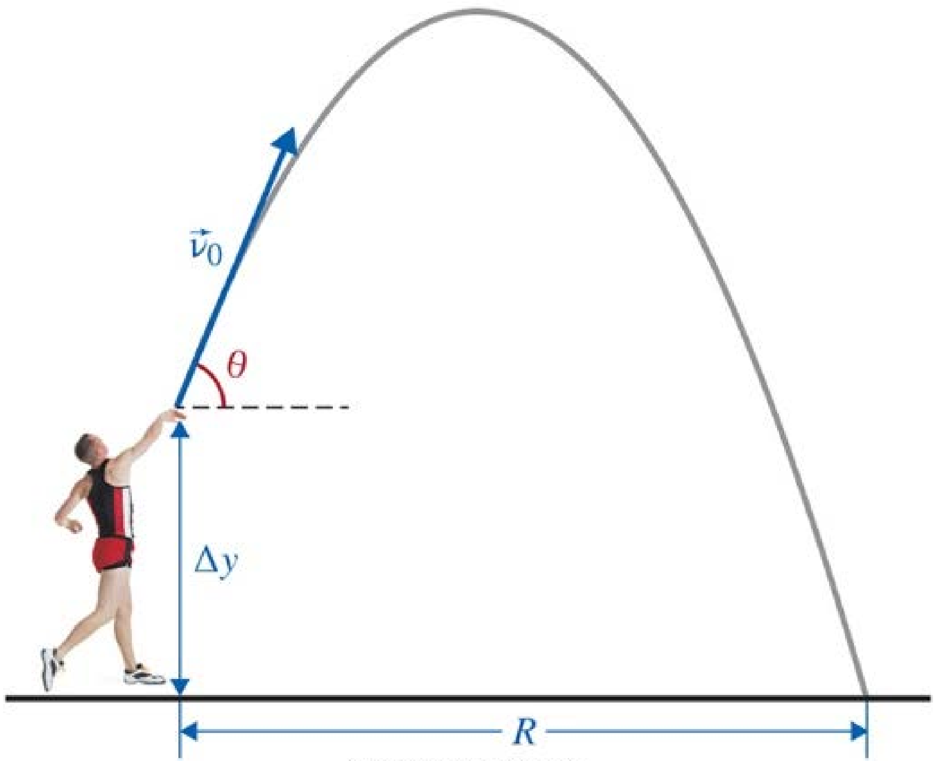
Optimum shot-put launch angle

- **The question now is, which variable effect the range most: launch angle, initial velocity or launch height?**
- Say you are a shot-putter right in the middle of table above, releasing the shot at 26 mph (11.62 m/s) from a height of 6 ft 6 in.
- With persistent practice, you might be able to change any quantity by, say, 5%.
- Let's start with the angle. Rather than launching at the optimum angle of 41.4∘, what if you threw sometimes 5% less, that is, 39.3∘? Then, all else being unchanged, your throw would be:
- (Do in Excel) [Ans: 15.61 m]



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Optimum shot-put launch angle

- How about the height? Rather than launch it at 1.98 m, you might rework your technique to release it 5% higher, at 2.08 m. (This is an increase in release height of 4 in. It is probably doable, with work.) The range is then … [15.75 m]
- how about increasing the launch speed? Rather than launching at 11.62 m/s, you hit the weights and grow strong enough to launch it at 12.2 m/s. (Approximately speaking, you increase your launch speed by 5% by getting 5% stronger.) Now your range is … [17.06 m]

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Optimum shot-put launch angle

- Conclusion: Rather than focusing on hitting precisely the right launch angle or stretching to the highest possible release height, a shot-putter is well advised to work on maximizing launch velocity.

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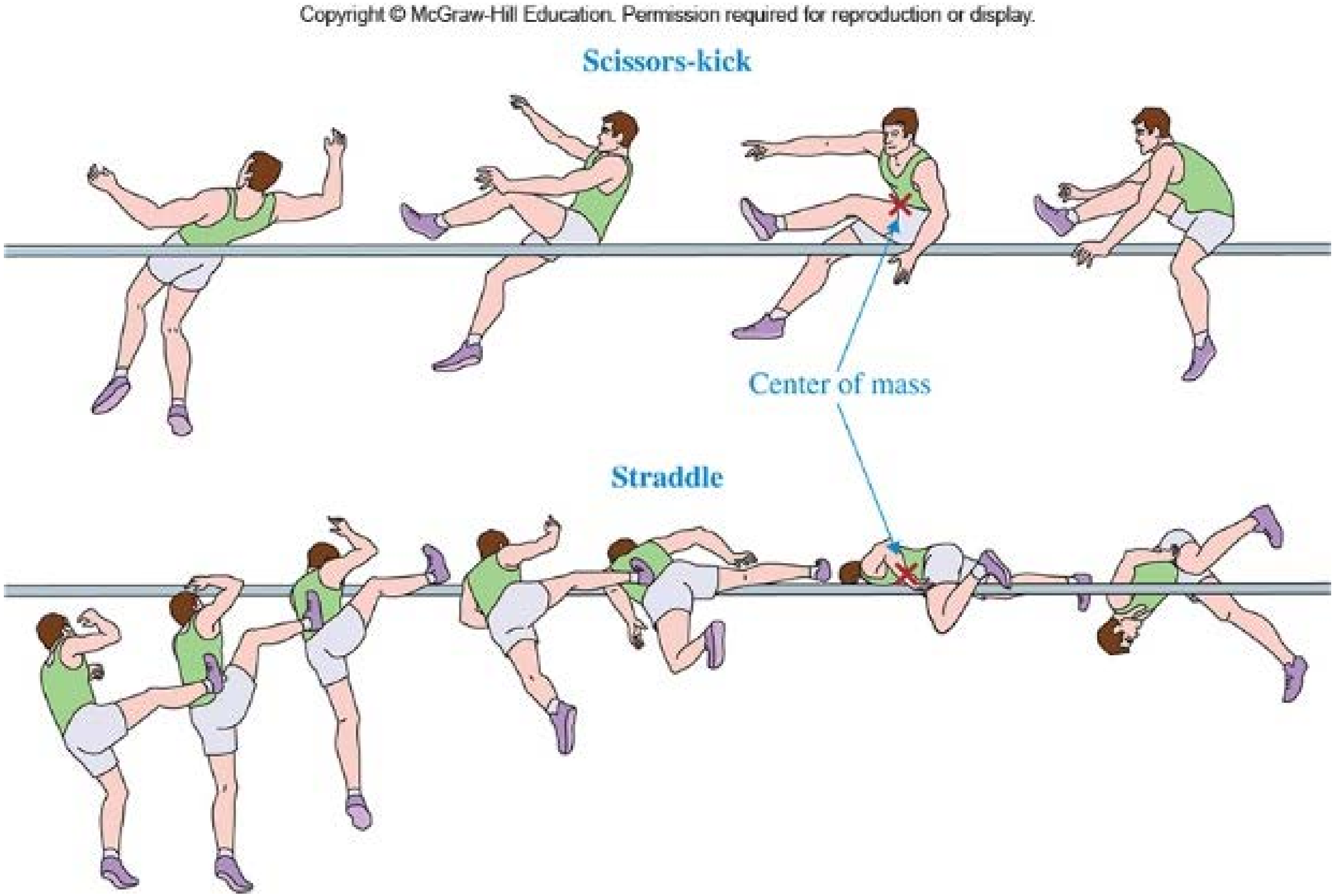
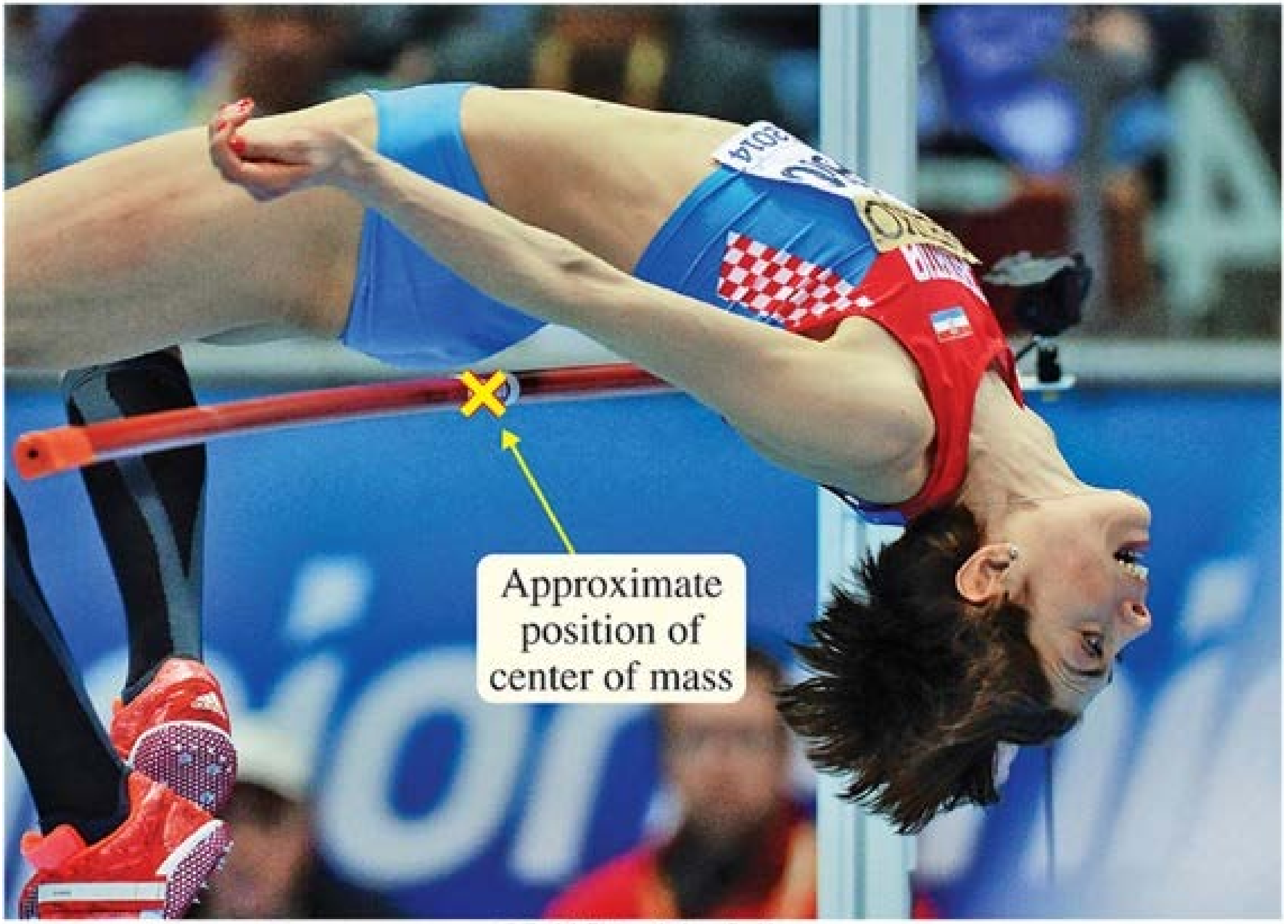
Human Projectiles

- An athlete uses physics to shatter world records: https://www.youtube.com/watch?v=RaGUW1d0w8g

High Jump

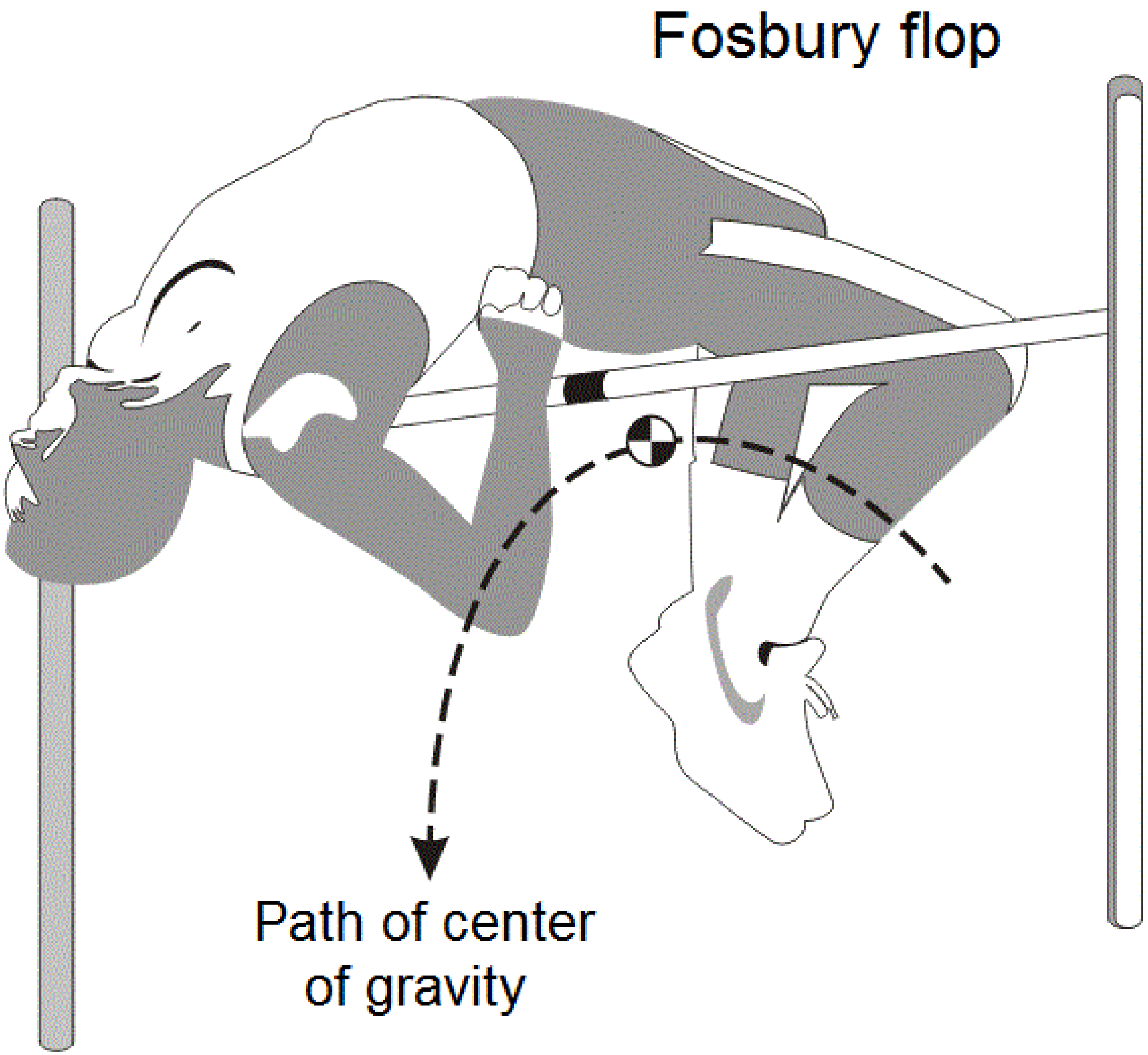


Two high-jump techniques commonly used before the invention of the Fosbury Flop in 1968. The center of mass of the jumper at his highest point is indicated by the red X.



© Radek Pietruszka/epa/Corbis

Croatia's Blanka Vlašić executes a perfect Fosbury Flop (popularized and perfected by the American athlete Dick Frosbury) in the women's High Jump final at the Athletics World Indoor Championships at Ergo Arena in Sopot, Poland, March 8, 2014. (© Radek Pietruszka/epa/Corbis).


Fosbury flop
Path of center
of gravity

Long Jump

Bob Beamon in the 1968 Mexico City Olympics in the incredible first jump to smash the 28-ft barrier, returning to Earth again only after smashing the 29-ft barrier as well.

https://youtu.be/FJRq5PREim8?t=11m46s

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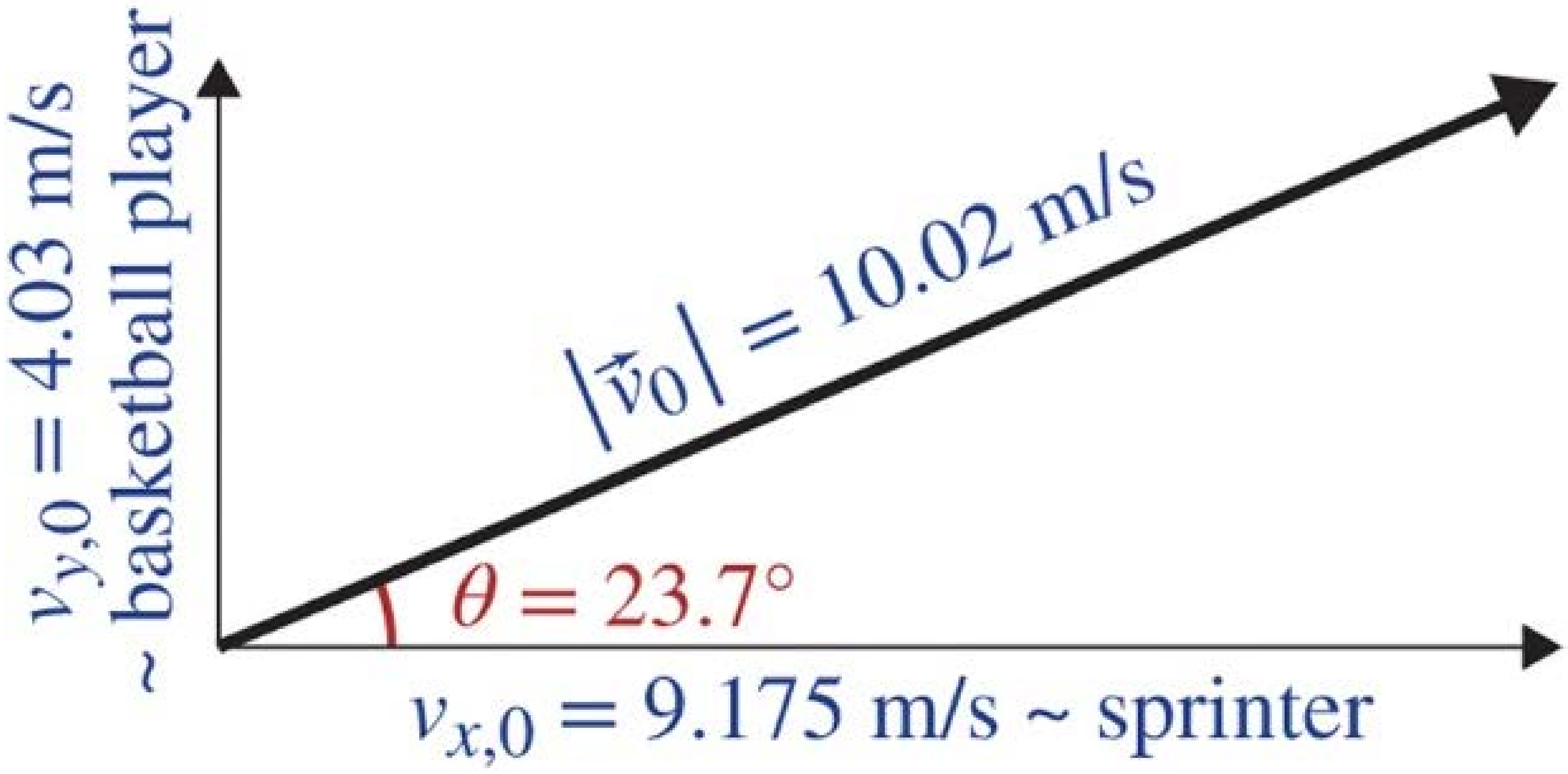

The vertical component of Beamon's launch velocity is comparable to that of a basketball player, and the horizontal component comparable to that of a top sprinter. Together, they combine to produce a 23.7° launch angle.

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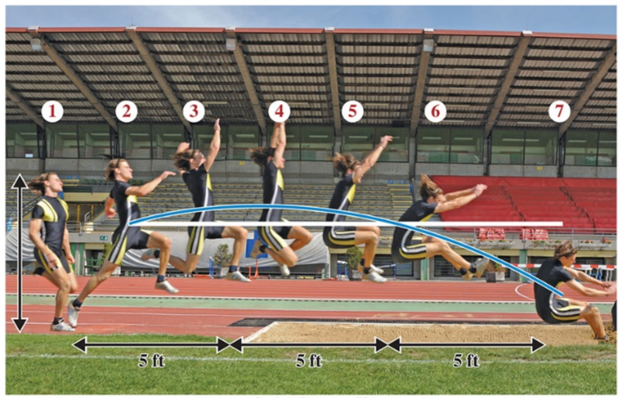
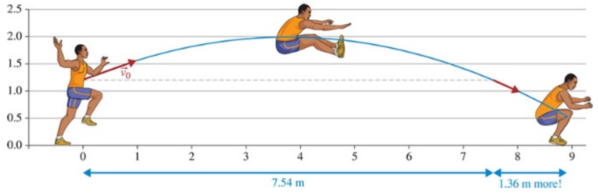
Analysis of Bob Beamon's long jump

- Knowing his horizontal and vertical velocities (coming from video analysis), what do you think was his maximum height (height of his center of mass, to be exact)?
- What was the range?

Finally, Bob Beamon's 'extra' distance

- Now it's time for some numbers: Just how much extra distance was Bob Beamon able to gain by manipulating his center of mass?
- Beamon's height is listed at 6 ft 3 in. (1.91 m). In a position similar to image 1 in figure 4.13, we'll estimate the height of his center of mass to be 1.2 m.
- Beamon landed in a crouch much more extreme than the athlete shown in figure 4.13, and we'll estimate the height of his center of mass upon landing at just 50 cm. His trajectory is shown in figure 4.14.





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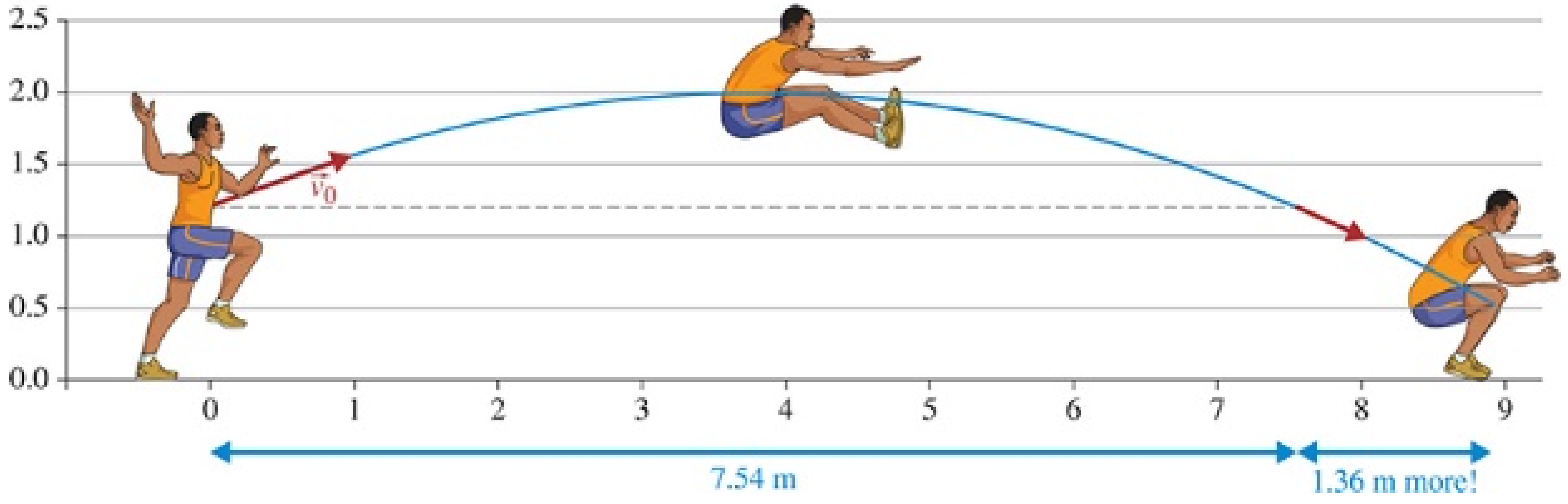
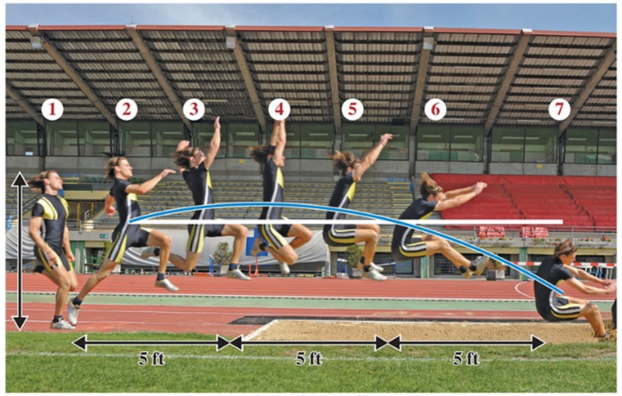
1
2
3
4
5
6
7
5 ft
5 ft
5 ft

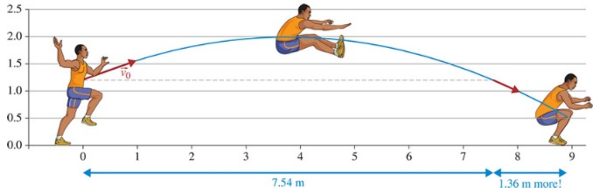

2.5
2.0
1.5
1.0
0.5
0.0
$\vec{v}_0$
0
1
2
3
4
5
6
7
8
9
7.54 m
1.36 m more!

Finally, Bob Beamon’s ‘extra’ distance

- Hence Del_y = -0.7m, speed = 10.02m/s, and angle is 23.7. Find R in m and then convert to ft and inches.



- Hence by precisely controlling his body, Beamon exploited the laws of physics to his advantage to cheat another 1.36 m (4.42 ft) from the tyranny of parabolic motion.



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Curveballs, Foul Shots, and Bent Kicks

- How many of you have heard of the word “Buoyancy” in physics?
- The water in a pool pushes up on a person with a force equal to the weight of the volume of water that the person’s body displaces.
-

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Buoyancy in Air

- When we step out of the pool, we are immersed in another fluid—air. Since any object will be fully submerged in air, the buoyant force on the object is:

- The above equation allows us to estimate the importance of this force to the flight of a ball.

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Buoyancy in Air

- For baseballs, lacrosse balls, and golf balls, the effects of buoyancy in air are essentially negligible.
- For basketballs, footballs, soccer balls, and table tennis balls, the effect is small, 1%–2%, but can be significant.

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Buoyancy in Air

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Moving through Fluid Drag

- The force on the ball should be essentially the number of collisions times the force each collision produces.
- The collision rate will be larger if:
  - There are more atoms to run into, that is, #collisions $\propto$ *p*
  - The cross-sectional area of the ball (the area that "faces forward" as the ball moves) is larger, that is, #collisions $\propto$ A.
  - More atoms smash into the ball per second, that is, #collisions $\propto$ *v*.
  - So #collisions $\propto$ A*pv*

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Moving through Fluid Drag

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A very interesting calculation

- Cooling Verlander’s heat:
- Among the pitches in Detroit Tiger Justin Verlander’s repertoire is a fastball that some- times registers 100 mph on the radar gun. This is some serious heat! But equally important to the batter is the ball’s speed as it crosses the plate. How much does air resistance slow down a 100-mph fastball?

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A very interesting calculation

- We know the distance the ball travels and its initial speed. If the acceleration is constant, then equation 2.6 (Kinematic equations) give us our answer.
- The problem is that the acceleration is not constant, because the drag force is not constant—it gets a little weaker as the ball slows on its path.
- What we'll do is approximate this as a constant-force situation and see how well it works.
- Figure 5.4 tells us that the drag coefficient on a 100-mph (146.7 ft/s) baseball is about 0.3, and the ball's acceleration is:

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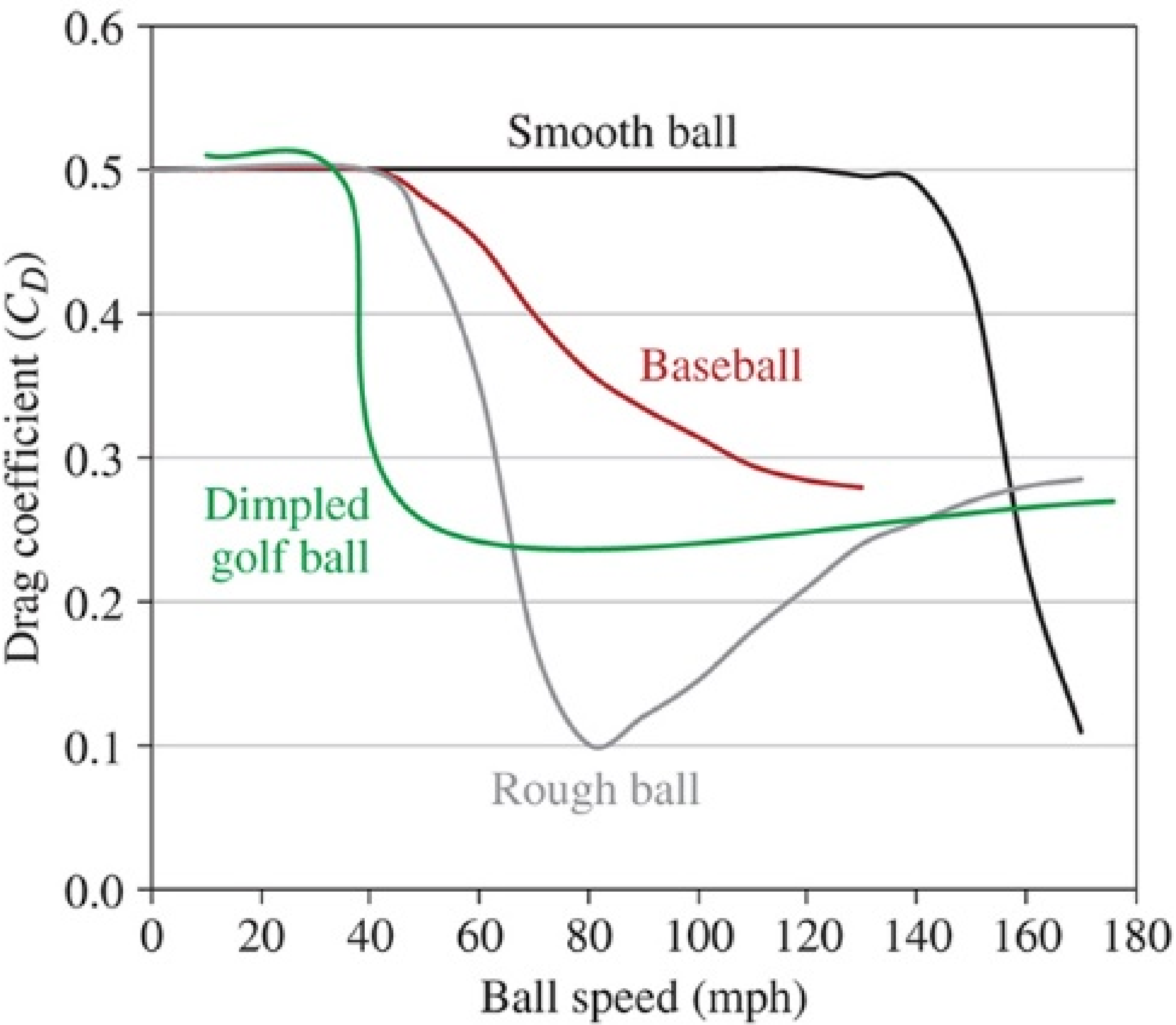
Fig 5.4

The drag coefficient for some typical balls moving through the air, as a function of speed

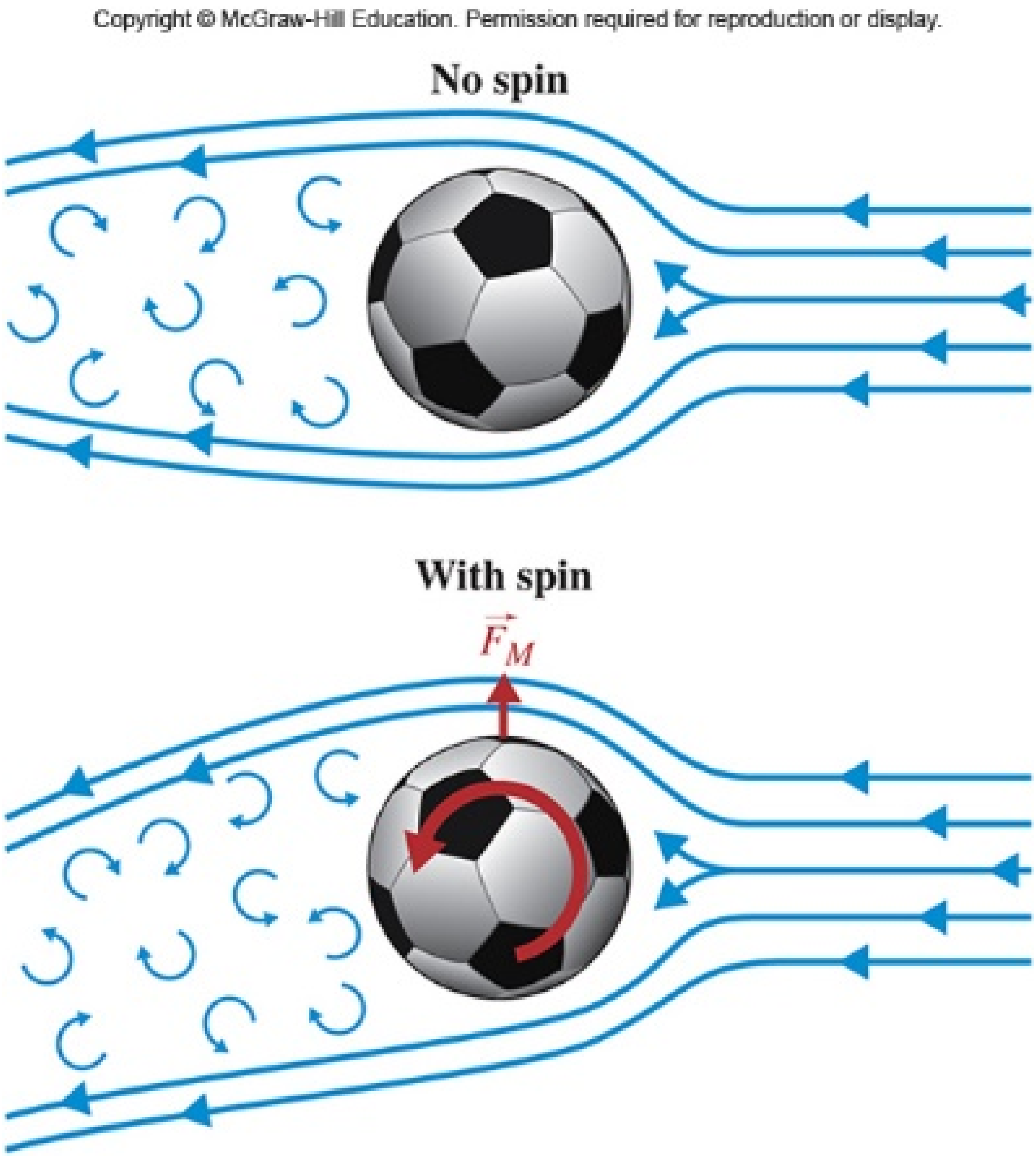


A very interesting calculation (cont.)

Bending a ball’s flight, the Magnus effect

- The Physics Behind a Curveball - The Magnus Effect
- https://youtu.be/YIPO3W081Hw?t=15s
- How to curve a ball backwards using science,
- https://www.youtube.com/watch?v=akjQbPKKD7I

- The force exerted by air on a nonspinning ball passing through it is directed opposite the ball's velocity vector.
- If the ball is spinning, the bottom surface of the ball approaches the air at a larger speed than does the top half, and there is an asymmetry in the forces.
- While there is still a backward drag force in this case, there is also a sideways-pointing Magnus force.



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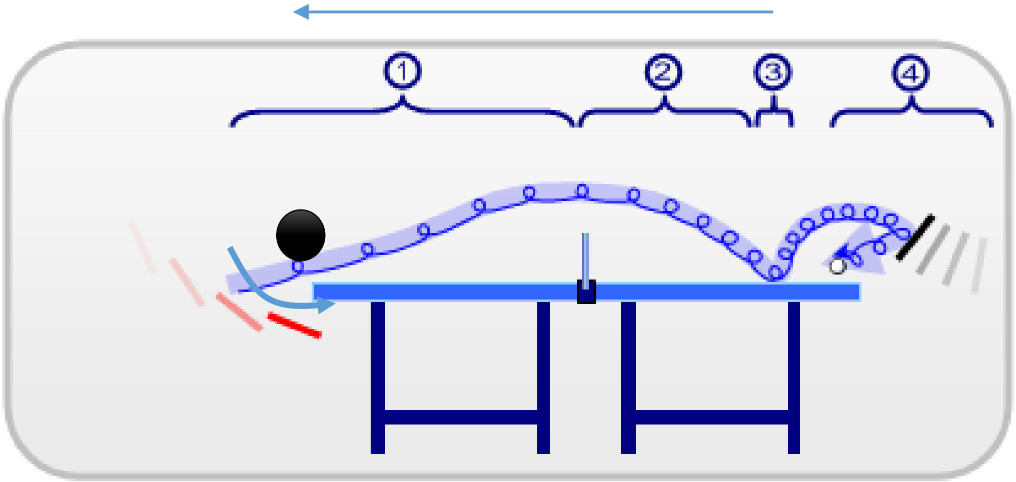
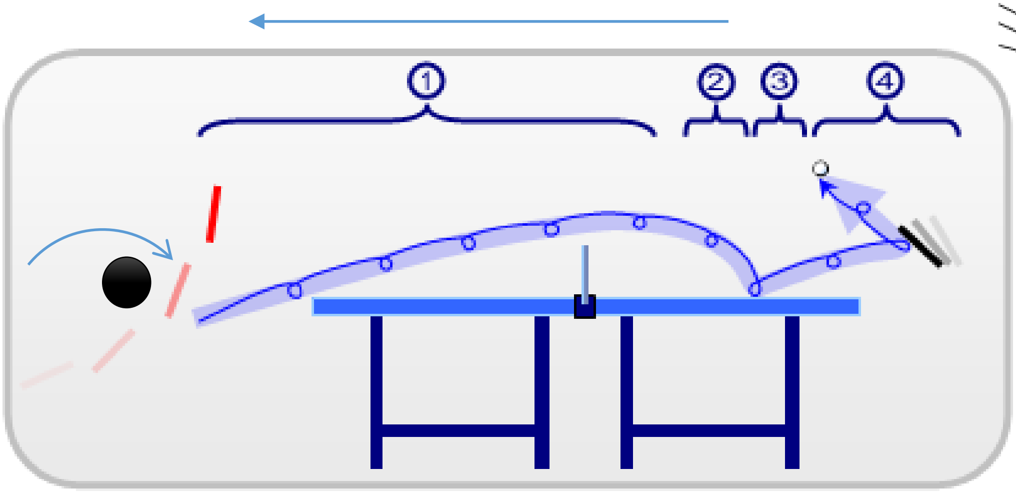
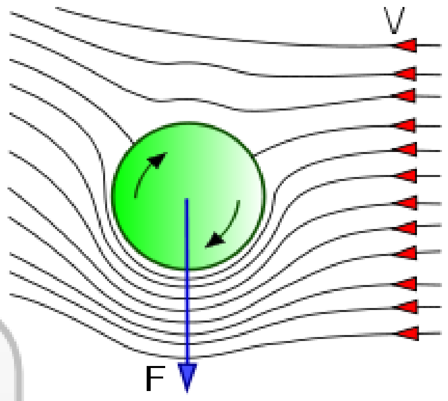
Bending a ball’s flight, the Magnus effect (cont.)

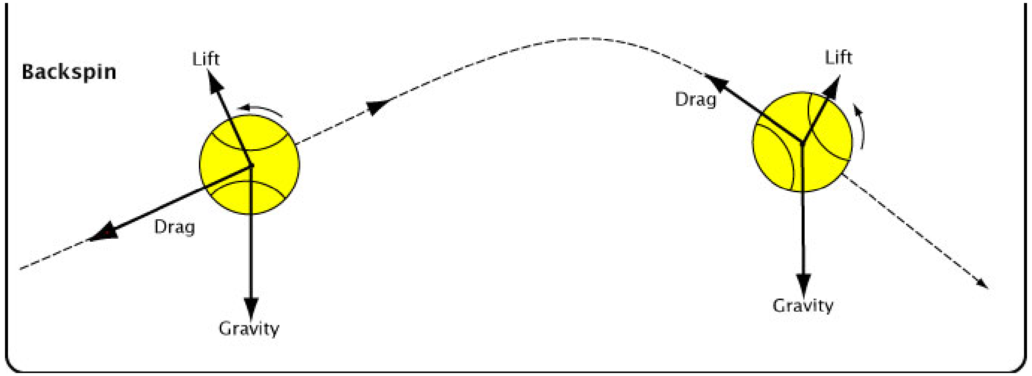
4 phases in a backspin curve

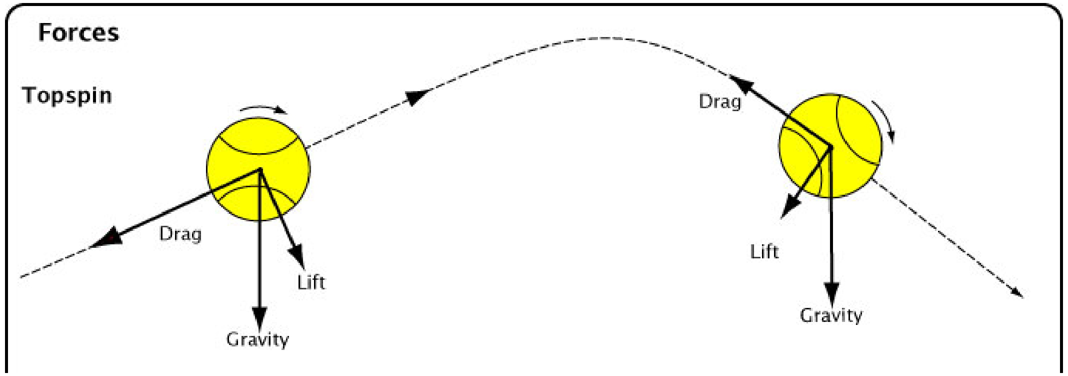


4 phases in a topspin curve

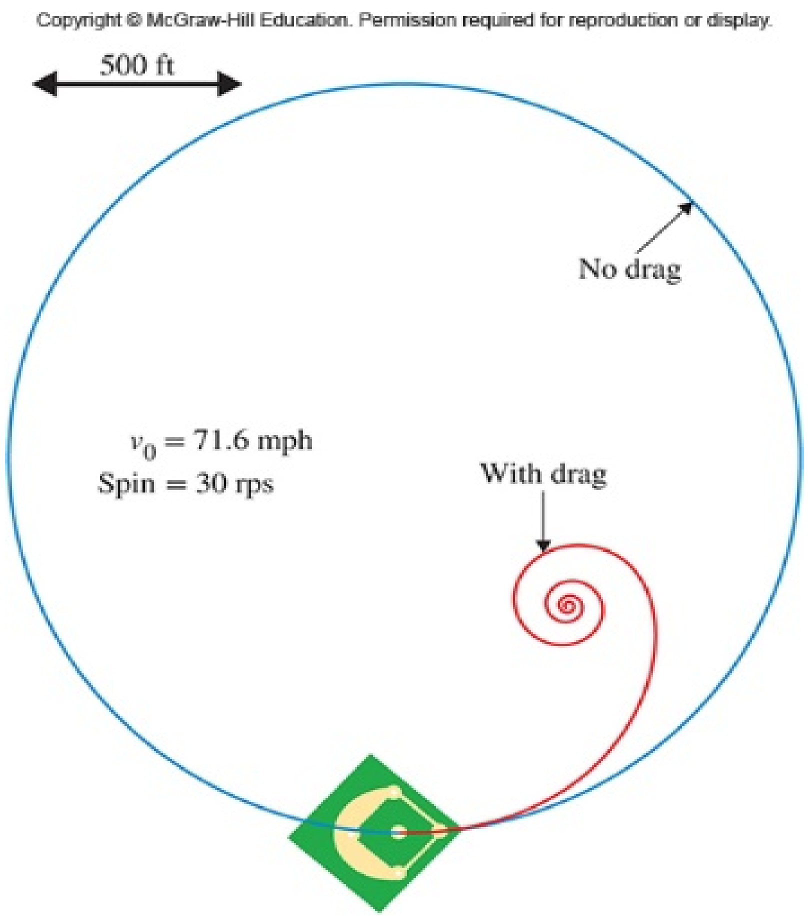








https://en.wikipedia.org/wiki/Table_tennis



Watch:
https://www.youtube.com/watch?v=whb6W-CxGgU
https://www.youtube.com/watch?v=O2vrVwjqktg

Another Numerical

Q. We have discussed how, if there were only the Magnus force, a curveball would follow a circular path.

(a) For a typical pitch, what would be the radius of its circular path?

(b) In this unrealistic but interesting case, the pitcher could pitch the ball and then turn around and catch the ball he'd just thrown! How much time would pass between his pitch and his catch?

Problem 12, Chapter 5. Lisa, Michael. *The Physics of Sports*. McGraw-Hill Higher Education, 20150220. VitalBook file.