Get In The Swing
The Physics of Baseball Bats
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Physics of a Baseball Bat

How would a physicist pick out a baseball bat?
Physics of a Baseball Bat

How would a physicist pick out a baseball bat?

Physicist’s Bat

Ballplayer’s Bat

Why are they different?
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The center of mass (CM)

CM in the middle

Where is the CM of a real bat?
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The center of mass (CM)

Cut out the bat and find its center of mass.

Is it closer to the handle end or the barrel end?
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The center of mass (CM)

CM in the middle

CM is closer to the barrel end
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The rotational inertia (I)

Rotational inertia is a measure of how hard an object is to rotate.
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The rotational inertia (I)

Rotational inertia is a measure of how hard an object is to rotate.

Which is it easier to balance on your hand, 0cm mark or the 100cm mark?
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The rotational inertia (I)

Rotational inertia is a measure of how hard an object is to rotate.

Which is it easier to balance on your hand, barrel up or barrel down?
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The rotational inertia (I)

Rotational inertia is a measure of how hard an object is to rotate.

The bat has a larger rotational inertia about the handle. Why is this an advantage?
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The center of oscillation (CO)

Physical Pendulum

Simple Pendulum

The CO is equal to the length of a simple pendulum with the same period as the bat or meter stick.
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The center of oscillation (CO)

For the meter stick, the CO is $\frac{2}{3}$ of the length. For the bat, the CO is more than $\frac{2}{3}$ of the length.
The rotational inertia ($I$) calculation

**Physical Pendulum**

$$T = 2\pi \sqrt{\frac{I}{mgr_{cm}}}$$

**Simple Pendulum**

$$T = 2\pi \sqrt{\frac{r_{co}}{g}}$$

$$\sqrt{\frac{r_{co}}{g}} = \sqrt{\frac{I}{mgr_{cm}}} \Rightarrow r_{co} = \frac{I}{mgr_{cm}} \Rightarrow I = mr_{co}r_{cm}$$
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The center of percussion (CP)

The spot were an applied force causes pure rotation about the end of the bat

Center of Mass

Pivot point

Force

$L$

Second Law for Rotation

$$\sum \tau = I\alpha$$

Pure Rotation

$$r_{cp}F = I\alpha$$

Second Law

$$r_{cp}ma = I\frac{a}{r_{cm}}$$

Center of Percussion

$$r_{cp} = \frac{I}{mr_{cm}}$$

but...

$$r_{cp} = \frac{mr_{co}r_{cm}}{mr_{cm}} = r_{co}$$
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The center of percussion (CP)

We can verify the fact that the CP and the CO are the same.
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The vibrational nodes (VN)

You can demonstrate vibrational nodes with a stick that is more flexible than a bat.
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The vibrational nodes (VN)
Physics of a Baseball Bat

The vibrational nodes (VN)
Physics of a Baseball Bat

The vibrational nodes (VN)

The standing waves on a baseball bat

fundamental

1\textsuperscript{st} overtone

2\textsuperscript{nd} overtone

3\textsuperscript{rd} overtone
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The vibrational nodes (VN)

If you wrap a paper megaphone around the top of the bat you can hear the vibrations.

The place where the sounds is minimum is the node of the fundamental.
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The vibrational nodes (VN)

The fundamental oscillation of a “free” meter stick.

The nodes are ¼ of the way from each end.
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The vibrational nodes (VN)

The VN for the meter stick is $\frac{3}{4}$ of the way down.

The VN for the bat is a bit more than $\frac{3}{4}$ of the way down.
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Summary of the Physicist’s Bat

- **Static Properties**
  - The center of mass (CM)
  - The center of oscillation (CO)
  - The rotational inertia (I)

- **Dynamic Properties**
  - The center of percussion (CP)
  - The vibrational nodes (VN)
Summary of the Ballplayer’s Bat

- **Static Properties**
  - The center of mass (CM)
  - The center of oscillation (CO)
  - The rotational inertia (I)

- **Dynamic Properties**
  - The center of percussion (CP)
  - The vibrational nodes (VN)

*The VN is at the same spot as the CP and CO! This is the “Sweet Spot.”*
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“The Sweet Spot”

A bat has a sweet spot.
A meter stick does not!

During the ball-bat collision, energy is used to vibrate the bat and to exert forces (do work) on your hands.

If the collision occurs at the sweet spot, no energy is used for bat vibrations or to do work on your hands.

At the sweet spot, the maximum energy is available to go into the ball.
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Why are aluminum bats different than wooden bats?

The internal vibrations of aluminum bats can be engineered.
Drop a “sad” ball on the table. Do you know why it is called a sad ball?

Drop the sad ball on the aluminum can. What happens?
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The hoop modes of a hollow bat

fundamental  1\textsuperscript{st} overtone  2\textsuperscript{nd} overtone
Physics of a Baseball Bat

*What have we learned?*

- A baseball bat is shaped in such a way to have a “sweet spot.”
- The sweet spot is due to the fact that the CP/CO and the VN coincide.
- A wooden bat really only has transverse vibrations.
- A hollow bat can have hoop modes that can be tuned to maximize energy transfer to the ball.