TECHTALK

Bob Jewett

Newton on the Ball

The flaws of the 90-degree rule.

Guest columnist (and fellow billiard-physics fanatic) Dr. George McBane is a professor of chemistry at Ohio State University, where he and his graduate students study collisions between molecules. Tools used there can be applied to billiard balls, as you will see.

Anyone who has played pool for more than ten minutes has figured out that the thinner the cut, the slower the object ball goes, and the faster the cue ball goes after they collide. And the first thing most players are told when they start to learn position play is "After the collision, the cue ball leaves at right angles to the object ball's path." The first of those statements is true, the second is only sometimes true.

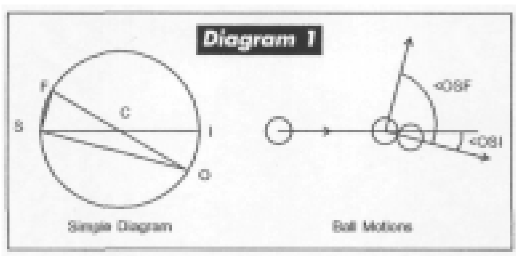
People who study collisions—of planets, of subatomic particles, of balls—use a simple diagram, called a Newton diagram (after Sir Isaac) or velocity vector diagram, to help figure out what laws of conservation of energy and momentum require of a collision.

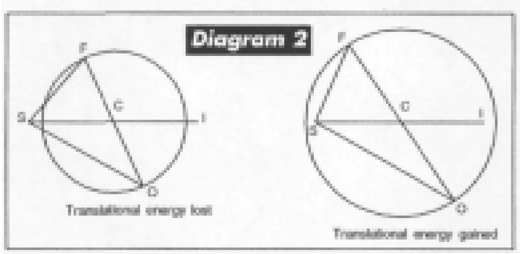
The diagram is easy to draw. Cueists can use it to show how fast the cue and object balls will go in a cut shot, what the angle will be between the cue and object balls' paths after a collision and how the behavior of the balls will change if the cue ball is lighter or heavier than the object ball. It can also occasionally disprove plausible-but-incorrect statements about how balls behave, including the "right-angle rule."

The simplest version is shown in Diagram 1, along with the shot it corresponds to on the table. To draw it, start with a line along the direction you will shoot the cue ball. The line's length represents the cue ball's speed just before the collision.

Mark the beginning of the line with S (for "stationary"), and the end with I ("initial"). At the midpoint of that line, put a dot (C). Draw a circle with its center at C that passes through S. Now, starting at S, draw another line, parallel to the path the object ball must take to the pocket; extend it until it touches the circle. Mark the point of its intersection with the circle O ("object"). Draw a line from O through C to the circle on the other side; mark that intersection F ("final"), and finally draw a line from S to F.

The line from S to O gives the direction and speed of the object ball after the collision. The line from S to F gives the direction and speed of the cue ball. It's easy to see that as the cut angle (the angle from I to S to O) gets bigger, the object ball speed will get smaller and the cue ball speed will get bigger, until finally for a perfect 90-degree cut the object ball will not move at all and the cue ball will go straight forward without slowing down. If you remember your geometry, you might also be able to show that, with this diagram, the angle between the final cue and object ball directions is exactly 90 degrees, no matter what the cut angle is; the "right-angle rule" is correct in this case.





In carom games, one-pocket and safeties at pool, it is often important to control the speeds of both object ball and cue ball, and this diagram can show you how those speeds vary with the cut angle (The diagrams tell you only about the collision between the balls, so they apply directly to stun shots. Follow or draw will affect the speed and direction of the cue ball; those effects must be "added on" to these).

What assumptions lie behind this picture? First, these diagrams assume that all the action takes place in a single plane. If the cue ball is airborne, or is different in size from the object ball, the slate enters the picture in an intimate way and the diagrams are not as useful. Diagram 1 also assumes that the cue and object balls have the same mass, and that the total translational energy (energy of motion along the table) is the same before and after the collision. These latter assumptions are often violated, and slightly different diagrams must be used.

It's rare for there to be no change in the translational energy. Usually there is some change in the spins of the two balls during their collision, so that translational energy is converted to rotational energy or vice versa; to prevent that, you have to either hit a straight — in stop shot, or you have to hit a stun shot with just enough outside english that the surfaces of the two balls do not rub together when they collide. When the balls do rub together, some energy changes from moving the balls along the cloth to making them spin, or vice versa. Some also goes to producing the sound of the hit, and some warms up the balls; both of those amounts are usually too small to worry about.

In the Newton diagram, changes in translational energy change the size of the circle. In the majority of shots, translational energy is lost, and the circle gets smaller. This is true for shots where the throw tends to decrease the cut angle: inside English, center ball, or little/enough outside English that the cue ball still "slips forward" on the object ball as it hits. If you use enough outside english that the cut angle is increased (which is easiest for nearly straight-on hits), then some of the initial spin of the cue ball ends up as translational energy, and the circle can get bigger.

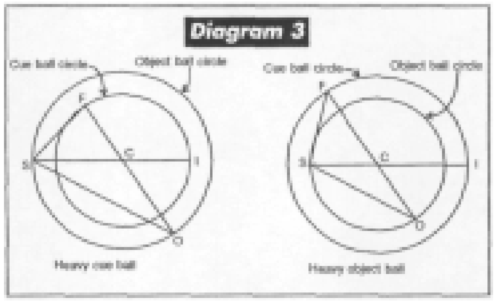
Diagram 2 shows how this works. The two diagrams drawn there are both for 30-degree cut shots to the right. On the left, the shot was hit with center-ball. At the moment of contact, the balls rubbed together, and the friction from that rubbing threw the object ball to the left and imparted some clockwise spin to each ball (See *Tech Talk,* April 2000). The throw has no effect on the diagram, since the line from S to O was drawn in the direction the object ball actually traveled. It takes energy to makes the ball spin, though, and that energy comes from the initial translational motion of the cue ball; that makes the circle smaller, so that the line from O to F is shorter than the line from S to I. Now the angle from O to S to F is less than 90 degrees.

On the right, the same shot was hit with heavy outside (left) English (The player aimed differently than on the left, so that the object ball would still leave in the same direction—toward the pocket). In this shot, when the two balls came together, the rubbing between them was in the other direction; the object ball was thrown to the right and picked up a little counter-clockwise spin, and the cue ball lost spin. The **translations!** energy increased overall, so the line from O to F is longer than that from S to I. Now, the angle from O to S to F is larger than 90 degrees; the separation angle widens in this case.

How big are these changes in separation angle? It's reasonable to think of them this way: the cue ball always leaves at right angles to the line between the two ball centers at contact, while the object ball will be thrown to the right or left of the line between centers. So, the changes in separation angle are the same size as the throw angles, and with clean balls those are rarely bigger than five degrees. That argument is not exactly right; some energy is lost to heat and sound, and the balls do move slightly during the time they are in contact so the "line between centers" is not precisely defined, but it gives a good estimate of the maximum change from right angles.

You can occasionally use these changes in separation angle to maneuver around an obstructing ball in your path to the next shot, or even to take a free carom shot at the nine ball while still pocketing your main object ball. The diagrams also show that it is not possible to make a cut shot without having the cue ball move in the direction opposite the cut, as is sometimes claimed.

If the cue ball and object balls do not weigh the same, there is a dramatic effect on the cue-ball path. This situation is most common on coin-operated tables, but can also appear on other tables if the cue ball is mismatched or worn. To draw this diagram, instead of placing point C at the midpoint of the first line, you put it at the "balance point": the point where a light, stiff rod with its ends at S and I would balance if the cue ball was put at I and the object ball at S. In other words, the distance CI times the cue ball mass must equal the distance CS times the object-ball mass. Then, draw two circles. One should have its center at C and pass through I; that is the "cue-ball circle." The other, the "object-ball circle," has its center at C as well, but passes through S. Then draw the line from S in the object ball travel direction as before, and label its intersection with the object ball circle O. Draw a line from O through C and on to the cue ball circle; its intersection with the cue ball circle is F. Finally, draw the line from S to F that shows the final direction and speed of the cue ball. **Diagram** 3 shows a heavy cue ball (left) and a light cue ball (right). (Translational energy changes would make both circles smaller or bigger; Diagram 3 shows the case where there is no change.)



If the cue ball is heavier, the separation angle varies smoothly from zero for a straight — in hit to 90 degrees for a very thin cut. A heavy cue ball produces "instant follow"; the cue ball will start out moving forward of the right-angle line, even if it arrives with back spin, and before friction with the cloth has had any effect.

If the cue ball is lighter than the object ball, then you get "instant draw." For a straight — in shot, the cue ball will back up after contact even if it did not have any spin (Think of throwing a soccer ball at a bowling ball). As the cut gets thinner, the separation angle will decrease from 180 degrees, and finally for very thin cuts it will approach 90 degrees.

For both heavy and light cue balls, the most dramatic effects appear for shots near straight in. Because the separation angle changes dramatically with the cut angle, carom shots are much more difficult with mismatched balls.

—George C. McBane