David Alciatore, PhD ("Dr. Dave") **ILLUSTRATED PRINCIPLES**

"Coriolis was brilliant ... but he didn't have a high-speed camera – *Part III: Cue Ball Paths are Like Satellite Dishes*"

***Note**: Supporting narrated video (NV) demonstrations, high-speed video (HSV) clips, and technical proofs (TP) can be accessed and viewed online at **billiards.colostate.edu**. The reference numbers used in the article (e.g., **NV 4.20**) help you locate the resources on the website.*

This is the third article in a series I am writing about the pool physics book written by the famous mathematician and physicists Coriolis in 1835. In last month's article, I described some high-speed camera work I've done and showed some examples that relate to some of Coriolis' conclusions. Over the next few months, I will look at Coriolis' conclusions in more detail and explain when they do and don't apply. As with all of my past articles, my July '05 article summarizing Coriolis' conclusions can be viewed on my website.

Principle 23 summarizes one of Coriolis' conclusions, which states that the cue ball's path curves in the shape of a parabola after hitting an object ball with follow or draw (see **Diagram 1**). Interestingly, a parabolic curve is the same shape used to make radio telescopes, satellite TV dishes, and headlight mirrors. As with all of Coriolis' work, he backed up all of his results with rigorous physics and mathematical analysis. For the sadistic readers out there with math and physics backgrounds, you can check out the nitty-gritty details of **Principle 23** at **TP A.4**. There I present and illustrate the derivation with modern terminology and techniques and show plots of example results.

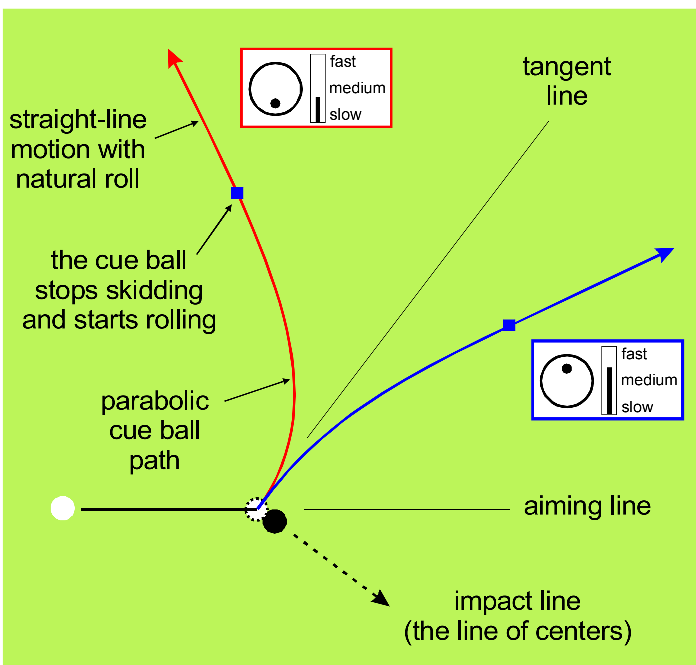


Diagram 1 Parabolic cue ball paths

<u>Principle 23</u> Parabolic Cue Ball Paths

The curved path followed by a cue ball after impact with an object ball, due to draw or follow, is always parabolic *(see Diagram 1).*

- The shape of the parabola depends on shot speed (see **Diagram 2** and **Diagram 3**).
- For a stun shot, the path is a perfect straight line.

technical proof

TP A.4 – Post-impact cue ball trajectory for any cut angle, speed, and spin

As you can see in **Diagram 1**, the cue ball path is parabolic for both follow and draw shots (see **NV 4.20** and **NV 4.21** for demonstrations). The only time it is not parabolic is for a stun shot, where the cue ball is sliding at impact without bottom spin or topspin. With a stun shot, the cue ball heads in a straight line exactly along the tangent line, as predicted by the 90° rule (see my January '04 article). As indicated by the small blue boxes in **Diagram 1**, the cue ball path is curved only for as long as the ball is skidding (i.e., not "rolling without slipping"). At some point (indicated by the blue boxes), the skidding has changed the cue ball's spin enough to create natural roll. At this point, the cue ball starts rolling in a straight-line path, tangent to the end of the curved parabolic path (until it hits a cushion or stops).

normal video

NV 4.20 – Delay of follow and tangent-line deviation with higher speed
NV 4.21 – Delay of draw and tangent-line deviation with higher speed

The shape of the parabolic path and the point where skidding converts to natural roll varies with shot speed. I actually covered this already in my March '05 article, but I wanted to provide more information here. Also, the illustrations in my previous article were not properly drawn to scale for typical ball speeds. Bob Jewett pointed this out to me, allowing me to make amends. (Thanks, Bob). **Diagrams 2** and **3** show cue ball trajectories for various follow and draw shots covering a typical range of shot speeds (2 to 8 mph). **TP A.4** provides some additional plots for a range of slower speeds.

Shots "a" through "d" in **Diagram 2** are natural roll shots. In other words, the cue ball is rolling (i.e., not sliding or skidding) at object ball impact. There are several things worth noticing in **Diagram 2**:

1. The harder you hit a follow (or draw) shot, the longer the cue ball persists in the tangent line direction before curving (see **NV 4.20**, **NV 4.21**, and **NV 4.24**).

2. Regardless of speed, the angle of the final straight-line path of the cue ball is the same (close to 30 degrees away from the initial cue ball direction for most cut shots). This is one thing that makes the 30° rule so useful (see my April-July '04 and March-June '05 articles).

3. The cue ball's path stays curved longer for faster shots, before heading in the final straight-line direction.

4. To create natural roll at object impact, you need to hit the cue ball above center only for faster shots (and/or when the cue ball is close to the object ball to begin with). Path "a" can have a center-ball hit because the cue ball has enough time and distance to develop natural roll on its own (with the assistance of the friction from table cloth). For a fast shot like path "d," you must hit the cue ball above center to ensure natural roll at impact.

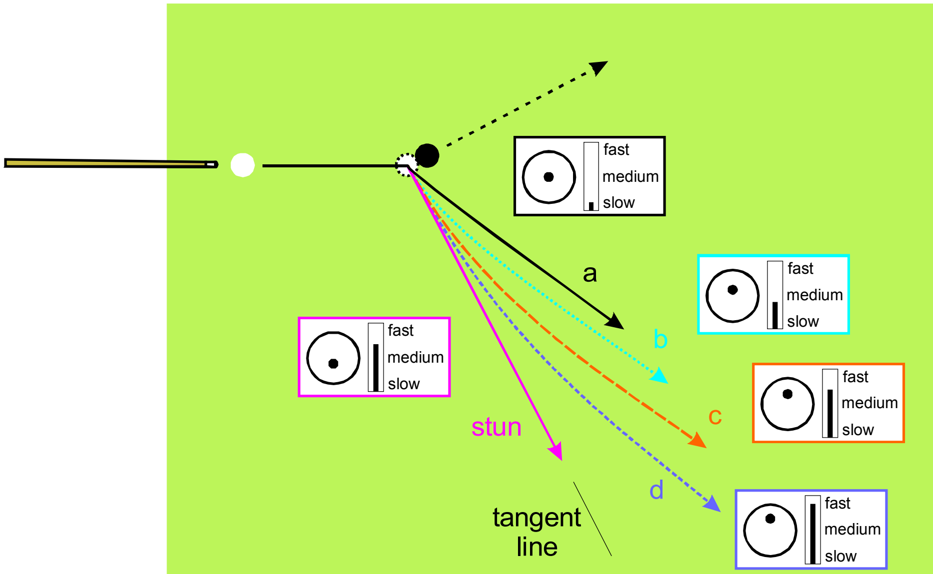
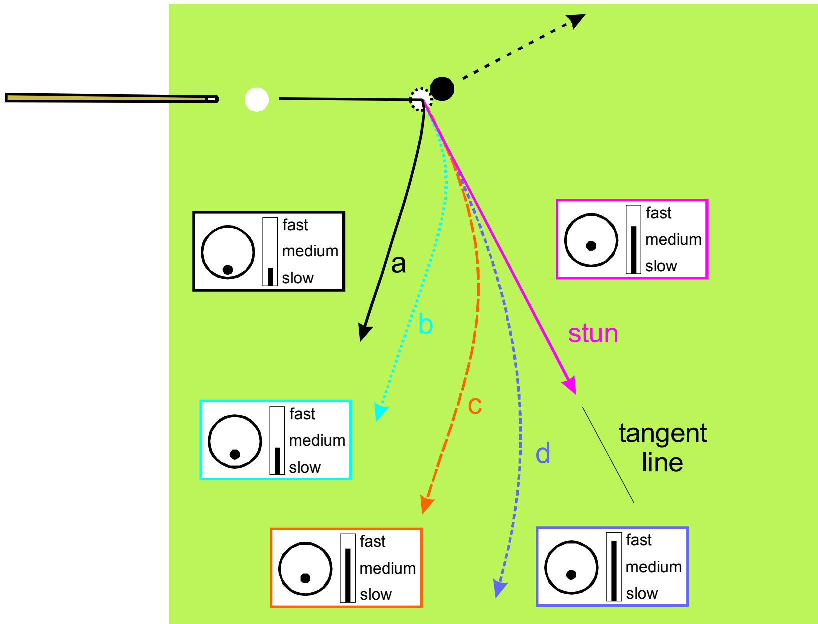


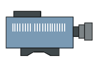
Diagram 2 Natural roll follow shots at different speeds

NV 4.24 – 30° rule speed effects

Diagram 3 shows the effects of speed on various draw shots. Shots "a" through "d" each have the same amount of bottom spin. That's why the slower shots (e.g., "a") are shown with larger cue tip offsets from center-ball than the faster shots (e.g., "d"). With slower speed, the skidding of the cue ball causes the bottom spin to wear off faster over distance. **HSV 3.1** provides a good illustration of this effect. Also notice that, as with natural-roll follow shots, all of the draw shot paths end up going in the same direction; although, the path shapes vary significantly with speed. Unfortunately, with draw shots, there is no magical 30° rule that will help you reliably predict cue ball motion because speed, spin, and cut angle have such big effects. But don't despair ... we will look at this closer in future articles.



<u>Diagram 3</u> Constant bottom spin draw shots at different speeds


high-speed video

HSV 3.1 – Stop-shot showing loss of bottom spin over distance

I hope you are enjoying my series of articles about the work of Coriolis. In future articles, I will use some high-speed video results to help explain how and why some of Coriolis' other conclusions may or may not be valid in different situations. I will also show how some of Coriolis' other conclusions might be useful in your game.

Good luck with your game, and practice hard,
Dr. Dave

<u>PS</u>:

- If you want to refer back to any of my previous articles and resources, you can access them online at ***<u>billiards.colostate.edu</u>***.
- If you interested in the physics of pool, you might be interested in the new "Pool/Billiards Physics Resources" section of my website. It lists and provides links to many general interest and technical books and articles that explore the world of pool physics.

Dr. Dave is a mechanical engineering professor at Colorado State University in Fort Collins, CO. He is also author of the book: "The Illustrated Principles of Pool and Billiards" (2004, Sterling Publishing).