The Physics of Baseball

What happens when a 30-oz. Bat traveling 70 mph strikes a 5-0z baseball traveling 90 mph?

What happens if the bat contacts the ball just a few millimeters above or below center?

How do pitch speed and bat speed effect the collision between the two?

Collisions: Momentum and Force

Momentum is a moving object's mass multiplied by it's velocity: Momentum = Mass X Velocity.

Calculate momentum for the following questions:

1. A 5-oz ball traveling at 85 mph
2. A 30-oz bat traveling at 65 mph

Compare the momentum of a slow moving heavy object and a fast moving light object.

Force = Change in momentum/ Time to change momentum

OR

Force X Time Interval = Change in momentum

To cause a change in momentum you can apply a LARGE force for a short time interval, or you could apply a SMALL force for a long time. This means that you could stop a rolling car with your breath as long as you had a very long time.

1. Give ten examples of small and big forces changing momentum.
2. Explain the force required for baseball player to hit a homerun.

The vertical location of the contact matters! The baseball is round and the bat is cylindrical or barrel shaped. A few millimeters either way can affect the kind of hit that occurs.

1. How does a ground ball happen?
2. How does a fly ball happen?
3. How does a line drive happen?

The chart below shows a sample of balls hit at different speeds and angles under different conditions of temperature, humidity, and altitude. Notice that even a 5 percent difference in drag can make the difference between a fly ball and a home run.

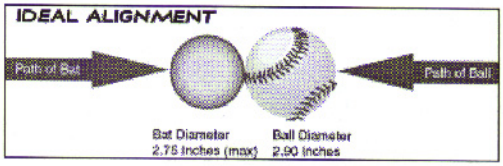
Trajectory Number	Speed (ft/sec)	Angle (deg.)	Distance in feet given standard temp (70 degree) and pressure (sea level).	Vacuum	-10% air density (hot and humid)	-5% air density (hot and humid)	+5% air density (cold and dry)	+10% air density (cold and dry)	'head' wind	'tail' wind
			Range in feet							
1	161	45	400	812	419	409	391	382	363	434
2	140	35	341	577	354	348	335	329	310	370
3	120	60	236	390	245	241	232	228	186	282
4	100	25	192	239	196	194	190	188	166	216
5	75	55	133	165	136	134	131	130	91	171

Trajectory number:
1 = home run
2 = catchable flyball
3 = catchable flyball
4 =line drive
5 = pop-up

Table based on initial figures provided by:

Watts, Robert G., and A. Terry Bahill. **Keep Your Eye on the Ball: The Science and Folklore of Baseball.** New York: W.H. Freeman and Co., 1990.

ANGLE OF CONTACT: *FLY BALL OR GROUNDER?*



The vertical location of the contact matters too. The baseball is round, and the bat is cylindrical, or barrel-shaped. If the batter's swing is off-center by more than a few millimeters vertically, the hit will be a fly ball or a grounder. A dead-center hit will be a line drive, and a hit a few millimeters below center could be a home run. But it could also result in a deep fly ball, easily caught by the fielders for an out. What's the difference? The determining factor lies in the physical properties of the bat and the ball, the moment of contact between the bat and the ball, and the interaction of the ball with the air as the ball flies towards the outfield.

COLLISIONS: *MOMENTUM AND FORCE*

Let's pause here for a word about some of the elements involved in any collision: momentum and force.

Momentum is a moving object's mass multiplied by its velocity: Momentum = Mass x Velocity

So a slow-moving, heavy object has great momentum, as does a fast-moving, light object.

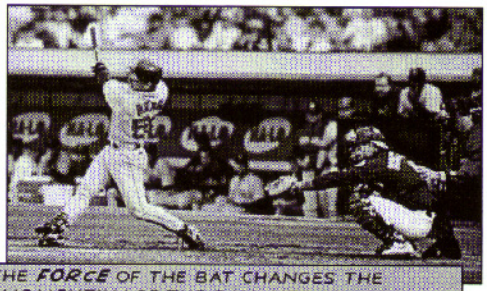
The next question to look at in a collision between bat and ball is the question of force.

To slow any moving object (like a pitched ball), one has to apply a retarding force to slow it down. The net force required depends on how much you want to change the momentum and how quickly you want to change it. The quicker the change, the greater the force. In other words:

Force = Change in momentum/Time to change momentum

or

Force x Time interval = Change in momentum

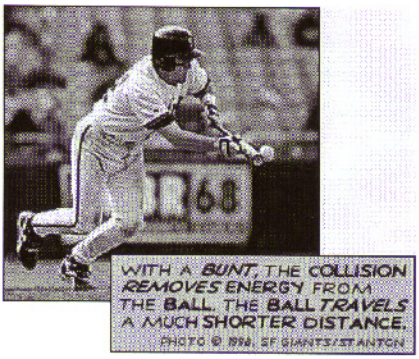

THE *FORCE* OF THE BAT CHANGES THE *MOMENTUM* OF THE BALL *VERY* RAPIDLY...
PHOTO BY AMY SNYDER

This equation tells us that we have a balancing act. To cause a given change in momentum you can apply a LARGE force for a short time interval, or you could apply a SMALL force for a long time (or anything in between, as long as the two multiply to the same number).

This means that you could stop a rolling car with your little finger, if you could push against the car for a long time. You could even stop the Queen Mary by breathing on it . . . for a VERY long time.

For more on the physics of hitting visit our interactive exhibit, "Scientific Slugger "!

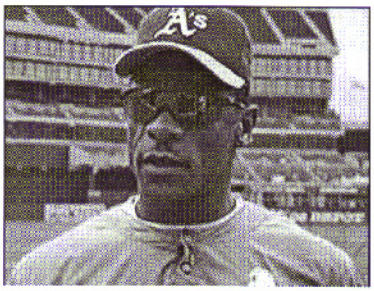
However, to effect a similar change in momentum over a very short time would require a much larger force. In real-world terms, this means that it takes A LOT of force to stop a heavy, fast moving object quickly.



When a 30-oz. bat traveling 70 mph strikes the 5-oz. ball traveling 90 mph in the opposite direction, they remain in contact for about 2 milliseconds. What happens? Well, we know from experience that the ball ends up sailing towards the outfield at about 100 mph. But what happened in the collision? There is a very important principle in physics called "conservation of momentum." This law states that there must be the same amount of momentum after the collision as there was before the collision. You have to add up ALL the momentum before and after. So in our case, you add up the bat + ball before, and that must equal bat + ball after. In this collision, the bat slows down and gives much of its momentum to the baseball.

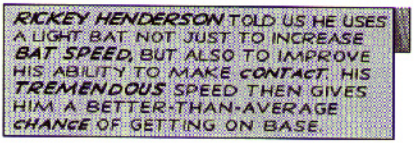
So in our collision between bat and ball, what is happening? Both objects experience an equal change in momentum as a result of the collision. But the greater mass of the bat means that, for a given change in momentum, it will experience a much smaller change in velocity than the ball. The much lighter ball undergoes a large change in velocity, which results in the ball flying away towards the outfield.

BAT SPEED: A BIG STICK IS GOOD, BUT A FAST STICK IS BETTER



It would seem, then, that a large, heavy bat would be best for hitting a ball a long way, since once a big bat is moving at a given speed it has greater momentum than a light bat. However, a large, heavy object also requires a great deal of effort to accelerate into motion from a

standstill. It has LOTS of inertia. (Inertia is the tendency of a still object to remain still, and a moving object to keep moving.)

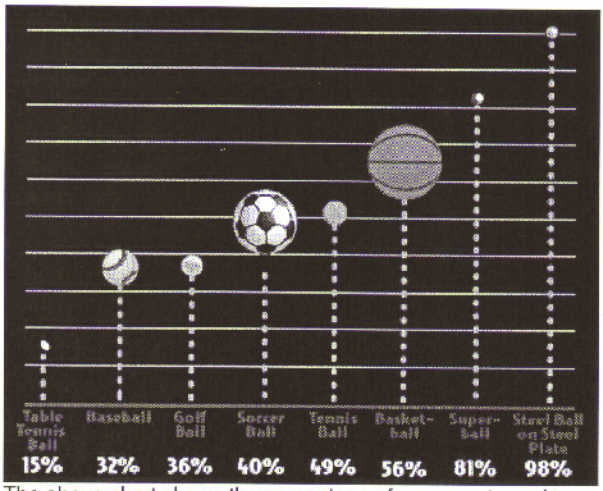


A batter has only split-seconds in which he must decide to swing and accelerate the bat to meet the ball. A heavy bat requires great strength and excellent reflexes to use, otherwise it becomes a liability. If the bat is too heavy, the pitch will pass by before the batter can hit it. Some professional hitters prefer relatively light bats, which they can accelerate and swing quickly and accurately. As Rickey Henderson indicates, you have to have perfect timing and judgment to get a hit with a heavy bat: "I use a light bat, about 32 or 34 ounces, to get some more bat speed. Bat speed can give you more distance, but it really gives you a chance to wait a little longer (before deciding to swing), to see the ball to the plate a little longer, so you can just make contact with it."

Many hitters who use lighter bats are "contact" hitters like Rickey Henderson. They specialize in carefully placed base hits, instead of "swinging for the fences." However, some light-bat hitters have managed to hit a lot of home runs. Hank Aaron, for instance, broke Babe Ruth's lifetime record of 714 home runs using a light bat. Remember, momentum has two components, velocity and mass. A hitter with quick wrists using a light bat can generate tremendous bat speed, thereby generating great momentum.

ELASTICITY AND THE "COEFFICIENT OF RESTITUTION": WHY BOUNCY BALLS GO FARTHER

The speed of the ball as it approaches the hitter also affects its flight after being hit. The greater the speed of the ball before impact, the greater its rebound speed will be. This is due to the elasticity, or bounciness, of the ball. Though it seems quite hard, the modern baseball is very elastic, which means that when it is deformed by an impact, it tends to bounce back, returning the kinetic energy of the impact into motion in the other direction. The measure of this bounce is called the "coefficient of restitution," which is a measure of how much of the energy of the collision is returned into the motion of the ball, rather than being dissipated as heat.



THIS CHART SHOWS THE ***BOUNCINESS*** OF DIFFERENT BALLS. NOTICE THAT THE ***BASEBALL*** IS NOT AS BOUNCY AS MOST OF THOSE FROM ***OTHER*** SPORTS. TO LEARN MORE, VISIT OUR "***BOUNCING BALLS***" ACTIVITY PAGE...

The above chart shows the percentage of energy returned to the ball after one bounce.

No ball is perfectly elastic: The elasticity of a particular ball depends on its construction. After 1920, baseballs were made much livelier to encourage power hitting. The next season, the number of major league home runs more than doubled, and the nature of the game was drastically altered. Over time, changes in materials have changed the nature of the game. But the forces of nature remain the same.