The center of percussion (COP) is the place on a bat where it may be struck without causing a reaction at the point of support. When a ball is hit at the COP the contact feels good and the ball seems to explode off the bat, springing away with its greatest speed, and therefore this is often referred to as the sweet spot. At points other than this spot, the bat may vibrate or even sting your hands. In this experiment you will investigate the effect by seeing what happens when you strike a suspended bat at various places. Sometimes the COP is referred to as the center of oscillation. The reason for this can be demonstrated by suspending a simple pendulum\(^1\) whose length is equal to the distance from the pivot point to the COP. The bat and the pendulum will have the same period of oscillation.\(^2\) Thus the understanding of the sweet spot draws on concepts related to translational and rotational dynamics, the action of torques, and harmonic motion of simple and physical pendula.

**Introduction**

When a bat is struck at its center of gravity (COG), it moves forward (without rotation) in the direction of the force. Hitting a bat at some place other than its COG produces a torque about its COG resulting in both rotational as well as translational motion, as illustrated below for the case of a rod.

![Diagram](a.png)

![Diagram](b.png)

Furthermore, there is a point which, when struck, will result in the forward translational velocity and the backward rotational velocity being equal and opposite. This point is called the center of percussion and may be determined as follows.

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\(^1\) For an explanation of the simple pendulum see Giancoli, section 11.4, p 296.

\(^2\) The period of oscillation is explained in the appendix of this write-up.
Let the rod, pictured above, represent a bat which is suspended from a horizontal bar by a loop of rope at point P, as shown. The rod can rotate about the point of suspension and the suspension loop (pivot point) can itself move horizontally. In the first of the three situations depicted in the drawings, a force (hammer blow) is applied below the COP. This results in a considerable rotational counterclockwise velocity (greater than the forward translational velocity) and the suspension point gets jerked to the left. If the force is applied between the COP and the COG (middle illustration), the forward velocity will exceed the rotational velocity at the pivot point and there will be a forward push on the pivot point to the right. Hitting above the COG (not illustrated) will impart rotational and translational velocities in the same direction, and the suspension point will clearly move to the right. In the third drawing, the rod is struck at the COP (which is located 2/3 the way down for the case of a rod). The forward and rotational velocities are equal and opposite at the suspension point, which remains stationary. We can prove this as follows (refer to the third illustration above).

The translation effect, acting alone, would make the suspension point P move to the right with an acceleration

\[ a_{\text{right}} = \frac{F}{m}. \]

The rotational effect, acting alone, would produce a counterclockwise angular acceleration about the COG given by

\[ \alpha = \frac{\tau}{I} = \frac{F(L/6)}{(1/12)mL^2} = \frac{2F}{mL}, \]

where L is the length of the rod, I is the rotational inertia about an axis through the COG, and (L/6) is the distance between the COG and the COP. Because of this angular acceleration, P would move to the left with a translational acceleration

\[ a_{\text{left}} = \alpha \left( \frac{L}{2} \right) = \frac{2F}{mL} \cdot \frac{L}{2} = \frac{F}{m}. \]

Thus \( a_{\text{right}} = a_{\text{left}} \) and there is no movement at point P.

\[ ^3 \text{For various rotational inertia, see page 208 of Giancoli.} \]
Procedure

The shape of a bat is more complex than a uniform rod and it will take a little experimenting to identify the COG and COP locations. First find the COG by balancing the bat on your finger. Mark the COG location with a piece of tape. Next, suspend the bat and strike it with a rubber mallet. Carefully observe its reaction, especially the reaction at the point of suspension. Strike it at many locations along its length. By observing the bat's reaction to being struck you should be able to verify the behavior described above. Remember, when struck at the sweet spot the bat will swing like a pendulum with no translational movement at the point of suspension. Mark the sweet spot with a piece of tape.

With a stopwatch, determine the period of oscillation of the bat (time at least ten complete oscillations to obtain a reasonably accurate number for the period). Now compute the length of a simple pendulum that would have this same period (see the appendix below). Next, construct a simple pendulum that has this length and check its period. Is the period of your simple pendulum equal to the period of the bat? If the periods of the bat and your pendulum differ, adjust the length of pendulum until they match. The length of this simple pendulum should approximately correspond to the COP location on the bat. Mark on the bat with a piece of tape a new COP location as determined by your simple pendulum.

1→ This mark should be close to but not exactly the same as the COP location you found with your striking observations. Why?

Weigh the bat and, using the equation given in the appendix below, calculate the bat's rotational inertia.

2 → Is the moment of inertia of the bat greater or less than the moment of inertia of a uniform rod of equal mass and length? Why?
Appendix:

The period of a physical pendulum is given by the general formula $T = 2\pi \sqrt{\frac{I}{mgd}}$, where $I$ is the rotational inertia about the pivot (suspension) point, $m$ is the mass of the pendulum, $g$ is the acceleration of gravity, and $d$ is the distance between the pivot point and the center of gravity. The rod is a physical pendulum whose period of oscillation is $2\pi \sqrt{\frac{2L}{3g}}$, compared to a simple pendulum whose period is $2\pi \sqrt{\frac{L}{g}}$. The factor of $2/3$ is a result of the mass being distributed uniformly along the rod, rather than being concentrated at its lower end, as is the case with the simple pendulum. Thus, a rod shaped physical pendulum, and a simple pendulum $2/3$ the length of the rod, will have identical periods.

3 → Derive the above formulas for the periods of a uniform rod and a simple pendulum (both of length $L$) by substituting the appropriate values of $I$ and $d$ into the general formula.\(^4\)

\(^4\)Note that $I$ in this case (rotation about the end) is different from the $I$ in the expression for $\alpha$ on the previous page.
Physics

Do sluggers swat on spot or swath?

Millions of baseball fans cheer each time Mark McGwire's or Sammy Sosa's bat kisses another home run good-bye. On Sept. 8, the St. Louis Cardinal star broke the 37-year-old, single-season record of 61 home runs with a sizzling drive over the left-field fence. Chicago Cub Sosa matched him a few days later.

While McGwire and Sosa are reaching the bleachers with uncanny ease this season, a physicist half a world away is offering evidence that the famed sweet spot of their bats is more complex than previously believed.

According to both baseball lore and earlier scientific studies, the sweet spot is composed of one or maybe two points about 15 centimeters from the end of the bat's barrel. Although batters can hit home runs on other parts of the bat, a hit from the sweet spot delivers an exceptionally powerful wallop to the ball without stinging the batter's hands.

Now, Australian physicist Rod Cross of the University of Sydney reports that the sweet spot is really a 3-cm-wide zone, rather than one or two distinct points. Cross measured forces on batters' hands and noted what batters said they felt during impacts at varying distances along the bat. On a bat 84 cm (33 inches) long, the zone extended down from 15 cm from the tip, he found.

Struck anywhere, a bat naturally vibrates with distinctive wave patterns, or modes. Previously, physicists identified one sweet spot as the point where the lowest-frequency wave pattern shrinks to zero and where an impact consequently causes minimal vibration in the handle.

Cross reports in the September AMERICAN JOURNAL OF PHYSICS that a higher-frequency wave pattern, which shrinks to zero at a nearby point, is also a sweet spot. "No one had measured these forces before or had identified that there are two equally important modes," he says. Because impacts along the barrel between those two points cause the weakest vibrations in the handle, Cross argues for a sweet zone.

Moreover, the zone concept is attractive, Cross contends, because recoil in the bat handle is minimized during hits near the two points. Such impacts cause the bat's barrel to shift to positions under the batter's hands where the torque drops to zero, minimizing the jarring felt in the hands and arms.

Why the interest in baseball Down Under? Although much less popular than cricket, Australian baseball is televised and growing in popularity, Cross says. —P.W.

Biology

Methylation: Protector of the genome?

Using enzymes as paintbrushes, the cells of vertebrates chemically coat large portions of their chromosomes with clusters of chemicals called methyl groups. The phenomenon, known as methylation, has drawn great scientific interest in recent years as its connections to cancer have emerged. In many tumors, for example, excessive methylation seems to silence certain genes that normally suppress cell division.

In general, however, cancer cells exhibit a puzzling decrease in methylation throughout the genome. Scientists now suggest that this increases the mutation rate within a noncancerous cell and may therefore speed its malignant transformation. The hypothesis implies that methylation does more than just help turn genes off. "It's also crucial to preserve the integrity of the genome," says Rudolf Jaenisch of the Whitehead Institute for Biomedical Research in Cambridge, Mass.

In 1985, Jaenisch and his colleagues showed that mice with half the normal amount of the enzyme used for methylation developed fewer colon tumors than expected, presumably because tumor-suppressor genes could no longer be silenced (SN: 4/22/85, p. 246). Mice completely lacking the enzyme died as embryos, however, implying that specialized adult cells can't survive without at least some methylation.

Jaenisch's group has followed up this earlier work with experiments on a type of embryonic cell that tolerates the absence of methylation. In particular, the researchers have monitored mutations of two genes. In the Sept. 3 NATURE, they report that in the unmethylated embryonic cells, the genes' mutation rates were 6 to 10 times those observed in normally methylated cells. Most of the mutations were DNA deletions caused by recombination, a shuffling of genetic material among pairs of chromosomes that occurs when cells divide. This shuffling is rare in vertebrate cells other than sperm or eggs, which are typically low in methylation. Methylation represses recombination, protecting cells from cancer-causing mutations, concludes Jaenisch. Removing this restraint "is an advantage for cancer cells because it increases the mutation rate by decreasing the stability of the genome," he says.

While researchers still need to find a way to extend the findings of Jaenisch's team to normal adult cells, the current study "backs the growing suggestion that if you lose methylation . . . from key sites, you're in some way interfering with genome stability," says Stephen B. Baylin of Johns Hopkins Oncology Center in Baltimore. —J.T.

Looking to moths for immune insights

The human immune response may be more sophisticated than that of an insect, but the two do have a common heritage that scientists find revealing. "By examining what happens in an insect, you can infer what happens in people," notes Charles A. Janeway Jr. of Yale University School of Medicine.

While the human immune system, unlike that of the insect, eventually generates antibodies and immune cells specifically targeted to particular microbes, both systems have an ability to respond quickly to infectious agents by recognizing common features such as bacterial cell wall components. Scientists in Sweden have now identified a new protein that helps insects, and presumably people, accomplish this feat.

The Swedish team infected moths with bacteria and identified the genes subsequently turned on. The researchers found that the insects increase production of a protein that can bind to the bacterial surface molecule called peptidoglycan. Genes for a related protein have been identified in mice and people and are active in tissues associated with the human immune system, Håkan Steiner of Stockholm University and his colleagues report in the Aug. 18 PROCEEDINGS OF THE NATIONAL ACADEMY OF SCIENCES. —J.T.