



Sliding Friction

How far will you slide?

It is **the** various kinds of friction that make cue sports interesting. Without rolling friction, the balls wouldn't stop until they had all found pockets. Without the friction between tip and ball, which is aided by chalk, we would have no control of spin and position. Without the friction between the balls, the dimension added by throw shots would disappear. Without ball-cushion friction, position play would be severely restricted.

Another kind of friction that is at work on every shot is sliding friction between the balls and the cloth. This was mentioned briefly in the two recent columns about calculating and plotting the speed and spin of a ball as it achieves normal rolling on the cloth. The natural state of the ball is normal rolling, because any sliding between the ball and the cloth produces a force on the ball that will tend to eliminate the sliding.

Sliding friction is harder to measure than the other kinds. Rolling friction — which causes the ball to roll to a stop — can be measured easily with a stopwatch. Friction between the balls is shown by the maximum throw angle. You can get at least a feel for friction on the cushion by the resulting angle for a cue ball with maximum spin going straight into the cushion.

The friction between ball and cloth is dynamic; it always has time as part of its measurement. An example shot of the effect is shown in Diagram 1. This standard fancy shot demonstrates how to make the cue ball curve without masse. The idea is to pocket the first object ball, and then curve around the obstacle ball without hitting the side cushion and pocket the hanger. Shoot slightly fuller than half-ball, which will allow the draw to pull the cue ball back enough.

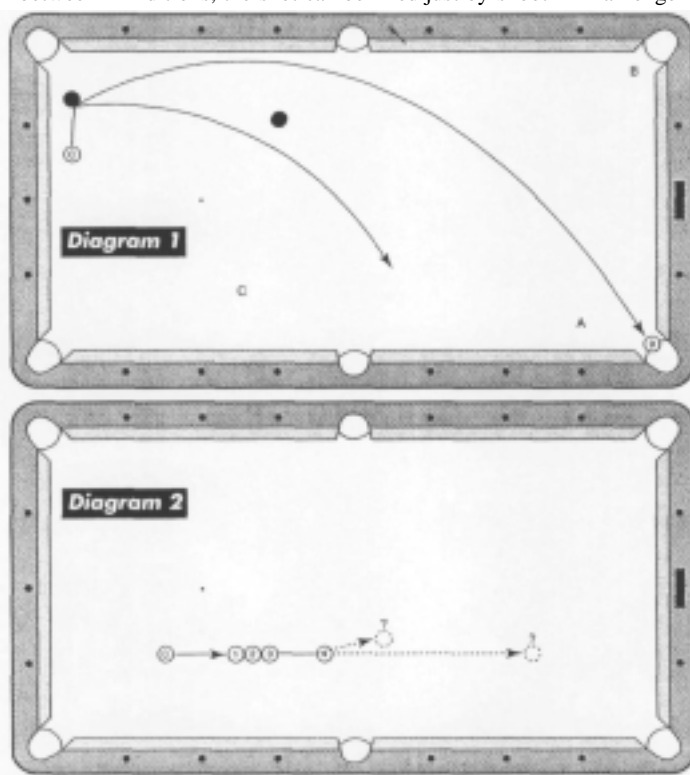
Shown in the diagram are two curves for the cue ball's path. They represent shooting the shot at the same speed, and with the same amount of draw but with different amounts of sliding friction. If the cloth is

new or the cue ball is waxed — try silicone spray if you want to do the experiment — the cue ball will take the wide course and will look as if it is moving in slow motion. If the cloth and balls are sticky, the result is the sharper, faster curve. Under sticky conditions, the shot can be fixed just by shoot-

With little friction, the force on the base of the ball is less. This leads to less acceleration at each instant the rubbing is going on, so the curve happens more slowly. It also means that the spin is not being rubbed off the ball as quickly, so the curve goes on for a longer time. In some sense these two

effects balance, so that in Diagram 1, the final angle that the cue ball takes is the same regardless of how much friction there is. A sharper curve for a shorter time gives the same angle.

The effect is present on straight shots as well, but it is a little harder to see. The main result is that with low friction, the cue ball holds its draw for much longer. Have some fun with a friend: On a table with old cloth, secretly grease up the cue ball. Put an object ball in the jaws of a foot pocket, and challenge your friend to shoot a stop shot from behind the line. If he's got a pretty good stroke, and is calibrated for the old, sticky cloth, he's likely to draw the cue ball clear back to the kitchen. Normally, the considerable draw at the start of the shot would be worn away over the six diamonds of travel, but the silicone reduces the rubbing and holds the draw for longer.



ing harder, but that can get you into miscues, jumped balls, and other problems.

Silicone spray has become a standard tool for fancy-shot artists who want to move from amazing to impossible shots. The main effect is to get much wider, slower curves with less effort. An example is a shot by Semih Sayginer in his closing exhibition at the Conlon WorldCup Tournament, July 18-23, in Las Vegas. The cue ball was at A, and the target was at about B. The actual shot was a carom shot, but it would also work as a pool shot. The cue ball massed around the obstacle ball over five diamonds away and came back to the target. With an unwaxed cue ball, the standard shot is to make just a right-angle turn from C and then go to the target at B.

Exactly how does "slipperiness" enter in?

How can we measure sliding friction? These shots give you a feel for whether a particular ball/cloth combination is more or less sticky than you're used to, but it's good to have an actual number to compare. Physics books suggest measuring sliding friction between an object and a surface below it by pulling the object sideways, and noting what fraction of its weight must be applied to keep it in steady motion. Balls tend to roll when pulled sideways, so that's not convenient. You could glue three balls together, like a mini-rack, and pull that sideways, but you would need glue, spare balls, and a string, pulley and weights to do the pulling.

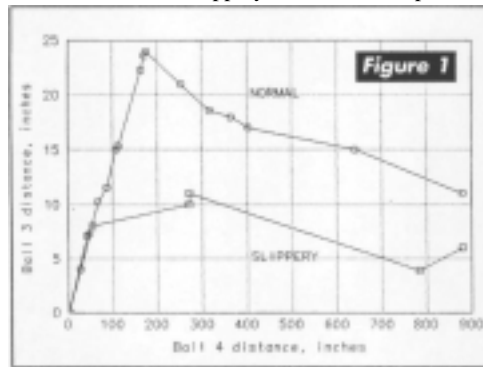
Another way would be to videotape a curve shot like the one in Diagram 1, plot the result to scale along with the time of

each location, and do a lot of arithmetic. A simpler way is shown in **Diagram 2**. The idea is that if you shoot the three-ball 1-2-3 combo at the 4 ball, the 3 ball will roll forward some distance after hitting the 4 ball, and that distance will tell us how much follow the 3 ball picked up on the way to the 4. If there is more sliding friction, the 3 will pick up more follow and will roll farther.

Suppose we vary the speed of this shot from very slow to fast. For the slowest shots, the 3 will just get to the 4 ball and will surely be rolling smoothly on the cloth. It will drive the 4 down the table and roll a little after it. These two distances will follow a simple rule that was covered here last December: the 4 will roll seven times as far as the three. This holds for full shots where the "cue ball" is rolling smoothly on the cloth. As the shot gets faster, there will be a point when the 3 just gets to smooth rolling on the cloth as it hits the 4. This should result in the maximum run-through of the 3, since for faster shots, it doesn't have enough time to pick up full follow. In effect, we are shooting a stop shot with the 3.

The measured result is shown in **Figure 1**, where the follow distances of the two balls are shown. For the regular case, there is a very clear peak which shows the maxi-

mum speed that still achieves smooth rolling on the 3 ball. I also tried polishing the 3 to reduce the friction, and the lower curve was the result. It shows only about half the peak run-through of the regular case, since the slippery 3 ball doesn't pick



up follow as effectively.

If we can figure out the speeds of the balls for these cases, it is a simple matter of algebra to figure out the friction of the cloth. The whole calculation goes roughly like this: A ball is measured to take eight seconds to roll 98 inches. This lets us calculate the speeds of the two balls, given their rolling distances; We can then calculate the speed of the balls at impact, and the speed of the 3 ball when it is struck by the 2 ball. Knowing that the distance between the 3

and 4 is 10 inches, we can calculate how much the 3 slowed in that distance due to picking up follow from the cloth. This in turn gives the sliding friction on the ball. The final result — details of the calculation available on request — is that the cloth-ball coefficient of friction is 0.25, so that the force on the ball when it is sliding is 25% of its weight. For the "slippery" case, the coefficient of friction is reduced to 70% of this value or about 0.18. These values agree well with the value that Coriolis measured over 160 years ago, of 0.20.

How can you use these ideas on the table? The main thing is to realize that on new cloth or with waxed balls, some things will change greatly. Many players like to shoot "stun run-throughs" or stop shots that don't quite stop. The success of such shots is critically dependent on how much sliding friction there is. As the weather gets humid, you will see the opposite of the slippery condition; the ball-cloth friction goes way up. In this situation, stop shots will turn into follow shots, and draw will be much harder to achieve.

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