
AP[®] Physics C: Mechanics

Sample Student Responses and Scoring Commentary

Question #3

DRAFT

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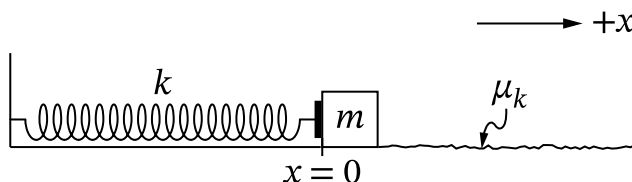
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Question 3

The following information applies to parts A and B.

3. A horizontal spring of known spring constant k is attached to a wall. A block of known mass m is placed on a horizontal surface next to but not attached to the spring. The spring is at its relaxed length when the block is at position $x = 0$, as shown in Figure 1. There is friction between the block and the surface only for positions $x > 0$.

Figure 1



A student is asked to experimentally determine the coefficient of kinetic friction μ_k between the block and the surface using a graph. The student is permitted to use only measurements from a meterstick.

Part A

- Indicate** quantities that could be measured by the student that would allow them to determine μ_k using a graph.
- Briefly **describe** a method to reduce experimental uncertainty for the measured quantities.

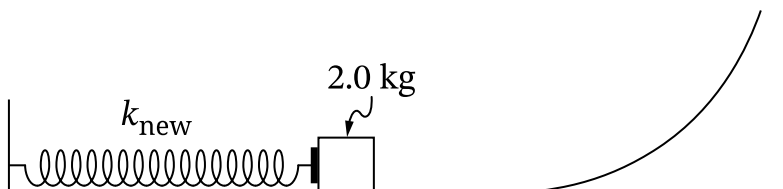
Part B

- Indicate** what quantities the student could graph on the horizontal and vertical axes to create a graph that can be used to determine μ_k .
- Briefly **describe** the relationship between μ_k and a feature of the graph from part B (i). Your answer may include an equation that relates μ_k and the chosen feature of the graph.

The following information applies to parts C and D.

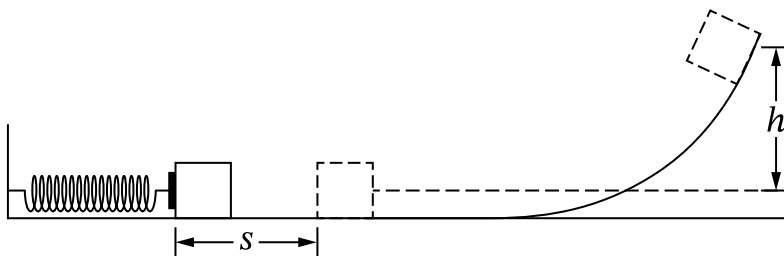
In a different experiment, the student is asked to determine the spring constant k_{new} of a new spring that is attached to a wall. A block of mass 2.0 kg is placed next to the spring on a surface where frictional forces are negligible. The surface is horizontal near the spring and slopes upward into a ramp to the right of the initial position of the block, as shown in Figure 2.

Figure 2



The student pushes the block, compressing the spring a distance s , as shown in Figure 3. The block is released from rest.

Figure 3



The student uses a meterstick to measure the maximum height h of the block on the ramp. The experiment is repeated several times with different compression distances s . The student's measurements of s and h are shown in Table 1.

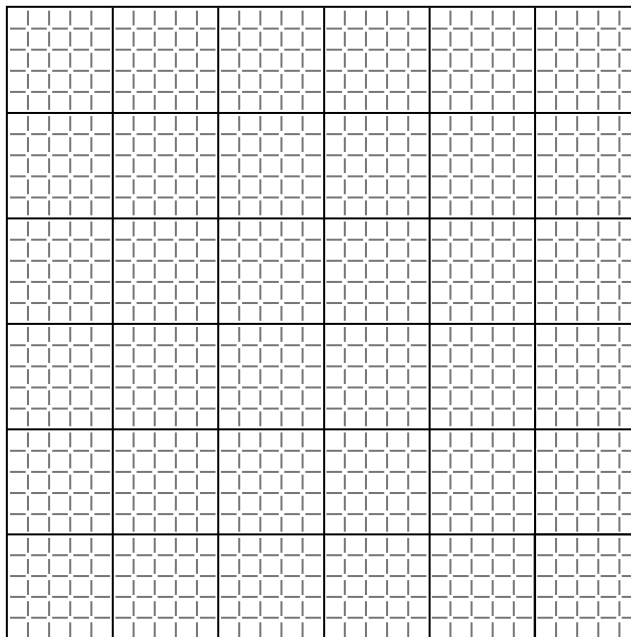
Table 1

s (m)	h (m)
0.020	0.02
0.040	0.04
0.060	0.13
0.080	0.18
0.100	0.33

Part C

- i. **Label** the axes of the grid provided with measured or calculated quantities. Include units, as appropriate. The graphed quantities should yield a linear graph that can be used to determine k_{new} .
- ii. On the grid provided, create a graph of the quantities indicated in part C (i).
- Clearly **label** the vertical and horizontal axes with numerical scales.
 - Plot** the corresponding data points on the grid.
 - Table 2 is provided in your booklet for scratch work and will not be scored.

Quantity (units, if appropriate)



Quantity (units, if appropriate)

- iii. **Draw** a best-fit line for the data graphed in part C (ii).

Part D

Using the best-fit line that you drew in part C (iii), **calculate** an experimental value for k_{new} .

Question 3 Experimental Design and Analysis (LAB)**10 points****General Scoring Notes****NR (No Response):** A score of NR is only assigned to responses that are blank.**A (i)** For indicating **both** of the following quantities: **Point A1**

- the spring compression, x
- the distance the block slides to the right of $x = 0$, d

Scoring Note: The variables given are chosen only for illustrating algebraic relationships in parts A and B. Responses may earn this point by using any clearly defined quantities or variables.

(ii) For describing a reasonable method of reducing experimental uncertainty **Point A2**

Examples of acceptable responses include the following:

- completing multiple trials using different values for the spring compression
- repeat measurements for each trial
- improved measurement technology to measure length more precisely

Example Response

Measure the distance the spring has been compressed from equilibrium. Release the block and measure the distance the block traveled from the point at which the block loses contact with the spring. Perform multiple trials using different initial spring compressions.

B (i) For indicating quantities that produce a graph that has a linear trend that can be used to determine μ_k **Point B1**

Examples of acceptable responses include the following:

- d as a function of x^2
- $\sqrt{d}$ as a function of x

Scoring Note: Responses that include the reciprocals of the preceding examples, in addition to other equivalent graphs also earn this point.

Scoring Note: This point may be earned independently of the response in part A.

(ii) For correctly describing the relationship of the slope of the best-fit line to μ_k **Point B2**

Examples of acceptable responses include the following:

Graph	Analysis
d as a function of x^2	slope = $\frac{k}{2\mu_k mg}$
$\sqrt{d}$ as a function of x	slope = $\sqrt{\frac{k}{2\mu_k mg}}$

Example Response

Plotting sliding distance on the vertical axis and the square of the compression distance on the horizontal axis will yield a linear graph. The slope of the graph will be equal to

$$\frac{k}{2\mu_k mg}, \text{ so } \mu_k = \frac{k}{2mg(\text{slope})}.$$

- C (i) For labeling the axes with appropriate quantities (including units) that could be plotted to produce a linear graph that can be used to determine k_{new} , such as: **Point C1**

- h as a function of s^2
- $\sqrt{h}$ as a function of s
- mgh as a function of $\frac{1}{2}s^2$

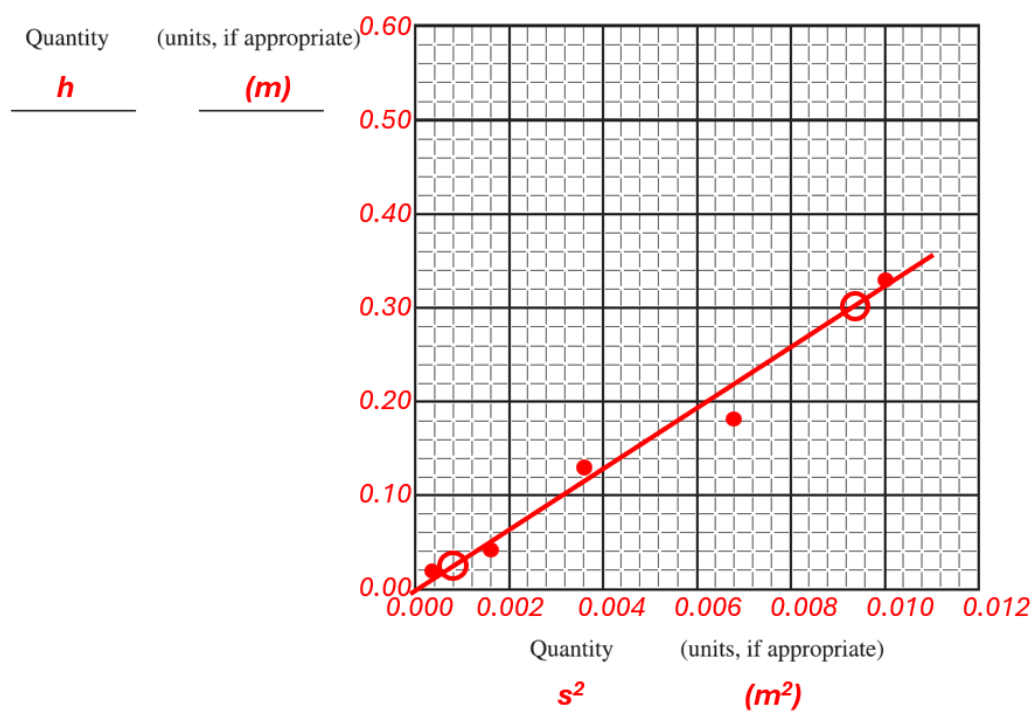
Scoring Note: Responses that include the reciprocals of the preceding examples, in addition to other equivalent graphs, also earn this point.

- (ii) For labeling **both** axes with a linear scale **Point C2**

For plotting data points consistent with the quantities labeled in part C (i) **Point C3**

- (iii) For drawing a line or curve that approximates the trend of the plotted data **Point C4**

Example Response



D For correctly relating the slope of the best-fit line to the value of k_{new}

Point D1

Examples of acceptable responses include the following:

Graph	Analysis
h as a function of s^2	$\text{slope} = \frac{k_{\text{new}}}{2mg}$
$\sqrt{h}$ as a function of s	$\text{slope} = \sqrt{\frac{k_{\text{new}}}{2mg}}$
mgh as a function of $\frac{1}{2}s^2$	$\text{slope} = k_{\text{new}}$

For calculating an experimental value of k_{new} within a range of 1150 N/m to 1400 N/m

Point D2

Example Response

$$mgh = \frac{1}{2}k_{\text{new}}s^2$$

$$\text{slope} = \frac{k_{\text{new}}}{2mg}$$

$$k_{\text{new}} = 2mg(\text{slope})$$

$$\text{slope} = \frac{0.30 \text{ m} - 0.024 \text{ m}}{0.0094 \text{ m}^2 - 0.0008 \text{ m}^2} = 32 \text{ m}^{-1}$$

$$k_{\text{new}} = 2mg(\text{slope})$$

$$k_{\text{new}} = 2(2.0 \text{ kg})(9.8 \text{ m/s}^2)(32 \text{ m}^{-1})$$

$$k_{\text{new}} = 1254 \text{ N/m}$$

Use a pencil or a pen with black or dark blue ink. Do NOT write your name. Do NOT write outside the box.

Question 3

PART A

- i. Measure compression distance of spring and measure max distance the block travels.
- ii. Repeat multiple trials for each spring compression distance to reduce uncertainty.

PART B

- i. Graph x , the distance the block travels, on vertical axis and graph A^2 where A is amplitude of spring on horizontal axis.
- ii. Slope can be analyzed with equation

$$\text{slope} = \frac{k}{2Mxmg} \text{ to find } k.$$

Use a pencil or a pen with black or dark blue ink. Do NOT write your name. Do NOT write outside the box.

Question 3

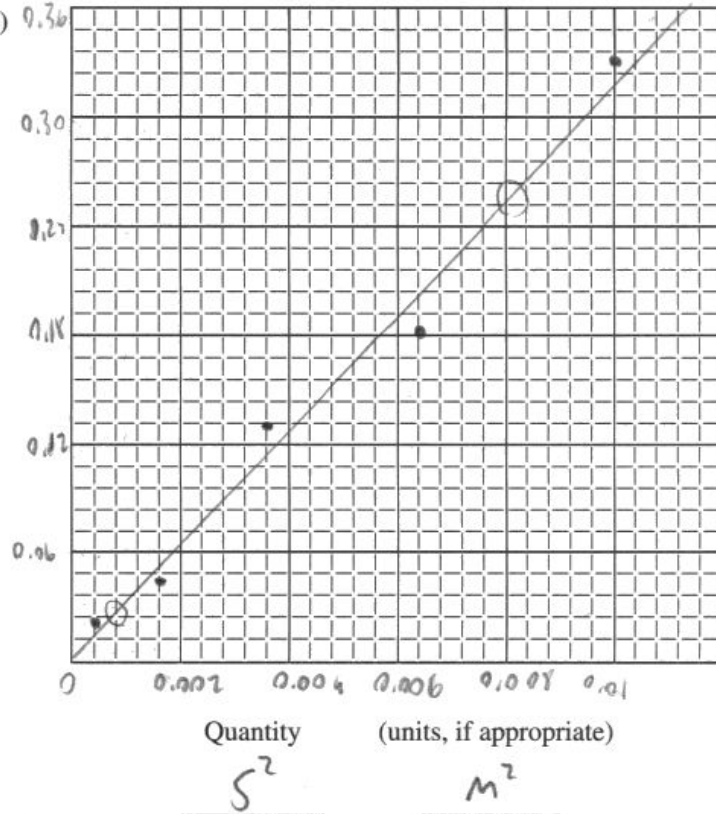
PART C

Quantity (units, if appropriate)

h m

Table 2
Anything you write in Table 2
will not be scored.

s^2	h
0.0024	0.02
0.0016	0.04
0.0036	0.13
0.0064	0.18
0.01	0.33



PART D

$$E_0 = E_F$$

$$U_1 = U_2$$

$$\frac{1}{2} k x^2 = m g h$$

$$\left(\frac{k}{2mg} \right) x^2 = h$$

$$m x = y$$

$$\text{slope} = \frac{k}{2mg}$$

$$(0.008, 0.252)$$

$$(0.0008, 0.024)$$

$$\frac{0.252 - 0.024}{0.008 - 0.0008} = \frac{k}{2 \cdot 2.10}$$

$$31.6667 \cdot 2.10 = k$$

$$k = 1266.67 \text{ N/m}$$

Go to Question 4 when you're done with this question.

Use a pencil or a pen with black or dark blue ink. Do NOT write your name. Do NOT write outside the box.

Question 3

PART A

- i) • Compressed length (Δx)
• Distance traveled on $x > 0$ (r)
- ii) • Take the relaxed spring length and subtract the compressed spring length to get Δx , making it easier to determine Δx

PART B

$$i) U_s = W_f = mgh$$

$$\frac{1}{2}k(\Delta x)^2 = M_k mgr \quad M_k = \frac{k(\Delta x)^2}{2mgr}$$

$$\text{Vertical: } k(\Delta x)^2 \text{ (Nm)}$$

$$\text{Horizontal: } 2mgr \text{ (Nm)}$$

- ii) The slope of the graph will equal the experimental value for M_k .

Use a pencil or a pen with black or dark blue ink. Do NOT write your name. Do NOT write outside the box.

Question 3

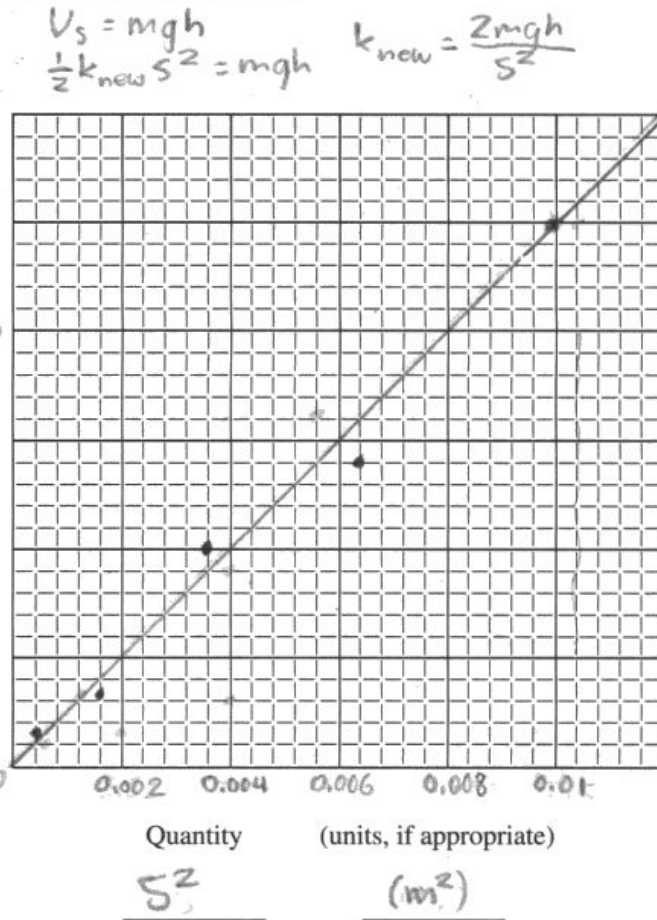
PART C

Quantity (units, if appropriate)
 $2mgh$ (J)

Table 2

Anything you write in Table 2 will not be scored.

s^2	$2mgh$
0.0004	0.784
0.0016	1.568
0.0036	5.096
0.0064	7.056
0.01	12.936



PART D

$$y = mx + b$$

$$K_{\text{new}} = m$$

$$y = 1252.5x - 0.023$$

$$K_{\text{new}} = 1253 \text{ N/m}$$

Go to Question 4 when you're done with this question.

Use a pencil or a pen with black or dark blue ink. Do NOT write your name. Do NOT write outside the box.

Question 3

PART A

$$\begin{array}{c} \leftarrow F_f \quad \text{to } k \Delta x \rightarrow \\ \downarrow F_g \\ \Sigma F = ma \\ F_{sp} - F_f = ma \end{array}$$

- (i) The student could measure the relaxed length of the spring, the stretched length of the spring, and the distance the block travels from $x=0$ to determine the coefficient of kinetic friction.
- (ii) Record the relaxed length of the spring. Compress the spring and record that length as well. Release the spring so that it pushes the block in the positive x -direction. When the block comes to rest, record the distance between the block's resting position and starting position $x=0$. Repeat with increasing compressions of the spring to reduce error.

PART B

$$\begin{aligned} (i) \quad \Sigma F &= ma & -F_f &= ma \\ F_{sp} &= ma & -\mu_k F_N &= m \left(\frac{k \Delta x}{m} \right) \\ a &= \frac{k \Delta x}{m} & -\mu_k mg &= \Delta x \end{aligned}$$

$$U_s = K = -W$$

$$\frac{1}{2} k \Delta x^2 = -F_f d$$

$$\frac{1}{2} k \Delta x^2 = -\mu_k F_N d$$

$$\Delta x^2 = -\frac{2\mu_k mg d}{k}$$

Graph Δx^2 , where Δx is the difference between the compressed and relaxed length of the spring, on the y -axis as a function of d , where d is the distance from the starting position, on the x -axis.

(ii) The slope of the graph will be $-2\mu_k mg/k$ where m , g , and k are all known constants that can be used to solve for μ_k .

Use a pencil or a pen with black or dark blue ink. Do NOT write your name. Do NOT write outside the box.

Question 3

PART C

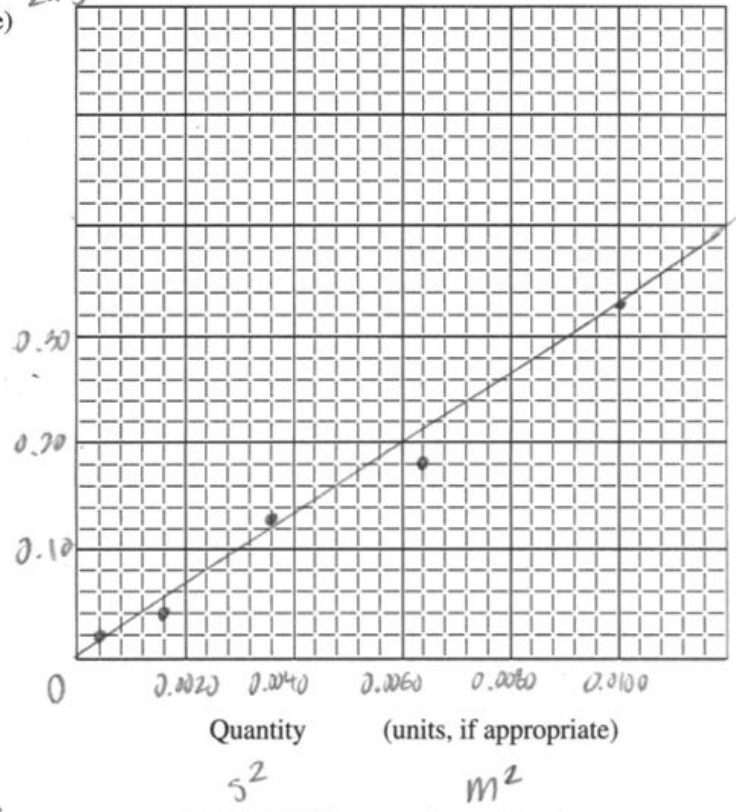
$U_s \rightarrow U_g$ $\frac{1}{2}k s^2 = mgh$
 $h = \frac{k}{2mg} s^2$

Quantity (units, if appropriate)
h m

Table 2

Anything you write in Table 2 will not be scored.

s^2	h
0.0004	0.02
0.0016	0.04
0.0036	0.13
0.0064	0.18
0.0100	0.33



PART D

$\text{slope} = \frac{k}{2mg}$ $\text{slope} = \frac{0.0120 - 0}{0.40 - 0} = 0.03 = \frac{k_{\text{new}}}{2(2)(10)}$
 $k = 1.20$

Go to Question 4 when you're done with this question.

Use a pencil or a pen with black or dark blue ink. Do NOT write your name. Do NOT write outside the box.

Question 3

PART A

$$ME_A + W_{NC} = ME_B$$

- i) Compress the spring a certain distance and measure
- 2) Allow the spring to oscillate and measure how far the spring goes each time
- 3) Repeat

ii) To reduce experimental error the student should do multiple trials by choosing multiple different distances to compress the spring to. The student can also repeat each trial 10 times and take the average value as their data points.

PART B

$$i) \Delta KE = \text{work}$$

$$(F_{\text{net}})d = \text{work}$$

$$U = \frac{1}{2} k x^2$$

$$2 \frac{U}{k} = x^2$$

$$x = \sqrt{\frac{2U}{k}}$$

ii) U_k is the slope

$$\frac{1}{2} k x^2 = U_k (mg)$$

$$F_N U_k = \Delta KE = \Delta PE \text{ for next compression}$$

$$\frac{\Delta \text{energy}}{F_N = mg} = U_k$$

The student should graph distance Spring compressed squared (x^2) times 10 m/s on the y axis. And the mass times 10 m/s on the x axis.

$$U_k = \frac{\frac{1}{2} k x^2}{mg}$$

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Question 3

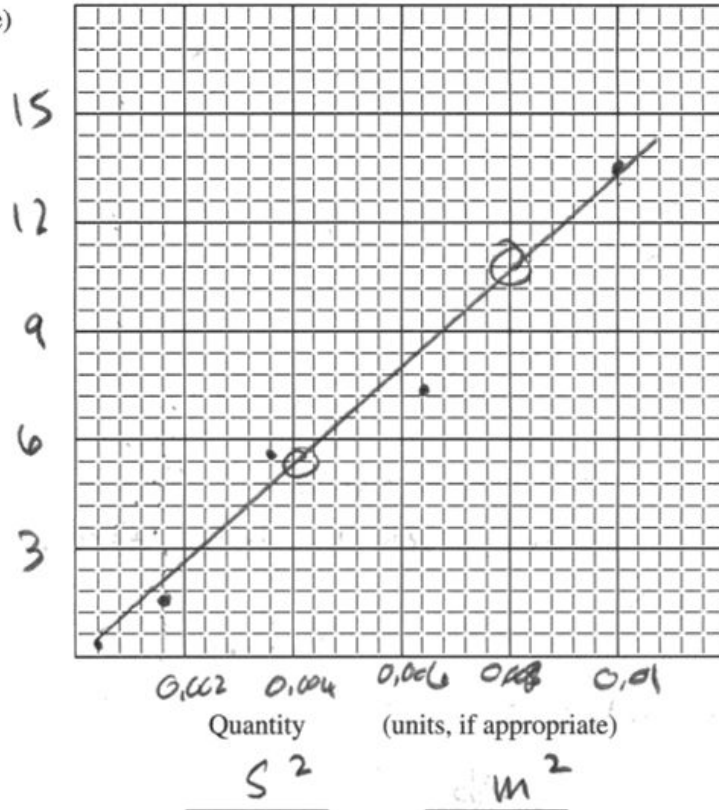
PART C

$$mgh = \frac{1}{2}kx^2 \quad \frac{2mgh}{x^2} = k$$

Quantity (units, if appropriate)
 $\frac{2mgh}{x^2}$ J

Table 2
 Anything you write in Table 2
 will not be scored.

$2mgh$	s^2
0.08	0.0004
1.6	0.0016
5.2	0.0036
7.2	0.0064
13.2	0.01



PART D

$$k_{\text{new}} = \frac{2mgh}{x^2}$$

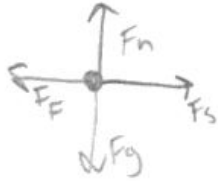
$$\frac{10.5 - 5.4}{0.008 - 0.004} = 1275$$

Go to Question 4 when you're done with this question.

Use a pencil or a pen with black or dark blue ink. Do NOT write your name. Do NOT write outside the box.

Question 3

PART A



$$F_n = mg$$

$$MF_n = -Kx$$

$$M = \frac{-Kx}{F_n}$$

$$F_s - F_f = ma$$

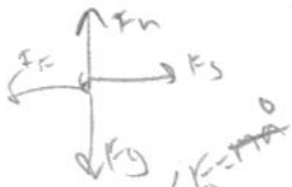
$$-Kx - Mg = ma$$

The student could push the block back a distance x and ~~then~~ then release the block & measure how far the block traveled before stopping.

Repeat the steps of pushing the block back & releasing 2-3 times to reduce experimental uncertainty. Compare the spring different distances and repeat the measurement 2-3 times.

PART B

$$M = \frac{Kx}{mg}$$



$$F_n = mg$$

$$\Sigma F_x = -F_f + F_s$$

$$-F_f + F_s = ma$$

$$\frac{-Mkg + Kx}{-m} = a$$

$$\frac{MKmg + Kx}{m} = a$$

$$\Delta E_{\text{initial}} = \Delta E_f = -W$$

$$U_s = \Delta y$$

$$\frac{1}{2}Kx^2 = mgh$$

$$\frac{Kx}{2} = \frac{mgh}{x}$$

$$K = \frac{2mgh}{x}$$

The slope of the graph is equal to the coefficient of kinetic friction μ_k

Use a pencil or a pen with black or dark blue ink. Do NOT write your name. Do NOT write outside the box.

Question 3

PART C

$$K = \frac{F_s}{x}$$

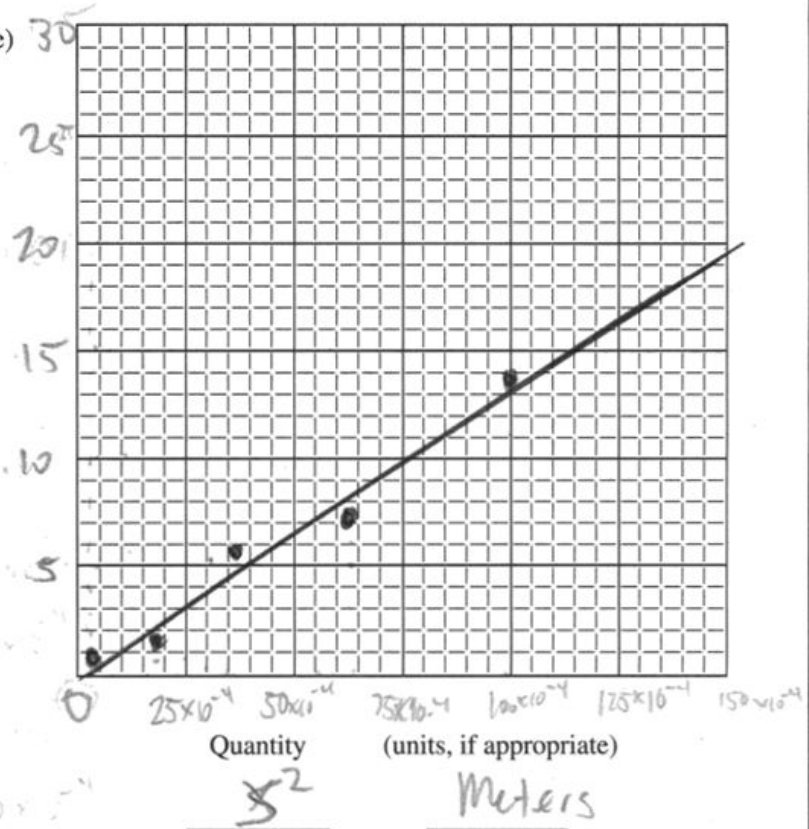
Quantity (units, if appropriate)

2mgh

Table 2

Anything you write in Table 2 will not be scored.

y	x
1.8	^{4 × 10⁻⁴} 0.0004
4.6	^{16 × 10⁻⁴} 0.0016
8.2	^{36 × 10⁻⁴} 0.0036
7.2	^{64 × 10⁻⁴} 0.0064
13.2	^{100 × 10⁻⁴} 0.01



PART D

$$\frac{\Delta y}{\Delta x} = K_{\text{new}}$$

$$\frac{75 \times 10^{-4} - 0}{10 - 0} = 75 \times 10^{-5} \text{ N}\cdot\text{m} = K_{\text{new}}$$

Go to Question 4 when you're done with this question.

Use a pencil or a pen with black or dark blue ink. Do NOT write your name. Do NOT write outside the box.

Question 3

PART A

Student can measure displacements from equilibrium in both friction and nonfriction area.

To reduce uncertainty, start in the same position on the nonfriction sides and repeat trials multiple times.

PART B

A student can use time and displacement graph. Horizontal axis is time while vertical one is displacement.

There is a sq root relationship between displacement and μ_k . $\mu_k = \frac{1}{2}kx^2$. Since displacement(x) is the variable in the equation, you would get μ_k .

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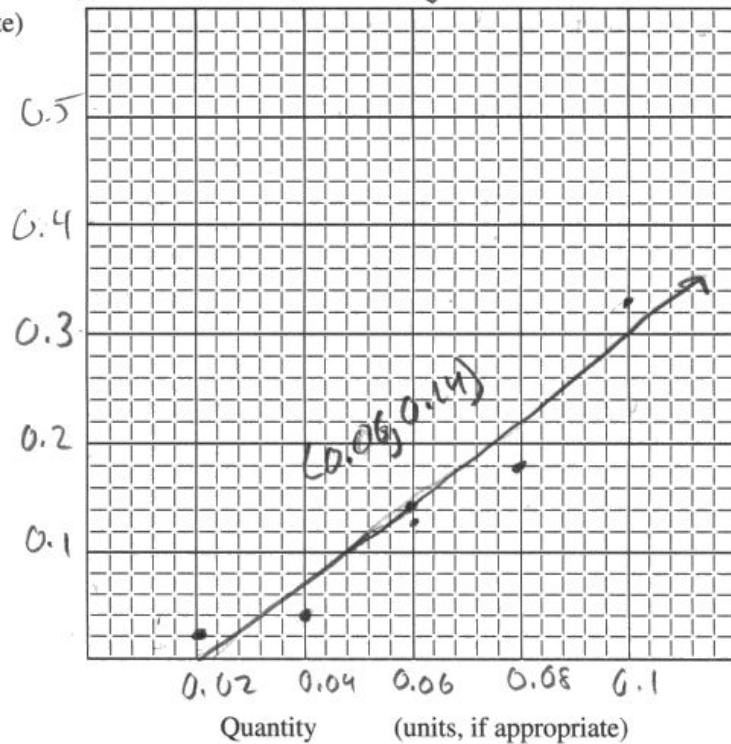
Question 3

PART C

Quantity (units, if appropriate)
height (m)

Table 2
 Anything you write in Table 2
 will not be scored.

$s(m)$	$h(m)$



compression (m)

PART D

$$mgh = \frac{1}{2} kx^2$$

$$\frac{2mgh}{x^2} = k$$

$$\frac{2(2)(9.8)(0.14)}{(0.06)^2} = k$$

$$k = 1524.44 \text{ N/m}$$

Go to Question 4 when you're done with this question.

Use a pencil or a pen with black or dark blue ink. Do NOT write your name. Do NOT write outside the box.

Question 3

PART A

- i) Use two points on the graph with whole number x are directly on the graph + circled, subtract them from each other + divide it by 2 to find the coefficient of kinetic friction (μ_k).
- ii) • measure the distance x of the spring from wall to end of spring
 • measure distance of the spring when completely stretched out
 • repeat the experiment multiple times (at least 3) and average out the results.

PART B

- i) the student could graph mass on the x-axis and then distance on the y-axis
- ii) for the distance, the lower it is towards the ground, the more KE is there which means the higher the μ_k will be, for the mass the more the mass is, the lower it is to the ground due to gravity unless a force is acted upon it, which means the higher the μ_k .



Use a pencil or a pen with black or dark blue ink. Do NOT write your name. Do NOT write outside the box.

Question 3

PART C

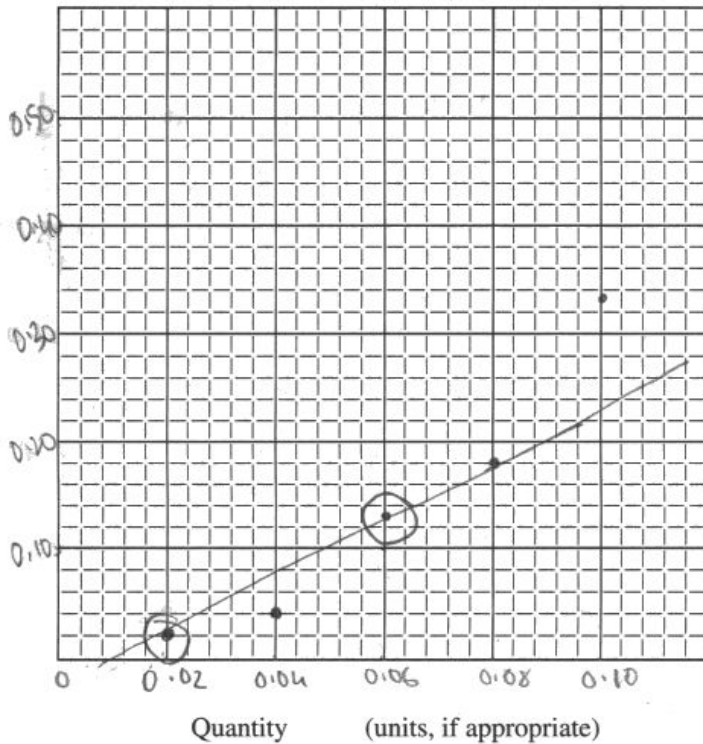
Quantity (units, if appropriate)

h m

Table 2

Anything you write in Table 2
will not be scored.

$s(m)$	$h(m)$
0.020	0.02
0.040	0.04
0.060	0.13
0.080	0.18
0.100	0.33



PART D

$$\frac{y_2 - y_1}{x_2 - x_1}$$

$$(0.020, 0.02) + (0.060, 0.13)$$

$$\frac{0.13 - 0.02}{0.060 - 0.020} = \frac{0.11}{0.04}$$

$$M_K = 2.75$$

Go to Question 4 when you're done with this question.

Use a pencil or a pen with black or dark blue ink. Do NOT write your name. Do NOT write outside the box.

Question 3

PART A

i. The student should measure the initial displacement of the box at different points where the spring is compressed. Then, they should measure distance in the +X direction after releasing the box from rest and letting it come to a stop, the box travels.

ii. Record 5+ trials at ~~the~~ 5+ different initial ΔX 's and avg. the data at the trials ~~for~~ @ each ΔX 's

PART B

The y-axis should represent the total distance in the +X

direction of the block after release.

X-axis should be the initial ΔX the ~~compressed~~ spring was compressed.

$$F_s = -k\Delta x \quad F_f = \mu_k \cdot mg \quad F_g = F_N$$

$$F_s - F_f = F_{net} = 0$$

$$F_s = F_f$$

$$\frac{-k\Delta x}{mg} = \frac{\mu_k mg}{mg}$$

$$x = x_0 + v_0 t + \frac{1}{2} a t^2$$

ii. ~~k\Delta x~~ $\mu_k = \frac{-k\Delta x}{mg}$

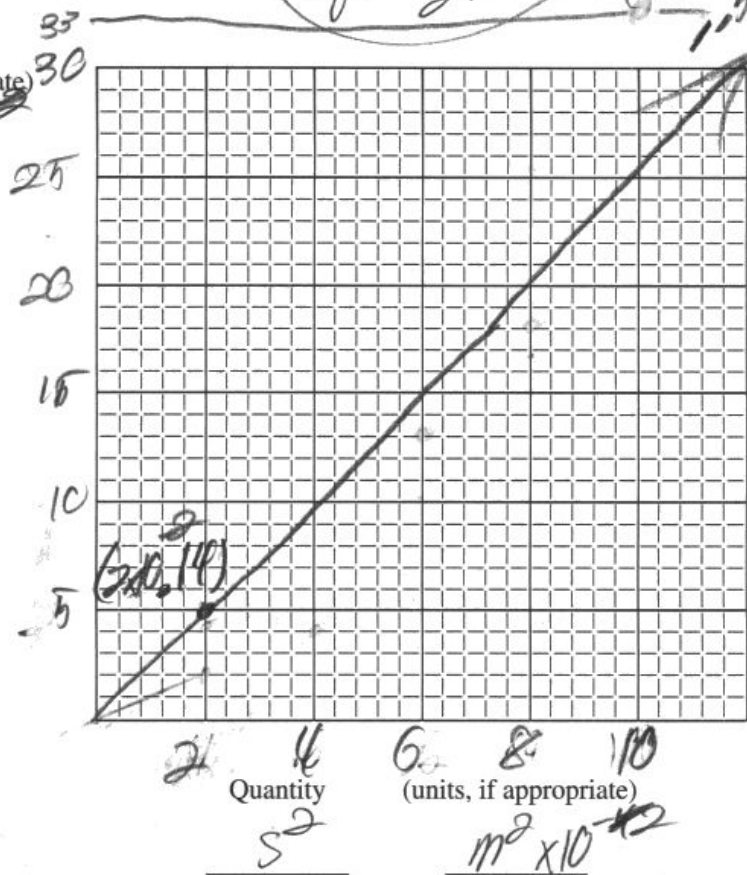
Use a pencil or a pen with black or dark blue ink. Do NOT write your name. Do NOT write outside the box.

Question 3

PART C

Quantity (units, if appropriate)
 $\sqrt{h}$ $m \times 10^{-2}$

Table 2
 Anything you write in Table 2
 will not be scored.



PART D

$$\frac{0.57 - 0.14}{8 \times 10^{-2}} = 5.375 = k$$

Go to Question 4 when you're done with this question.

Experimental Design and Analysis (LAB)

Sample: 3A

LAB Part A Point 1 Score: 1

LAB Part A Point 2 Score: 1

LAB Part B Point 1 Score: 1

LAB Part B Point 2 Score: 1

LAB Part C Point 1 Score: 1

LAB Part C Point 2 Score: 1

LAB Part C Point 3 Score: 1

LAB Part C Point 4 Score: 1

LAB Part D Point 1 Score: 1

LAB Part D Point 2 Score: 1

Score: 10

A.i.

- Point A1 was earned. The response indicates that the spring compression and the distance the block travels right of $x=0$ should be measured.

A.ii.

- Point A2 was earned. The response indicates uncertainty can be reduced by repeating measurements.

B.i.

- Point B1 was earned. The response indicates a linear graph to determine the coefficient of friction will be produced by graphing x vs A^2 with clear explanations defining the variables.

B.ii.

- Point B2 was earned. The response includes a relationship between the slope of the line and the coefficient of friction.

C.i.

- Point C1 was earned. The response includes quantities on the axes (h vs s^2) that should produce a linear graph and contain appropriate units.

C.ii.

- Point C2 was earned. The response includes a linear scale on each axis.

- Point C3 was earned. The response includes data points plotted consistently with the indicated quantities.

C.iii.

- Point C4 was earned. The response includes a line that approximates the trend of the plotted data.

D.

- Point D1 was earned. The response indicates the correct relationship between slope of the best-fit line and k_{new} .
- Point D2 was earned. The response includes a calculation of k_{new} between 1150 N/m and 1400 N/m.

Sample: 3B

LAB Part A Point 1 Score: 1

LAB Part A Point 2 Score: 0

LAB Part B Point 1 Score: 1

LAB Part B Point 2 Score: 1

LAB Part C Point 1 Score: 1

LAB Part C Point 2 Score: 1

LAB Part C Point 3 Score: 1

LAB Part C Point 4 Score: 1

LAB Part D Point 1 Score: 1

LAB Part D Point 2 Score: 1

Score: 9

A.i.

- Point A1 was earned. The response indicates that the spring compression and the distance traveled right of $x=0$ should be measured. It is inferred that the distance, $x>0$, is referring to the block.

A.ii.

- Point A2 was not earned. The response does not indicate a method that would reduce experimental uncertainty.

B.i.

- Point B1 was earned. The response indicates a linear graph to determine the coefficient of friction will be produced by graphing $k(\Delta x)^2$ vs $2mgr$.

B.ii.

- Point B2 was earned. The response includes a correct relationship between the slope of the line and the coefficient of friction.

C.i.

- Point C1 was earned. The response includes quantities ($2mgh$ vs s^2) on the axes that should produce a linear graph and contain appropriate units.

C.ii.

- Point C2 was earned. The response includes a linear scale on each axis.
- Point C3 was earned. The response includes data points plotted consistently with the indicated quantities.

C.iii.

- Point C4 was earned. The response includes a line that approximates the trend of the plotted data.

D.

- Point D1 was earned. The response indicates the correct relationship between slope of the best-fit line and k_{new} . This is inferred by the choice in vertical and horizontal axis quantities.
- Point D2 was earned. The response includes a calculation of k_{new} between 1150 N/m and 1400 N/m. This calculation is simplified by performing a linear fit using a calculator.

Sample: 3C

LAB Part A Point 1 Score: 1

LAB Part A Point 2 Score: 1

LAB Part B Point 1 Score: 1

LAB Part B Point 2 Score: 0

LAB Part C Point 1 Score: 1

LAB Part C Point 2 Score: 1

LAB Part C Point 3 Score: 1

LAB Part C Point 4 Score: 1

LAB Part D Point 1 Score: 1

LAB Part D Point 2 Score: 0

Score: 8

A.i.

- Point A1 was earned. The response indicates spring compression (in A.ii.) and the distance block travels right of $x=0$ should be measured.

A.ii.

- Point A2 was earned. The response indicates uncertainty can be reduced by repeating measurements with different compressions.

B.i.

- Point B1 was earned. The response indicates a linear graph will be produced by graphing compression length vs the distance traveled by the block.

B.ii.

- Point B2 was not earned. The response incorrectly places the spring constant in the numerator of the slope.

C.i.

- Point C1 was earned. The response includes quantities on the axes (h vs s^2) that should produce a linear graph and contain appropriate units.

C.ii.

- Point C2 was earned. The response includes a linear scale on each axis.
- Point C3 was earned. The response includes data points plotted consistently with the indicated quantities.

C.iii.

- Point C4 was earned. The response includes a line that approximates the trend of the plotted data.

D.

- Point D1 was earned. The response includes the correct relationship between slope of the best-fit line and k_{new} .
- Point D2 was not earned. The response does not include a calculation of k_{new} between 1150 N/m and 1400 N/m. The slope is calculated incorrectly as the inverse of the actual slope.

Sample: 3D

LAB Part A Point 1 Score: 0

LAB Part A Point 2 Score: 1

LAB Part B Point 1 Score: 0

LAB Part B Point 2 Score: 0

LAB Part C Point 1 Score: 1

LAB Part C Point 2 Score: 1

LAB Part C Point 3 Score: 1

LAB Part C Point 4 Score: 1

LAB Part D Point 1 Score: 1

LAB Part D Point 2 Score: 1

Score: 7

A.i.

- Point A1 was not earned. The response does not indicate the distance block travels right of $x=0$ should be measured. The response focuses on the oscillation of the spring rather than the displacement of the block.

A.ii.

- Point A2 was earned. The response indicates uncertainty can be reduced by repeating measurements.

B.i.

- Point B1 was not earned. The response incorrectly indicates a linear graph to determine the coefficient of friction will be produced by graphing initial spring energy vs normal force.

B.ii.

- Point B2 was not earned. The response incorrectly includes a relationship between the slope of the line and the coefficient of friction using a nonlinear energy vs force relationship.

C.i.

- Point C1 was earned. The response includes quantities on the axes that should produce a linear graph ($2mgh$ vs s^2) and contains appropriate units.

C.ii.

- Point C2 was earned. The response includes a linear scale on each axis.
- Point C3 was earned. The response includes data points plotted consistently with the indicated quantities.

C.iii.

- Point C4 was earned. The response includes a line that approximates the trend of the plotted data.

D.

- Point D1 was earned. The response indicates the correct relationship between slope of the best-fit line and k_{new} . The chosen axis quantities determine the slope is k_{new} .
- Point D2 was earned. The response includes a calculation of k_{new} between 1150 N/m and 1400 N/m. Units are not required to earn this point.

Sample: 3E

LAB Part A Point 1 Score: 1

LAB Part A Point 2 Score: 1

LAB Part B Point 1 Score: 0

LAB Part B Point 2 Score: 0

LAB Part C Point 1 Score: 0

LAB Part C Point 2 Score: 1

LAB Part C Point 3 Score: 1

LAB Part C Point 4 Score: 1

LAB Part D Point 1 Score: 1

LAB Part D Point 2 Score: 0

Score: 6

A.i.

- Point A1 was earned. The response indicates that the spring compression and the distance block travels right of $x=0$ should be measured.

A.ii.

- Point A2 was earned. The response indicates uncertainty can be reduced by repeating measurements.

B.i.

- Point B1 was not earned. The response does not indicate quantities that could be graphed to produce a linear graph.

B.ii.

- Point B2 was not earned. The response does not identify the slope of the graph in the relationship.

C.i.

- Point C1 was not earned. The response includes quantities on the axes that should produce a linear graph but does not include units for the vertical axis.

C.ii.

- Point C2 was earned. The response includes a linear scale on each axis.
- Point C3 was earned. The response includes data points plotted consistently with the indicated quantities.

C.iii.

- Point C4 was earned. The response includes a line that approximates the trend of the plotted data.

D.

- Point D1 was earned. The response indicates the correct relationship between slope of the best-fit line and k_{new} given the chosen axis quantities.
- Point D2 was not earned. The response includes a calculation of k_{new} that is not between 1150 N/m and 1400 N/m. The response includes an incorrect (inverted) calculation of slope.

Sample: 3F

LAB Part A Point 1 Score: 1

LAB Part A Point 2 Score: 1

LAB Part B Point 1 Score: 0

LAB Part B Point 2 Score: 0

LAB Part C Point 1 Score: 0

LAB Part C Point 2 Score: 1

LAB Part C Point 3 Score: 1

LAB Part C Point 4 Score: 1

LAB Part D Point 1 Score: 0

LAB Part D Point 2 Score: 0

Score: 5

A.i.

- Point A1 was earned. The response indicates measuring displacements in both friction and no-friction regions.

A.ii.

- Point A2 was earned. The response indicates uncertainty can be reduced by repeating trials.

B.i.

- Point B1 was not earned. The selected quantities will not produce a linear graph that can be used to solve for the coefficient of friction.

B.ii.

- Point B2 was not earned. The response does not includes a relationship between the slope of the line and the coefficient of friction.

C.i.

- Point C1 was not earned. The response includes quantities on the axes (h vs s) that will not produce a linear graph.

C.ii.

- Point C2 was earned. The response includes a linear scale on each axis.
- Point C3 was earned. The response includes data points plotted consistently with the indicated quantities.

C.iii.

- Point C4 was earned. The response includes a line that approximates the trend of the plotted data.

D.

- Point D1 was not earned. The response does not indicate the correct relationship between slope of the best-fit line and k_{new} .
- Point D2 was not earned. The response does not include a calculation of k_{new} between 1150 N/m and 1400 N/m.

Sample: 3G

LAB Part A Point 1 Score: 0

LAB Part A Point 2 Score: 1

LAB Part B Point 1 Score: 0

LAB Part B Point 2 Score: 0

LAB Part C Point 1 Score: 0

LAB Part C Point 2 Score: 1

LAB Part C Point 3 Score: 1

LAB Part C Point 4 Score: 1

LAB Part D Point 1 Score: 0

LAB Part D Point 2 Score: 0

Score: 4

A.i.

- Point A1 was not earned. The response indicates two distances that could be measured that would produce only one useful distance.

A.ii.

- Point A2 was earned. The response indicates uncertainty can be reduced by repeating measurements.

B.i.

- Point B1 was not earned. The response indicates a linear graph will be produced by graphing distance vs mass. This would not produce a line that could be used to determine the coefficient of friction.

B.ii.

- Point B2 was not earned. The response does not describe a relationship between the slope of the line and the coefficient of friction.

C.i.

- Point C1 was not earned. The response does not include quantities on the axes that should produce a line. Although the units are appropriate, h vs s produces a curve.

C.ii.

- Point C2 was earned. The response includes a linear scale on each axis.
- Point C3 was earned. The response includes data points plotted consistently with the indicated quantities.

C.iii.

- Point C4 was earned. The response includes a line that approximates the trend of the plotted data.

D.

- Point D1 was not earned. The response does not indicate the correct relationship between slope of the best-fit line and k_{new} .
- Point D2 was not earned. The response does not include a calculation of k_{new} between 1150 N/m and 1400 N/m.

Sample: 3H

LAB Part A Point 1 Score: 1

LAB Part A Point 2 Score: 1

LAB Part B Point 1 Score: 0

LAB Part B Point 2 Score: 0

LAB Part C Point 1 Score: 0

LAB Part C Point 2 Score: 1

LAB Part C Point 3 Score: 0

LAB Part C Point 4 Score: 0

LAB Part D Point 1 Score: 0

LAB Part D Point 2 Score: 0

Score: 3

A.i.

- Point A1 was earned. The response indicates that the spring compression and the distance the block travels right of $x=0$ should be measured.

A.ii.

- Point A2 was earned. The response indicates that uncertainty can be reduced by repeating measurements.

B.i.

- Point B1 was not earned. The response does not indicate a linear graph to determine the coefficient of friction. The response indicates a linear graph will be produced by graphing spring compression vs block distance.

B.ii.

- Point B2 was not earned. The response does not include a relationship between the slope of the line and the coefficient of friction.

C.i.

- Point C1 was not earned. The response does not include quantities ($\sqrt{h}$ vs s^2) on the axes that should produce a linear graph.

C.ii.

- Point C2 was earned. The response includes a linear scale on each axis.
- Point C3 was not earned. The response includes only one data point that is incorrectly plotted.

C.iii.

- Point C4 was not earned. The response does not include sufficient data points to demonstrate a trend of the plotted data.

D.

- Point D1 was not earned. The response does not indicate the correct relationship between slope of the best-fit line and k_{new} .
- Point D2 was not earned. The response does not include a calculation of k_{new} between 1150 N/m and 1400 N/m.