Question 2

12 points total | **Distribution of points**

Note: For parts (a) and (b), quantities that are proportional to mechanical energy, rather than energy itself, may be calculated, because terms like *g* or the ball's mass do not change during the experiment.

(a) 4 points

Parts i, ii, and iii are scored as a unit.

For an overall plan in which quantities are measured that could be used to compare mechanical energy before and after a collision with a hard surface — 1 point

For a conceptually plausible plan to measure pre- and post-collision positions and/or speeds that could be used to compare pre- and post-collision mechanical energies, without extraneous equipment and/or measurements — 1 point

For having lab equipment and measurement procedures well specified — 1 point

For a procedure that includes trials of different pre-collision speeds, ranging from low speed to high speed (as is needed to test the student's hypothesis) — 1 point

Example 1:

i. The drop height of the ball and the bounce height.
ii. A meterstick to measure the heights and a video camera to record the ball's motion.
iii. Place the meterstick upright against the wall.
Drop the ball from 10 different drop heights, using the video camera to record the bounce heights.

Example 2:

i. The speed of the ball immediately before and immediately after it bounces.
ii. A photogate near the floor, at a height just above the diameter of the ball, to measure the ball's speed.
iii. Drop the ball through the photogate.
Record the speeds measured by the photogate before and after the bounce.
Change the drop height of the ball at least five times, covering a range of heights from "low" to "high."

(b) 4 points

For describing how to plot or otherwise represent the data in a way that could be used to test the hypothesis — 1 point

For describing how to compare the post-collision to pre-collision mechanical energy (or a plausible alternative) to quantify the elasticity of the collision — 1 point

For comparing the low-speed versus high-speed results — 1 point

For addressing the hypothesis with an analysis such as a slope, ratio, or difference — 1 point

Question 2 (continued)

	Distribution of points
(b) (continued)	
Example 1: Make a graph of the bounce height h_f as a function of the drop height h_i. If the data are consistent with the hypothesis, then the data will (1) lie close to the line $h_f = h_i$ for low drop heights, and (2) lie below this line for high drop heights.	
Example 2: Make a graph of $v_f^2 - v_i^2$ as a function of v_i, where v_f and v_i are the ball's speed just after and just before the bounce, respectively. If the data are consistent with the hypothesis, then $v_f^2 - v_i^2$ will (1) be close to zero for low speeds, and (2) be negative for high speeds.	

(c)

i. 2 points

For drawing a graph or table that shows that the low-speed collisions are nearly perfectly elastic	1 point
For drawing a graph or table that shows a violation of a physics principle for higher-speed collisions	1 point

Example for energy conservation:

A graph of the ratio $\dfrac{\text{Post-collision mechanical energy}}{\text{Pre-collision mechanical energy}}$ as a function of pre-collision speed, in which the graph stays near 1.0 for low initial speeds but becomes greater than 1.0 for high-speed collisions.

ii. 2 points

For a correct description of the aspect of the graph or table that shows a violation of the physical principle indicated	1 point
For a correct explanation of why the representation shows a violation of the physical principle indicated	1 point

Example for energy conservation using the graph described above: The value of the energy ratio shows a violation of conservation of energy when it becomes greater than 1.0 because the final energy cannot be greater than the initial energy.

2. (12 points, suggested time 25 minutes)

A new kind of toy ball is advertised to "bounce perfectly elastically" off hard surfaces. A student suspects, however, that no collision can be perfectly elastic. The student hypothesizes that the collisions are very close to being perfectly elastic for low-speed collisions but that they deviate more and more from being perfectly elastic as the collision speed increases.

(a) Design an experiment to test the student's hypothesis about collisions of the ball with a hard surface. The student has equipment that would usually be found in a school physics laboratory.

i. What quantities would be measured?

~~mass of the ball~~
height of ball before collision
height of ball after collision

ii. What equipment would be used for the measurements, and how would that equipment be used?

A tape measure would be used to measure the height of the ball at its peak before and after the collision.

iii. Describe the procedure to be used to test the student's hypothesis. Give enough detail so that another student could replicate the experiment.

1. Drop the ball at a height of 1 foot determined by tape measure and record height with the same tape measure.
2. Repeat 3 times
3. Repeat 1-2 with heights 2ft, 3ft, 5ft, 10 ft, and 15 ft.

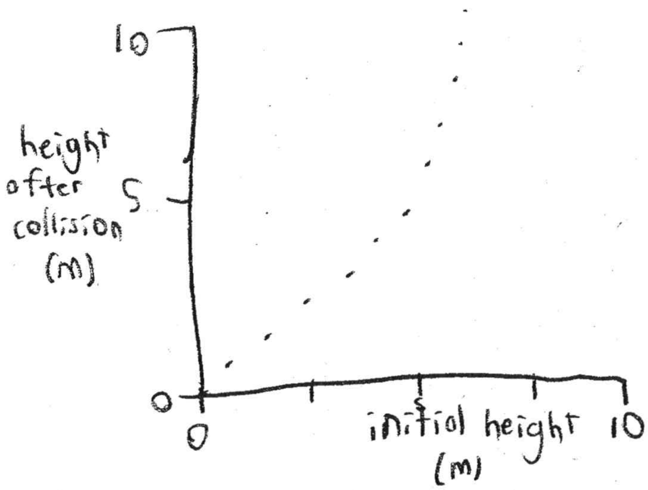
(b) Describe how you would represent the data in a graph or table. Explain how that representation would be used to determine whether the data are consistent with the student's hypothesis.

The X axis would be the height dropped from and the Y axis would be the new height. If the collison is elastic the data should be linear at a 1:1 ratio of the before and after heights. However, if the student's hypothesis is correct the data should deviate downward from this trendline at higher heights because the greater the height the more velocity produced upon collision.

GO ON TO THE NEXT PAGE.

(c) A student carries out the experiment and analysis described in parts (a) and (b). The student immediately concludes that something went wrong in the experiment because the graph or table shows behavior that is elastic for low-speed collisions but appears to violate a basic physics principle for high-speed collisions.

i. Give an example of a graph or table that indicates nearly elastic behavior for low-speed collisions but appears to violate a basic physics principle for high-speed collisions.



ii. State one physics principle that appears to be violated in the graph or table given in part (c)i. Several physics principles might appear to be violated, but you only need to identify one.

Briefly explain what aspect of the graph or table indicates that the physics principle is violated, and why.

Conservation of energy is being violated because the ball is getting higher after the collision than from when it was dropped. Because mass and acceleration due to gravity are constant that means the ball gained more energy after the collision and did not conserve it.

GO ON TO THE NEXT PAGE.

2. (12 points, suggested time 25 minutes)

A new kind of toy ball is advertised to "bounce perfectly elastically" off hard surfaces. A student suspects, however, that no collision can be perfectly elastic. The student hypothesizes that the collisions are very close to being perfectly elastic for low-speed collisions but that they deviate more and more from being perfectly elastic as the collision speed increases.

(a) Design an experiment to test the student's hypothesis about collisions of the ball with a hard surface. The student has equipment that would usually be found in a school physics laboratory.

i. What quantities would be measured?

Height of drop and height of bounce

ii. What equipment would be used for the measurements, and how would that equipment be used?

Meterstick to measure initial and final height.

Camera to replay for closer detail.

iii. Describe the procedure to be used to test the student's hypothesis. Give enough detail so that another student could replicate the experiment.

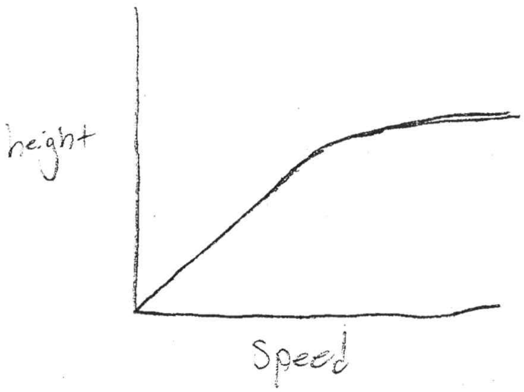
The student would drop the bouncy ball on a constant, hard surface from varying heights and measure the height it returns to. Record the experiments to get a closer measurement of the returning height and see if ball is rotating.

(b) Describe how you would represent the data in a graph or table. Explain how that representation would be used to determine whether the data are consistent with the student's hypothesis.

Make a graph of drop height vs bounce height and if the slope of the graph is constant and linear the ball is perfectly elastic. If it is very close to perfect at low heights but not perfect at higher heights, the student is correct.

(c) A student carries out the experiment and analysis described in parts (a) and (b). The student immediately concludes that something went wrong in the experiment because the graph or table shows behavior that is elastic for low-speed collisions but appears to violate a basic physics principle for high-speed collisions.

i. Give an example of a graph or table that indicates nearly elastic behavior for low-speed collisions but appears to violate a basic physics principle for high-speed collisions.



ii. State one physics principle that appears to be violated in the graph or table given in part (c)i. Several physics principles might appear to be violated, but you only need to identify one.

Briefly explain what aspect of the graph or table indicates that the physics principle is violated, and why.

The graph flattens out after a certain speed and violates the principle that energy is conserved because with increased velocity and constant mass the ball should continue to go higher. $KE = \frac{1}{2}mv^2$ but energy is not being conserved within the ball.

GO ON TO THE NEXT PAGE.

2. (12 points, suggested time 25 minutes)

A new kind of toy ball is advertised to "bounce perfectly elastically" off hard surfaces. A student suspects, however, that no collision can be perfectly elastic. The student hypothesizes that the collisions are very close to being perfectly elastic for low-speed collisions but that they deviate more and more from being perfectly elastic as the collision speed increases.

(a) Design an experiment to test the student's hypothesis about collisions of the ball with a hard surface. The student has equipment that would usually be found in a school physics laboratory.

i. What quantities would be measured?

- Height of the original drop
- Height of the bounce
- Mass of the ball
- Amount of time it takes to reach peak
- Initial velocity of drop

ii. What equipment would be used for the measurements, and how would that equipment be used?

Equipment necessary would be a scale to mass the ball, a meterstick to measure the height of the dropping location as well as the bounce, a stopwatch to time the bounces, and a projectile to shoot the ball out of for high-speed collisions

iii. Describe the procedure to be used to test the student's hypothesis. Give enough detail so that another student could replicate the experiment.

① Measure height of table
② Mass the ball
③ Drop ball from table height
④ Measure height of bounce
⑤ Measure time of bounce
⑥ Shoot ball out of projectile with high initial velocity
⑦ Repeat steps 3-6 for several trials
⑧ Record data in table

(b) Describe how you would represent the data in a graph or table. Explain how that representation would be used to determine whether the data are consistent with the student's hypothesis.

I would record the height of the bounces differently in a table for the low-speed collision and for the high-speed collision. In order for a collision to be elastic, both momentum ($p=mv$) and KE must be conserved ($K=\frac{1}{2}mv^2$). Thus, I would record the results of the different velocities with $\frac{\text{distance}}{\text{time}}$ calculations for both types of collisions to determine whether or not the student's hypothesis was correct.

GO ON TO THE NEXT PAGE.

(c) A student carries out the experiment and analysis described in parts (a) and (b). The student immediately concludes that something went wrong in the experiment because the graph or table shows behavior that is elastic for low-speed collisions but appears to violate a basic physics principle for high-speed collisions.

i. Give an example of a graph or table that indicates nearly elastic behavior for low-speed collisions but appears to violate a basic physics principle for high-speed collisions.

Low-speed collision

Height of drop	Height of bounce
3 meters	2.95 m
3 meters	2.98 m
3 meters	2.97 m

High-speed collisions

Height of drop	Height of bounce
3 meters	1.03 m
3 meters	1.0 m
3 meters	.85 m

Momentum is not conserved

ii. State one physics principle that appears to be violated in the graph or table given in part (c)i. Several physics principles might appear to be violated, but you only need to identify one.

Conservation of momentum

Briefly explain what aspect of the graph or table indicates that the physics principle is violated, and why.

Conservation of momentum states that the momentum before should always equal the momentum after ($P_b = P_A$). Thus, taking into account the effect of gravity, the bounce height should only be a little bit less than the original height. However, as seen in the table, the height was drastically smaller, violating the conservation of momentum principle.

GO ON TO THE NEXT PAGE.

Question 2

Overview

This question assessed learning objectives 4.C.1.1, 5.A.2.1, 5.B.2.1, 5.B.4.2, and 5.B.5.1. The question's main purpose was to evaluate a student's ability to communicate experimental design and experimental evidence that a collision is elastic. This question assessed experimental design and data analysis, energy conservation, work, and elastic/inelastic collisions.

Sample: P1 Q2 A
Score: 12

In part (a) all 4 points were earned for a conceptually plausible plan to measure the pre- and post-collision heights, specifying a procedure and lab equipment (a tape measure) to measure the heights, and using trials at different drop heights. Part (b) earned all 4 points for addressing the hypothesis, describing a relevant plot and comparison of pre- and post-collision data, and comparing the low-speed and high-speed results. In part (c)(i) both points were earned for a graph showing low-speed elastic collisions and a violation of energy conservation at high speeds. In (c)(ii) both points were earned for a correct description and explanation of why the graph indicates a violation of energy conservation.

Sample: P1 Q2 B
Score: 8

Parts (a) and (b) each earned all 4 points. No credit was earned in part (c). The graph of height versus speed does not represent the experiment and analysis in parts (a) and (b), so the explanation cannot address an apparent violation of a physics principle in the experiment described.

Sample: P1 Q2 C
Score: 4

Two points were earned in part (a) for including measurements to obtain pre- and post-collision values and for including trials at both low and high speed. Full credit was not awarded because the procedure includes time as an extraneous measurement and does not specify how the initial projected speed would be determined. In part (b) 1 point was earned for including a comparison of low versus high-speed collisions, but the response does not specify that the bounce heights would be compared before and after the collision. The representation as described cannot be used to test the hypothesis, and the hypothesis is not addressed with an analysis such as slope, ratio, or difference. One point was earned in part (c)(i) for data that shows a nearly elastic collision for low speed. However, the data for high-speed collisions does not appear to violate any physics principle and merely indicates that the collisions are inelastic. No points were earned in (c)(ii) because "conservation of momentum" is not being tested in the experiment.