AAPT Apparatus Competition, Apparatus Description

Apparatus Title: **Compass and Wire Holder for Detecting Currents**

Abstract (50-75 words)
A good method for detecting and comparing currents in wires is to align a compass north-south and lay a wire along the length of the compass needle. Current passing through the wire deflects the needle, and larger deflections indicate greater currents. A vector analysis can produce numerical results.

Aligning the compass and wire and making other circuit changes at the same time is difficult. This holder makes it easy for students to work individually.

Construction of Apparatus:
(For instructions including diagrams, see attached instruction sheet.)
1. Cut a block of nominal 1” lumber to fit the compass you will be using. For the compasses PASCO supplies with their CASTLE kits, this is 1 7/8” x 2 1/4” (4.7 cm x 5.7 cm). Draw a centerline along the longer dimension of the block.
2. Also cut four slats from a jumbo craft stick (about 3/4” x 6”), two 7/8” (2.2 cm) long, and two 1 1/2” (3.8 cm) long. In the two longer slats, make a triangular notch at one end and cut a slot the width of the wires to be used from the center of the notch to the center of the slat. All of these operations can be performed on a stack of several parts at a time using a bandsaw.
3. If your compass has a hole in the base, like the PASCO compass, also cut a 7/8” (2.2 cm) length of 12 ga solid copper or aluminum wire. Drill a 5/64” hole 5/8” (1.6 cm) deep in the block and press the wire into it so that the hole in the compass base will fit over the wire to position the compass. For the PASCO compass, drill this hole on the centerline 3/8” (1.1 cm) from one end of the block.
4. Use tacky glue (or hot melt glue if don’t want to wait for tacky glue to dry) to attach the two longer slats to the block at opposite ends of the centerline. Align the unnotched end of the slats with the bottom of the block, being sure that the wire is visible when you look through both slots. The centerline will be the north-south line. Glue the two shorter slats at the east and west positions of the compass, extending about 1/8” (3 mm) above the top surface of the block. The slats and the Cu or Al wire will hold the compass in place.

Use of Apparatus:
5. To use the device, place the hole in the compass over the Cu or Al wire and rotate the whole device (and the compass top if yours rotates) until the compass needle and the N-S arrow printed on the compass both lie along the centerline. Use a loop of masking tape under the device to attach it to the table in this position.
6. Stretch the wire you are using between the two slits, so that it lies along the compass needle. When current passes through the wire, the needle should deflect. Record the position of the compass needle. The first wire can easily be removed and replaced with another to compare the deflections produced by the currents in as many wires as you wish to investigate. Keep other wires and iron objects well away.
Name: Bill Franklin

AAPT Apparatus Competition, Apparatus Description
Parts List

Apparatus Title: **Compass and Wire Holder for Detecting Currents**

Equipment and costs required to construct apparatus:

<table>
<thead>
<tr>
<th>Item</th>
<th>Source</th>
<th>Part number</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>1” lumber (4.7 cm x 5.7 cm)</td>
<td>building supply</td>
<td>8’ 1x4 about $3</td>
<td>$0.01</td>
</tr>
<tr>
<td>Jumbo craft stick (one)</td>
<td>craft store</td>
<td>500 about $5</td>
<td>$0.01</td>
</tr>
<tr>
<td>Tacky glue (few drops)</td>
<td>craft store</td>
<td>4 oz about $1</td>
<td>$0.01</td>
</tr>
<tr>
<td>16 ga. Al or Cu wire (2.2 cm)</td>
<td>building supply</td>
<td>1 ft about $0.10</td>
<td>$0.01</td>
</tr>
<tr>
<td>Compass (one)</td>
<td>PASCO</td>
<td>EM-8631A, 5 for $25</td>
<td>$5.00</td>
</tr>
</tbody>
</table>

**Total Cost** $5.04

*Prices do not include shipping or tax.*
Compass and Wire Holder for Detecting Currents
© Bill Franklin, 6/16/05

For those using CASTLE materials or anyone else who wants students to detect and compare currents in wires, a good method is to align a compass north-south and lay a wire along the length of the compass needle. When a direct current passes through the wire, the needle will be deflected, and larger deflections will indicate greater currents. If numerical results are required, a vector analysis can be done. Since this would be done at an early stage in studying electricity, the device could not be calibrated as an ammeter by calculation. However, it could be calibrated by comparison to a standard ammeter, if one wanted to outfit the whole class with ammeters, using only one commercial meter.

Aligning the compass and wire and making other circuit changes at the same time requires enough hands and eyes that it is difficult to accomplish with only one or even two students. The holder described here, makes it easy for students to work individually.

1. Cut a block of nominal 1" lumber to fit the compass you will be using. For the compasses PASCO supplies with their CASTLE kits, this is 1 7/8" x 2 1/4" (4.7 cm x 5.7 cm). Draw a centerline along the longer dimension of the block.

2. Also cut four slats from a jumbo craft stick (about 3/4" x 6"), two 7/8" (2.2 cm) long, and two 1 1/2" (3.8 cm) long. In the two longer slats, make a triangular notch at one end and cut a slot the width of the wires to be used from the center of the notch to the center of the slat. All of these operations can be performed on a stack of several parts at a time using a bandsaw.

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Name: Bill Franklin

AAPT Apparatus Competition, Apparatus Description

Apparatus Title: Shot Drop Lab:
Converting Gravitational Potential Energy to Thermal Energy

Abstract (50-75 words)
An old standby for finding the mechanical equivalent of heat is to repeatedly invert a mailing tube filled with metal shot and measure the temperature increase of the shot. Careful measurements convinced me that the warming was due more to the students’ warm hands than to the loss of gravitational energy. This apparatus is designed to reduce extraneous effects and give an honest, if imprecise, result.

Construction of Apparatus:
(For instructions including diagrams, see attached instruction sheet.)
Parts:
A. 7 3/4" length of fluorescent tube cover (2)
B. 1 1/4" x 1 1/4" x 1/2" PVC tee
C. Walgreens pill bottle that fits into part A (2)
D. 3 1/2" x 2 5/8" x 1 1/2" wood block with holes
E. 1/4" x 1" thumb screw
F. axle: 4" length of 1/2" PVC pipe, one end plugged
G. handle: 4" length of 1/2" PVC pipe
H. 1/2" PVC elbow
I. 6 1/2" x 6" piece of aluminized bubble wrap (2)
J. 1 1/2" x 3" piece of aluminized bubble wrap
K. rubber band

Also needed: hot glue & gun, metal shot, clear package tape, temperature probe, drill & bits to fit probe. PVC cement is optional.

Building the Apparatus
1. Slip one of the tubes (A) into an end of the tee (B). Run a bead of hot melt around the joint. Repeat with the other tube in the other end.

2. Cut two circles from the small piece of bubble wrap (J) and cut a small X in the center of one. Glue these into the pill bottles (C) about 2 mm below the top. (A probe will be pushed through the X later.)

3. Screw the top on the bottle whose circle does not have the X cut, push the bottle into the end of a tube, and run a bead of hot melt glue around the joint. Do NOT add the other bottle until the probe has been fitted to it.

4. If your temperature probe has a protective steel case, drill holes in the bottle cap and bottom to hold the probe in place, poking through the bubble wrap and out of the cap about 2". Make the fit tight enough to keep the probe from slipping out of place during the experiment.

5. If your probe is unprotected, such as the thermistor supplied with the Vernier CBL, then make a cover for it from a soda straw. Drill holes in the bottle cap and bottom to fit the straw, and hot glue the straw in place, poking through the bubble wrap and extending about 2 1/2" beyond the cap. Cut off a screw anchor or use a short piece of dowel to plug the cap end of the straw. Hot glue it in place. Slip the probe in and use a bit of tape to hold it to the end of the straw.
6. Once the probe is in place, pour metal shot into the tube, and hot glue the bottle containing the probe into the open end of the tube as shown in steps 4 and 5b. To ensure that the shot is absorbing much more thermal energy than the container, fill the lower tube at least half full of shot. (Because denser metals have lower specific heat capacities, comparable results are obtained with about the same volume.)

7. The 6.5" side of an aluminized bubble wrap sheet (I) is a little smaller than a transparent tube's circumference, so that when you wrap one around one of the tubes there will be a narrow gap that will allow you to see what is inside. Place the gap 90 degrees away from the tee side arm, and use an 8" length of clear package tape across the gap to tape the sheet in place. Repeat with the other sheet, lining the gaps up.

8. The wood block (D) has three holes drilled in it. A 7/8" hole runs from the top to bottom with its center about 1" from the near (back) edge and about 7/8" from the right edge. A 7/32" hole is drilled from the near (back) side to the center of the 3/4" hole. Screw the thumb screw into the smallest hole. This will hold the apparatus to a vertical lab support pole.

9. Glue the open end of the axle (F) into one end of the elbow (H), and glue the handle (G) into the other end, using PVC cement or hot glue.

10. Push the plugged end of the axle through the 7/8" hole in the block (D) and on into the side arm of the tee (B). If you added shot at step 6, press the axle firmly into the tee. If not, you can add shot through the tee side arm before pressing this joint tightly. Don't glue it in any case, so that shot can be removed or added through the side arm hole in the future. Note that the probe wire is attached to the tee with a rubber band (K) to keep it from flopping about during the flipping.

Use of Apparatus:

Slide the 3/4" hole in the block over a vertical support pole and tighten it to the pole with the thumb screw. Be sure that the probe wire will not hit the table or anything else when the apparatus is tipped back and forth to make the shot drop. To tip the apparatus, hold the handle. This will minimize any heating of the shot by conduction from your hand. The aluminized bubble wrap will help to minimize both radiation and conduction to or from the surroundings. The narrow gap in the bubble wrap allows you to see the level of the shot and the position of the bottle caps. Use a meter stick to measure the vertical distance from the top of the shot to the bottom of the upper bottle cap. This is the distance the shot can fall when the device is inverted. Invert it, and make this measurement again. Because the probe has some volume, these two measurements may not agree precisely. Use their average as h, the distance of fall.

Collecting Temperature Data

I recommend collecting data at 1 second intervals for a fixed time period of not more than 5 minutes. Flip the apparatus once per second, with one member of the group calling out seconds. By using one flip per second, the slope of the temperature vs. time graph will also be the temperature rise per flip.

I would have students figure out that the lost gravitational potential energy, nmgh, ends up as thermal energy, mCΔT, where n is the number of flips, and C is the specific heat capacity of the shot. (Al 900, Fe 470, Cu 390, Pb 130, all in J/kg K) If they assume energy conservation and take C to be the unknown, then they can solve for C = ngh/T or C = gh/(T/n) = gh/temperature change per flip.

The temperature change per flip is quite small, and you need to have a large enough temperature change to get a decent estimate for the slope of the graph. This takes several hundred flips. But the effect we seek to measure can easily be dwarfed by extraneous exchanges of thermal energy with the surroundings. If you continue the experiment much over 5 minutes, the shot will warm enough that it will approach an equilibrium temperature, at which it loses energy to the surroundings as fast as you add it. For this reason, repeated trials tend to become increasingly inaccurate. Give the shot plenty of time to return to room temperature between trials. One trial per class period with a given piece of apparatus is best.

Don't be surprised by values off as much as fifty percent. An effort was made to minimize the mass of those parts of the apparatus being heated along with the shot. It is much less than the mass of the shot, but it is not negligible. The biggest problem remains that of exchanging energy with the surroundings.
Name: Bill Franklin

AAPT Apparatus Competition, Apparatus Description
Parts List

Apparatus Title: **Shot Drop Lab:**
Converting Gravitational Potential Energy to Thermal Energy

Equipment and costs required to construct apparatus:

<table>
<thead>
<tr>
<th>Item</th>
<th>Source</th>
<th>Part number</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>7 3/4&quot; of fluorescent tube cover (2)</td>
<td>building supply</td>
<td>about $3 for 4’</td>
<td>$1.00</td>
</tr>
<tr>
<td>1 1/4&quot; x 1 1/4&quot; x 1/2&quot; PVC tee</td>
<td>Lowes</td>
<td>$1.47</td>
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<td>pill bottle that fits into tube cover (2)</td>
<td>Walgreens</td>
<td>free with pills</td>
<td>$0.00</td>
</tr>
<tr>
<td>2 5/8&quot; of 2x4 lumber with holes</td>
<td>building supply</td>
<td>about $3 for 8’</td>
<td>$0.35</td>
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<tr>
<td>1/4&quot; x 1&quot; thumb screw</td>
<td>Home Depot</td>
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<tr>
<td>8&quot; length of 1/2&quot; PVC pipe</td>
<td>building supply</td>
<td>about $3 for 10’</td>
<td>$0.25</td>
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<td>1/2&quot; PVC elbow</td>
<td>building supply</td>
<td>$1.30 for 10</td>
<td>$0.13</td>
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<tr>
<td>8&quot; x 12&quot; of aluminized bubble wrap</td>
<td>Home Depot</td>
<td>$10 for 20 sq ft</td>
<td>$0.35</td>
</tr>
<tr>
<td>rubber band, size 33</td>
<td>office supply</td>
<td>$1 for ¼ lb</td>
<td>$0.01</td>
</tr>
<tr>
<td>Digital thermometer, 0.1 C precision</td>
<td>Science Kit</td>
<td>31054-00</td>
<td>$25.95</td>
</tr>
<tr>
<td>Aluminum shot, 250 g (1/2 of pkg.)</td>
<td>Science Kit</td>
<td>9400806</td>
<td>$5.00</td>
</tr>
</tbody>
</table>

Prices do not include shipping or tax.

Total Cost: $35.39
Shot Drop Lab:
Converting Gravitational Potential Energy to Thermal Energy
© Bill Franklin, 2005, revised 2/27/2005, physicsnerd@yahoo.com

Parts:
A. 7 3/4" length of fluorescent tube cover (2)
B. 1 1/4" x 1 1/4" x 1/2" PVC tee
C. Walgreens pill bottle that fits into part A (2)
D. 3 1/2" x 2 5/8" x 1 1/2" wood block with holes
E. 1/4" x 1" thumb screw
F. axle: 4" length of 1/2" PVC pipe, one end plugged
G. handle: 4" length of 1/2" PVC pipe
H. 1/2" PVC elbow
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K. rubber band

Also: hot glue & gun, metal shot, clear package tape, temperature probe, drill & bits to fit probe. PVC cement is optional.

Building the Apparatus

Check the box as each step is completed.

☐ 1. Slip one of the tubes (A) into an end of the tee (B). Run a bead of hot melt around the joint. Repeat with the other tube in the other end.

☐ 2. Cut two circles from the small piece of bubble wrap (J) and cut a small X in the center of one. Glue these into the pill bottles (C) about 2 mm below the top. (A probe will be pushed through the X later.)

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11. Slide the 3/4" hole in the block over a vertical support pole and tighten it to the pole with the thumb screw. Be sure that the probe wire will not hit the table or anything else when the apparatus is tipped back and forth to make the shot drop. To tip the apparatus, hold the handle. This will minimize any heating of the shot by conduction from your hand. The aluminized bubble wrap will help to minimize both radiation and conduction to or from the surroundings. The narrow gap allows you to see the level of the shot and the position of the bottle caps. Use a meter stick to measure the vertical distance from the top of the shot to the bottom of the upper bottle cap. This is the distance the shot can fall when the device is inverted. Invert it, and make this measurement again. Because the probe has some volume, these two measurements may not agree precisely. Use their average as h, the distance of fall.

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Shot Drop Lab   page 2 of 2   © Bill Franklin, 2005   revised 4/27/2005
AAPT Apparatus Competition, Apparatus Description

Apparatus Title: Stacked Balls -
How a ball can bounce higher than its starting point.

Abstract (50-75 words)
An attention-grabbing demonstration is the amazingly high bounce of a ball atop another ball, or a stack of them. A tennis ball atop a basketball is an old favorite. The Astro-Blaster™ is a commercial version with a stack of four balls, which has been around a while, too. The system described here is an easily made and inexpensive stack of three “high bounce” balls obtained from Oriental Trading Co. (www.orientaltrading.com).

Construction of Apparatus:
(For instructions including diagram, see attached instruction sheet.)
Drill the small and medium sized balls to fit a stirrer straw, using a drill press with a short piece of 1/2” PVC pipe centered under the bit to hold the balls in place. Use a high rotational speed and drill slowly to get a clean hole. Insert the stirrer straw and snip it off about 2 mm shorter than the diameter of the ball (to get ball to ball, rather than straw to straw, collisions). The straw greatly reduces friction between the wire and the ball.
Cut a 4 1/2” (21.5 cm) length of straight 1/16” (1.6 mm) wire. Four of these can be cut from a marker flag, available at building supply stores for about $2/ten or $0.05 per device. Push the wire in to about the center of the large ball, being careful to keep it centered.

Use of Apparatus:
Begin the demonstration by holding the small ball (or an undrilled one to avoid questions about why the ball is drilled) over a hard surfaced, massive object. Ask the students to decide how high they think it will bounce, and to write their answer down (or to discuss it with a neighbor first). Most will say that it will bounce to a point as high as it started or a little less. Try it to check their answers. Note that it bounces not quite as high as it started.
A discussion of their reasoning should follow, making sure that they recognize that kinetic energy was nearly conserved during the collision and that momentum was conserved as well. The ball rebounded because its mass was much smaller than that of the surface, whose velocity after the collision was near zero. Be sure that they understand that the surface velocity could not have been exactly zero if momentum was conserved, but that it was so small that the ball had virtually all of the kinetic energy of the system after the collision. This was somewhat less that that before the collision, indicating that some kinetic energy was transformed into thermal energy.
At this point thread the medium ball, then the small ball onto the wire, hold the stack of balls above the surface, and ask how high the top ball will bounce. Students know the answer is going to be different, but are often unsure of what to expect. I just collect their answers and then drop the stack, without further prior discussion. (Hold the end of the wire loosely so that the stack of balls will hang with their centers of mass along a vertical line below your fingers. Goggles are suggested for the demonstrator and any nearby observers.) Almost everyone is surprised to see how high the small ball goes, unless they have seen a prior demonstration.
Ask them to consider each collision in turn. The first collision (large ball and surface) is the same as before. Students should expect the ball to bounce back with a moderate loss of speed. The second collision (large and medium balls) is between balls traveling almost the same speed in opposite directions. Clearly, the large ball will “win,” but the mass ratio and the elasticity must be known to make a definite prediction.

I wouldn’t take class time for a detailed calculation, although it could be made a homework challenge for capable students. Students can easily check the possibility that the large ball might stop, while the medium ball reverses its direction at twice the speed. Since the mass ratio is three, this possibility would conserve momentum and kinetic energy, assuming both collisions were perfectly elastic.

The last collision (medium and small balls) has a mass ratio nearer two. Again, students could check for conservation of momentum and kinetic energy if the medium ball were to stop and the small ball bounced upward at three times the initial speed. Applying energy conservation to the ball-earth system after the last collision, we would expect a speed around three times that acquired by falling to result in a final height about nine times greater than the fall. Of course, the mass ratio isn’t quite two, and the collisions are not perfectly elastic, but the large and medium balls almost stop, while the small ball bounces quite high, so our crude approximations are not very far off.

References are listed below for articles in The Physics Teacher dealing with this demonstration.
Name: Bill Franklin

AAPT Apparatus Competition, Apparatus Description
Parts List

Apparatus Title: **Stacked Balls - How a ball can bounce higher than its starting point.**

Equipment and costs required to construct apparatus:

<table>
<thead>
<tr>
<th>Item</th>
<th>Source</th>
<th>Part number</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>3/4&quot; (19 mm) high bounce ball (one)</td>
<td>Oriental Trading Co.</td>
<td>12/518</td>
<td>$0.04</td>
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<td>1&quot; (25 mm) high bounce ball (one)</td>
<td>Oriental Trading Co.</td>
<td>39/1111</td>
<td>$0.07</td>
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<tr>
<td>1 3/8&quot; (35 mm) high bounce ball (one)</td>
<td>Oriental Trading Co.</td>
<td>12/154</td>
<td>$0.33</td>
</tr>
<tr>
<td>Marker flag (1/4 of one)</td>
<td>building supply</td>
<td>about $8/100</td>
<td>$0.02</td>
</tr>
<tr>
<td>Stirrer straw (1/3 of one)</td>
<td>grocery store</td>
<td>about $1/100</td>
<td>$0.01</td>
</tr>
</tbody>
</table>

**Prices do not include shipping or tax.**

**Total Cost** $0.47
Stacked Balls
How a ball can bounce higher than its starting point.
© Bill Franklin, 6/18/05

An attention-grabbing demonstration is the amazingly high bounce of a ball atop another ball, or a stack of them. A tennis ball atop a basketball is an old favorite. The Astro-Blaster™ is a commercial version with a stack of four balls, which has been around a while, too. The system described here is an easily made and inexpensive stack of three “high bounce” balls obtained from Oriental Trading Co. (www.orientaltrading.com).

The balls I used are:

3/4” (19 mm) 12/518 $5.95/gross ($0.04 each) 2.9 g with hole and straw

1” (25 mm) 39/1111 $9.95/gross ($0.07 each) 6.7 g with hole and straw

1 3/8” (35 mm) 12/154 $3.95/dozen ($0.33 each) 20.1 g with wire

Drill the small and medium sized balls to fit a stirrer straw, using a drill press with a short piece of 1/2” PVC pipe centered under the bit to hold the balls in place. Use a high rotational speed and drill slowly to get a clean hole. Insert the stirrer straw and snip it off about 2 mm shorter than the diameter of the ball (to get ball to ball, rather than straw to straw, collisions). The straw greatly reduces friction between the wire and the ball.

Cut a 4 1/2” (21.5 cm) length of straight 1/16” (1.6 mm) wire. Four of these can be cut from a marker flag, available at building supply stores for about $2/ten or $0.05 per device. Push the wire in to about the center of the large ball, being careful to keep it centered.

Begin the demonstration by holding the small ball (or an undrilled one to avoid questions about why the ball is drilled) over a hard surfaced, massive object. Ask the students to decide how high they think it will bounce, and to write their answer down (or to discuss it with a neighbor first). Most will say that it will bounce to a point as high as it started or a little less. Try it to check their answers. Note that it bounces not quite as high as it started.

A discussion of their reasoning should follow, making sure that they recognize that kinetic energy was nearly conserved during the collision and that momentum was conserved as well. The ball rebounded because its mass was much smaller than that of the surface, whose velocity after the collision was near zero. Be sure that they understand that the surface velocity could not have been exactly zero if momentum was conserved, but that it was so small that the ball had virtually all of the kinetic energy of the system after the collision. This was somewhat less that that before the collision, indicating that some kinetic energy was transformed into thermal energy.

At this point thread the medium ball, then the small ball onto the wire, hold the stack of balls above the surface, and ask how high the top ball will bounce. Students know the answer is going to be different, but are often unsure of what to expect. I just collect their answers and then drop the stack, without further discussion. (Hold the end of the wire loosely so that the stack of balls will hang with their centers of mass along a vertical line below your fingers. Goggles are suggested for the demonstrator and any nearby observers.) Almost everyone is surprised to see how high the small ball goes, unless they have seen a prior demonstration.

Ask them to consider each collision in turn. The first collision (large ball and surface) is the same as before. Students should expect the ball to bounce back with a moderate loss of speed. The second collision (large and medium balls) is between balls traveling almost the same speed in opposite directions. Clearly, the large ball will “win,” but the mass ratio and the elasticity must be known to make a definite prediction.

I wouldn’t take class time for a detailed calculation, although it could be made a homework challenge for capable students. Students can easily check the possibility that the large ball might stop, while the medium ball reverses its direction at twice the speed. Since the mass ratio is three, this possibility would conserve momentum and kinetic energy, assuming both collisions were perfectly elastic.

The last collision (medium and small balls) has a mass ratio nearer two. Again, students could check for conservation of momentum and kinetic energy if the medium ball were to stop and the small ball bounced upward at three times the initial speed. Applying energy conservation to the ball-earth system after the last collision, we would expect a speed around three times that acquired by falling to result in a final height about nine times greater than the fall. Of course, the mass ratio isn’t quite two, and the collisions are not perfectly elastic, but the large and medium balls almost stop, while the small ball bounces quite high, so our crude approximations are not very far off.

References are listed below for articles in The Physics Teacher dealing with this demonstration.