Pitching Speed

Arthur Eisenkraft

Topic

Conservation of momentum and energy

Time

1½ hours

Safety

Please click on the safety icon to view the safety precautions.
Be careful when climbing the ladder. Make sure everyone is out of the range of the softball when you are throwing it, and clear the area of anything that could be damaged by the swinging box or a stray ball.

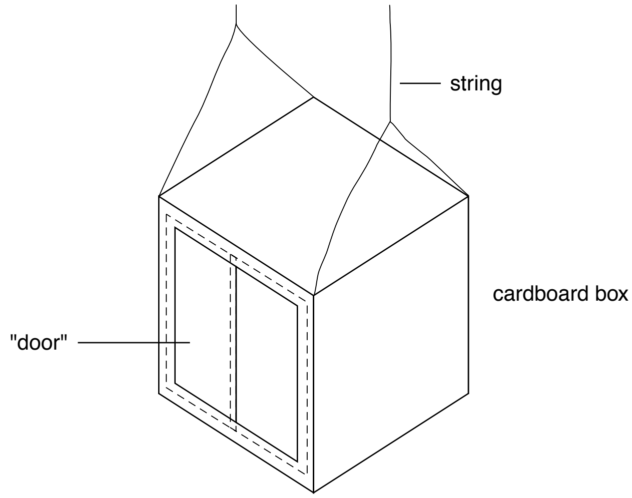
Materials

- cardboard box (approximately .5 m 2 .5 m 2 .5 m, but exact size is not important)
- softball
- string
- construction paper
- masking tape
- meterstick
- newspaper
- scissors
- ladder or step stool
- slide projector, large flashlight, or desk lamp
- triple beam balance scale, hanging scale, or food scale

Procedure

1. Choose a partner for this experiment.
2. Cut a large square hole in one side of the cardboard box. Almost the entire side of the box should be removed. Using construction paper and masking tape, make a "door" in the opening so that two pieces of paper overlap approximately ½ in. at the center of the opening. This will prevent the ball from falling out of the box (see figure 1).

Figure 1

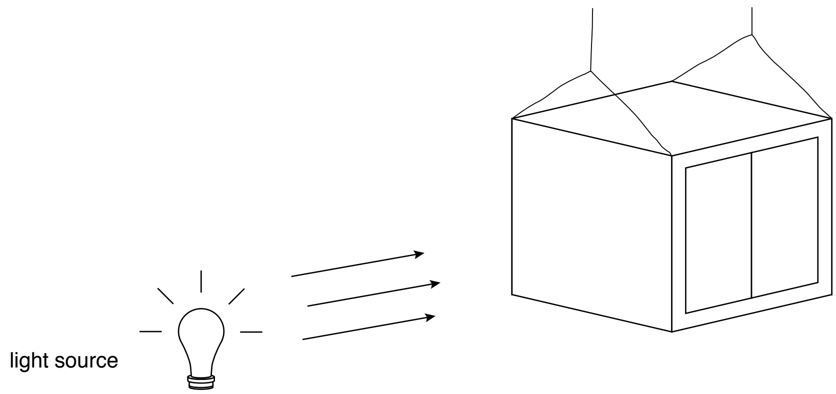


3. Fill the box with crumpled newspaper.
4. Attach string, as shown in figure 1. The string should be long enough to suspend the box to strike-zone height. Turn the box over. Using the meterstick, draw two diagonals to locate the center of the box, and mark it.
5. Use the scale to measure the mass of the box filled with newspaper. Convert the mass to grams if necessary, and record this figure as *M* on the data table.

Data Table	
h_1 (starting height of box)	
h_2 (height after hit)	
Δh ($h_2 - h_1$)	
M (mass of box)	
m (mass of ball)	

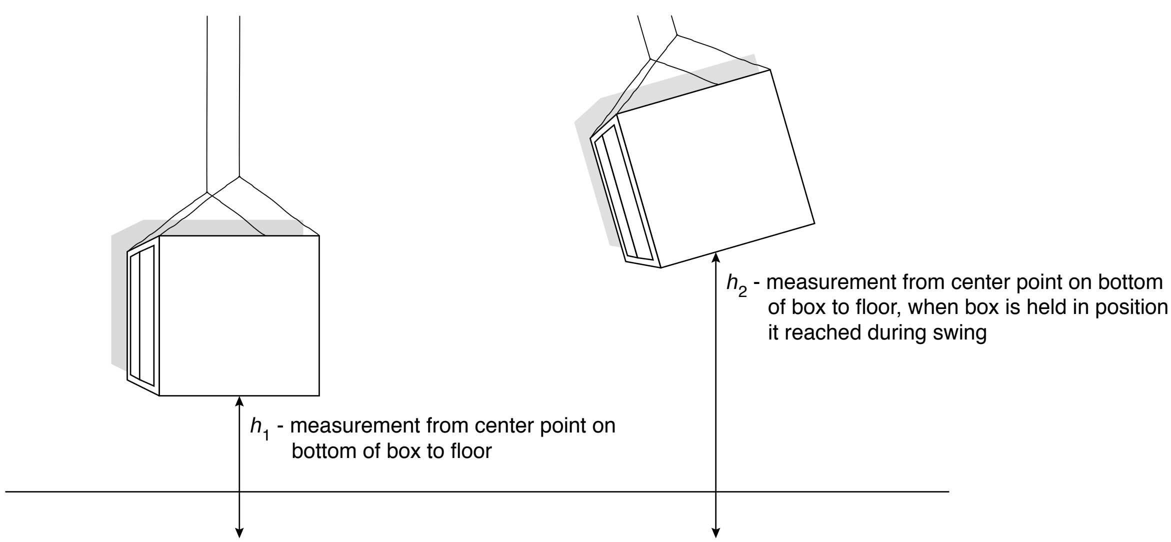
6. Measure the mass of the ball, and record this figure on the data table.
7. Choose a garage or a safe outdoor location where there is a place to suspend the cardboard box by strings (e.g., a garage ceiling beam or tree branch). There must be a wall nearby on which the box will cast a shadow. If you are doing the experiment outside, choose a cloudy day.
8. Suspend the box by the strings, with the hole facing the direction from which you will throw the ball. The box should be at strike-zone height and should be able to swing freely when hit by the softball. Clear the area of anything that could be damaged by the swinging box or a stray ball.
9. Set up the slide projector, flashlight, or lamp in such a location that the shadow of the side of the moving box will be cast on the wall (figure 2).

Figure 2



10. Have your partner standing nearby to observe the shadow of the box as it swings. The partner must be able to mark the highest point reached by the bottom front edge of the box on its first swing.
11. Throw the softball into the box. As the box undergoes its first swing, have your partner observe the farthest distance the shadow on the wall moves, and then draw a line on the wall to indicate the position of the bottom front edge at that point (figure 3). Practice throwing the ball into the box. You can stand at whatever distance is most comfortable for you. Try to throw the ball so that it goes through the center of the "door" and hits the back of the box as squarely as possible. This will result in a good, sharp swing with minimal rotation and make it easier to take accurate measurements.

Figure 3



12. Allow the box to hang in its original position. Using the meterstick, measure the distance from the floor to the center of the bottom of the box. Record this figure as h_1 on the data table. Now pull the box to the position it reached at the height of its first swing. Measure the distance from the floor to the center of the bottom of the box in this position (figure 3). Record this figure as h_2. Subtract h_1 from h_2 to determine the change in height (Δh). Record this figure on the data table.

When the softball strikes the back of the box, momentum in the ball-box system is conserved. The appropriate equation is:

$$mv = (M + m)V \qquad \text{(equation 1)}$$

where m = mass of the ball
v = velocity of the ball
M = mass of the box
V = velocity of the box with the ball inside

You have measured the masses of the ball and box, so you have values for m and M. To solve equation 1 for v, the ball's velocity, you will need to know the value of V, the velocity of the box after it is struck by the ball. To obtain this value, use standard equations for two other physical quantities: kinetic energy and gravitational potential energy.

Kinetic energy (KE) is defined as the work an object is capable of doing by virtue of its motion. The equation for kinetic energy is

$$\text{KE} = \tfrac{1}{2}mv^2$$

where m = mass of the object
v = velocity of the object

Gravitational potential energy (PE) is defined as the work an object is capable of doing by virtue of its position relative to the earth. Its equation is

$$\text{PE} = mgh$$

where m = mass of the object
g = acceleration of gravity (980 cm/sec^2)
h = the object's height above a given reference point (often the ground)

The important principle of physics that allows you to manipulate these energy equations to find the velocity of the box with the ball inside is the principle of *conservation of energy.* That is, at any point the total energy in the system will be the same. Therefore, any change in KE will be balanced by a change in PE. The appropriate equation is DKE = DPE.

After the moment of impact, the box with the ball inside has both KE (it is moving) and PE (determined by its height from the ground). At the moment at which the box has reached the top of its upward swing, it has zero velocity and thus zero KE. At this point, all of its energy is in the form of PE (its height has increased). According to the principle of the conservation of energy, total energy at the two points must be the same, so we can write

$$\tfrac{1}{2}(M\ 1\ \ m)\ V^2\ 1\ \ (M\ 1\ \ m)\ gh_1 = 0\ 1\ \ (M\ 1\ \ m)\ gh_2$$

To simplify:

$$\begin{aligned} \tfrac{1}{2}(M\ 1\ \ m)\ V^2 &= (M\ 1\ \ m)\ gh_2\ 2\ \ (M\ 1\ \ m)\ gh_1 \\ &= (M\ 1\ \ m)\ gh_2\ 2\ \ gh_1 \\ &= (M\ 1\ \ m)\ g\ (h_2\ 2\ \ h_1) \\ \tfrac{1}{2}(M\ 1\ \ m)\ V^2 &= (M\ 1\ \ m)\ g\mathrm{D}h \end{aligned}$$

To further simplify and isolate V, cancel the quantity $(M\ 1\ \ m)$, which appears on both sides to get

$$\tfrac{1}{2}\ V^2 = g\mathrm{D}h \qquad \text{(equation 2)}$$

Multiply both sides by 2:

$$V^2 = 2g\Delta h$$

and take the square root of both sides:

$$V = \sqrt{2g\Delta h}$$

By substituting the value of V into equation 1 and solving for v, the velocity of the ball can be determined:

$$v = \frac{(M + m) \times \sqrt{2g\Delta h}}{m} \qquad \text{(equation 3)}$$

13. Substitute your measurements into equation 3 and solve for v, the velocity of the ball. Be sure that your units are consistent, that is, that all masses are in grams, distance is in centimeters, and the acceleration due to gravity is given as 980 cm/sec^2.
14. The speed of the ball will be in centimeters per second. To compare your pitching speed with that of a professional ball player, convert the experimental value into miles per hour. There are 30.5 cm in a foot and 5,280 ft in a mile. There are 3,600 (60×60) seconds in an hour. To convert to miles an hour, first divide your value in centimeters by 30.5 to convert to feet per second. Then, multiply by 3,600 to get feet per hour. Finally, divide by 5,280 to get miles per hour.

What's Going On

Ball speed will vary depending on the pitcher's arm and the conditions of the individual procedure.

Connections

The momentum of a body is the product of its mass and velocity. When a system of bodies undergoes an explosion or collision, individual bodies in the system may experience changes in their momentum, but the total momentum of the system before and after the event will be the same. This principle is known as conservation of momentum. Knowledge of this principle and the known laws under which energy is conserved make it possible to calculate physical quantities—such as velocities—in situations in which they cannot be measured directly. In this project, you used these principles to calculate your softball-pitching speed.

Safety Precautions

READ AND COPY BEFORE STARTING ANY EXPERIMENT

Experimental science can be dangerous. Events can happen very quickly while you are performing an experiment. Things can spill, break, even catch fire. Basic safety procedures help prevent serious accidents. Be sure to follow additional safety precautions and adult supervision requirements for each experiment. If you are working in a lab or in the field, do not work alone.

This book assumes that you will read the safety precautions that follow, as well as those at the start of each experiment you perform, and that you will *remember* them. These precautions will not always be repeated in the instructions for the procedures. It is up to you to use good judgment and pay attention when performing potentially dangerous procedures. Just because the book does not always say "be careful with hot liquids" or "don't cut yourself with the knife" does not mean that you should be careless when simmering water or stripping an electrical wire. It *does* mean that when you see a special note to be careful, it is extremely important that you pay attention to it. If you ever have a question about whether a procedure or material is dangerous, stop to find out for sure that it is safe before continuing the experiment. To avoid accidents, always pay close attention to your work, take your time, and practice the general safety procedures listed below.

PREPARE

- Clear all surfaces before beginning work.
- Read through the whole experiment before you start.
- Identify hazardous procedures and anticipate dangers.

PROTECT YOURSELF

- Follow all directions step by step; do only one procedure at a time.
- Locate exits, fire blanket and extinguisher, master gas and electricity shut-offs, eyewash, and first-aid kit.
- Make sure that there is adequate ventilation.
- Do not horseplay.
- Wear an apron and goggles.
- Do not wear contact lenses, open shoes, and loose clothing; do not wear your hair loose.
- Keep floor and work space neat, clean, and dry.
- Clean up spills immediately.
- Never eat, drink, or smoke in the laboratory or near the work space.
- Do not taste any substances tested unless expressly permitted to do so by a science teacher in charge.

USE EQUIPMENT WITH CARE

- Set up apparatus far from the edge of the desk.
- Use knives and other sharp or pointed instruments with caution; always cut away from yourself and others.
- Pull plugs, not cords, when inserting and removing electrical plugs.
- Don't use your mouth to pipette; use a suction bulb.
- Clean glassware before and after use.
- Check glassware for scratches, cracks, and sharp edges.
- Clean up broken glassware immediately.

- Do not use reflected sunlight to illuminate your microscope.
- Do not touch metal conductors.
- Use only low-voltage and low-current materials.
- Be careful when using stepstools, chairs, and ladders.

USING CHEMICALS

- Never taste or inhale chemicals.
- Label all bottles and apparatus containing chemicals.
- Read all labels carefully.
- Avoid chemical contact with skin and eyes (wear goggles, apron, and gloves).
- Do not touch chemical solutions.
- Wash hands before and after using solutions.
- Wipe up spills thoroughly.

HEATING INSTRUCTIONS

- Use goggles, apron, and gloves when boiling liquids.
- Keep your face away from test tubes and beakers.
- Never leave heating apparatus unattended.
- Use safety tongs and heat-resistant mittens.
- Turn off hot plates, bunsen burners, and gas when you are done.
- Keep flammable substances away from heat.
- Have a fire extinguisher on hand.

WORKING WITH MICROORGANISMS

- Assume that all microorganisms are infectious; handle them with care.
- Sterilize all equipment being used to handle microorganisms.

GOING ON FIELD TRIPS

- Do not go on a field trip by yourself.
- Tell a responsible adult where you are going, and maintain that route.
- Know the area and its potential hazards, such as poisonous plants, deep water, and rapids.
- Dress for terrain and weather conditions (prepare for exposure to sun as well as to cold).
- Bring along a first-aid kit.
- Do not drink water or eat plants found in the wild.
- Use the buddy system; do not experiment outdoors alone.

FINISHING UP

- Thoroughly clean your work area and glassware.
- Be careful not to return chemicals or contaminated reagents to the wrong containers.
- Don't dispose of materials in the sink unless instructed to do so.
- Wash your hands thoroughly.
- Clean up all residue, and containerize it for proper disposal.
- Dispose of all chemicals according to local, state, and federal laws.

BE SAFETY-CONSCIOUS AT ALL TIMES