Racquetball Kinetics

Activation Energy

Introduction

A bowl-shaped piece of rubber is dropped from a height of 5–10 cm and bounces a little as might be expected. It is then dropped from a height of 20–30 cm, and surprisingly bounces more than 100 cm into the air! This serves as an ideal model for the discussion of exothermic reactions and their activation energies.

Concepts

- Activation energy
- Activated complex
- Exothermic reaction
- Potential and kinetic energy

Materials

Pen

Racquetball

Sharp pair of scissors or utility knife

Table tennis ball (optional)

Safety Precautions

Care is needed when cutting the racquetball. The device may pop up with some force; wear safety glasses while performing this demonstration. Follow all laboratory safety guidelines.

Preparation

1. Obtain a new racquetball. Squeeze the ball and rotate it to locate the very thin equatorial seam. Mark it with a pen.
2. Insert the point of a scissors or a utility knife—either way use EXTREME care—into the seam, and cut the ball into two halves along the seam. *Note:* Once the ball is cut part way, it may be pulled apart along the seam.
3. Flex (invert) one of the halves by pushing on the convex side until it flexes inside out, and then push it back to its original, relaxed configuration (see Figure 1). Note that "un-inverting" the device takes a substantial force, not just a slight tap. The purpose of the step 4 below is to trim off just enough of the rim to enable the flexed device to un-invert with just a very slight force.

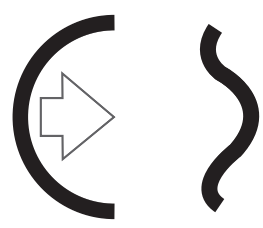

Figure 1.

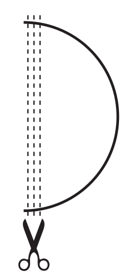

Figure 2.

4. Use the scissors to trim along the edge. Trim it down a little bit at a time (see Figure 2), and after each trimming, try inverting and drop-testing the piece from a height of 30–40 cm onto a hard, flat surface. When drop-testing, hold the flexed device horizontally, and drop it straight down with its concave (originally outer) surface facing downward, like a sombrero in the upright position (see Figure 3). If it rotates while falling and hits on an edge, drop-test it again; it may be ready, but just did not land correctly. Continue trimming and testing until the device, upon landing, pops from the flexed configuration to the relaxed configuration, and bounces back much higher (see Figure 3). *Caution:* If too much of the edge is trimmed away, the flexed configuration cannot be maintained, and you will need to start all over again.

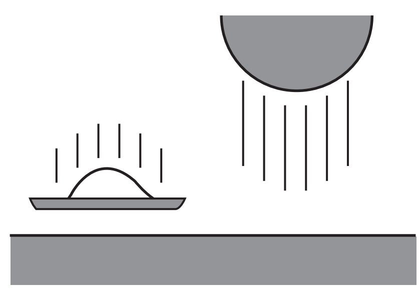

Figure 3.

Procedure

1. Drop the inverted bowl from a height of only 3–5 cm. It tends to bounce back normally with no change in its configuration.

2. Drop the inverted bowl from a slightly greater height. Again, just a normal bounce back.
3. Continue increasing the drop-height until, at about 30–40 cm, the flexed device un-inverts itself by popping into the relaxed configuration and springs upward to a height of 60 cm or more.

Tips

- Often the difference between a device that works and one that does not is only a very thin sliver of rubber. There is no simple rule as to how much material to trim away; an empirical approach is required!
- For an extension to this activity, obtain a table tennis ball. Invert the racquetball device and hold it with the bowl down. Place the table tennis ball in the bowl. Drop the device from about 30-40 cm and watch as the table tennis ball shoots up to the ceiling. The potential energy of the inverted racquetball is transferred to the lighter-weight table tennis ball as the racquetball un-inverts, thus causing an even greater acceleration of the table tennis ball.

Discussion

A normal bounce: When held a small distance above the tabletop, the device has increased potential energy relative to what it would have at the surface. When it is dropped from this small height, the potential is converted into kinetic energy (downward motion). When it strikes the table, it pushes downward on the surface, and the surface pushes upward on the device—for every action, there is an equal and opposite reaction. This reaction stops the device momentarily and causes a small deformation in the device's shape, stretching the rubber slightly; thus the kinetic energy is momentarily converted back into the potential energy of the stretched rubber. Just like a bouncing ball, when the rubber returns to the shape it had while falling, it pushes downward on the surface and the surface pushes upward on the device. This accelerates the device upward and the potential energy gets converted once again into kinetic energy (this time, as upward motion). As the device climbs back to its original height, the kinetic energy is converted again back to potential, and we are theoretically back where we started. (Actually, given air resistance and the less-than-perfect elasticity of the collision, much of the energy does get lost to the surroundings in the form of heat and sound—after all, we do hear it bounce!)

A super bounce: When the device is dropped from a greater distance, all of the same energy transitions mentioned above occur again, with one important addition. Since it has a greater potential energy to begin with—by virtue of its greater altitude—it will strike the table's surface with a greater kinetic energy and the deformation of the device will be more pronounced. In fact, it is so pronounced that it pushes the device past the inversion point, and the "unstretching" of the rubber this time is not one that restores it back to the shape it had while falling; it is the much greater unstretching of the rubber back to its original unflexed configuration. This pushes much harder on the table, and the table pushes much harder back, accelerating the device upward to a height 3–5 times greater than its original position! Whereas this event appears to defy the laws of physics, for it seems that energy is being created, essentially what is happening is that a potential energy is being tapped that was not being tapped with the smaller drop.

From a chemist's point of view, this ties in beautifully with the concepts of kinetics and activation energies for chemical reactions. The device is, after all, somewhat stable in the flexed configuration (this is analogous to reactants such as H_2 and O_2). The device is much more stable, however, in the normal, unflexed configuration (analogous to a product such as H_2O). There exists between the two configurations a sort of potential energy hill—an in-between configuration which is less stable than either of the other two, but which the device must go through to transform from one configuration to the other. (Trying to get the device to stay in this in-between configuration proves next to impossible, like trying to balance a ball on the peak of a hill.) This in-between state is analogous, of course, to the activated complex, and the energy required to transform the device from the inverted configuration to the unstable in-between configuration is analogous to the activation energy. When the ball is dropped a small distance, this is comparable to two reactant particles colliding with insufficient energy to form the activated complex—they simply bounce off one another, with no reaction taking place. When the ball is dropped a larger distance, giving it more kinetic energy on impact, is comparable to heating up the particles with a spark or a flame and increasing their kinetic energy. Now the collision is strong enough for the activated complex to form and the reaction (in this case spontaneous and exothermic) can occur. Also note, if the device is dropped from a sufficient height but it lands on its side, the "activated complex" will not be formed and the reaction will not occur. This, of course, is analogous to two reactant particles colliding with sufficient energy but with an ineffective orientation.

We usually talk about exothermic reactions being reactions that "give off heat," but this might give students the misconception that heat is something existing outside of the particles, something that is somehow released into the empty space between the atoms and molecules during a reaction. This model reminds us that, for the most part, the heat is the kinetic energy of the particles, and that an exothermic reaction is one where the product particles leave the collision with a greater kinetic energy than they had going into the collision. These fast-moving product particles then have the opportunity to collide with and transfer some of their energy to neighboring particles, thus raising the temperature of the surroundings.

Connecting to the National Standards

This laboratory activity relates to the following National Science Education Standards (1996):

Unifying Concepts and Processes: Grades K–12
- Systems, order, and organization
- Evidence, models, and explanation
- Constancy, change, and measurement

Content Standards: Grades 5–8
- Content Standard A: Science as Inquiry
- Content Standard B: Physical Science, properties and changes of properties in matter, motions and forces, transfer of energy

Content Standards: Grades 9–12
- Content Standard A: Science as Inquiry
- Content Standard B: Physical Science, structure and properties of matter, chemical reactions, motions and forces, conservation of energy and increase in disorder, interactions of energy and matter

Acknowledgments

Bill Brent of Rolla, Missouri, first shared this activity with Bob Becker at Chem Ed '93.

Flinn Scientific—Teaching Chemistry™ eLearning Video Series

A video of the *Racquetball Kinetics* activity, presented by Bob Becker, is available in *Activation Energy*, part of the Flinn Scientific—Teaching Chemistry eLearning Video Series.

Materials for *Racquetball Kinetics* are available from Flinn Scientific, Inc.

Catalog No.	Description
AP8949	Scissors, Heavy-Duty
AP9243	Laboratory Knife, Stainless Steel

Consult your *Flinn Scientific Catalog/Reference Manual* for current prices.