Begin your response to **QUESTION 1** on this page.

**PHYSICS C: MECHANICS**

**SECTION II**

**Time—45 minutes**

**3 Questions**

**Directions:** Answer all three questions. The suggested time is about 15 minutes for answering each of the questions, which are worth 15 points each. The parts within a question may not have equal weight. Show all your work in this booklet in the spaces provided after each part.

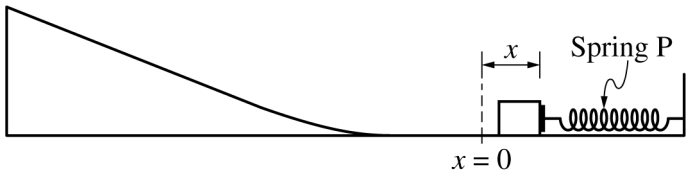


Figure 1

1. A block sitting on a horizontal surface is pushed against a spring, Spring P, that is attached to a wall, compressing the spring a distance $x$, as shown in Figure 1. The block is then released from rest. The block slides along the horizontal surface and up a ramp, reaching a maximum height $h_{\text{max,P}}$. Frictional forces between the block and all surfaces are negligible.

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A student compares $h_{max,P}$ for Spring P with the maximum height $h_{max,Q}$ achieved with a different spring, Spring Q. Each spring exerts a force of magnitude $F$ on the block that varies as a function of the distance $x$ that the spring is compressed, as shown in Figure 2. For Spring P, $F_P(x) = kx$, where $k = 100.0\,\text{N/m}$, and for Spring Q, $F_Q(x) = Cx^{1/2}$, where $C = 20.0\,\text{N/m}^{1/2}$.

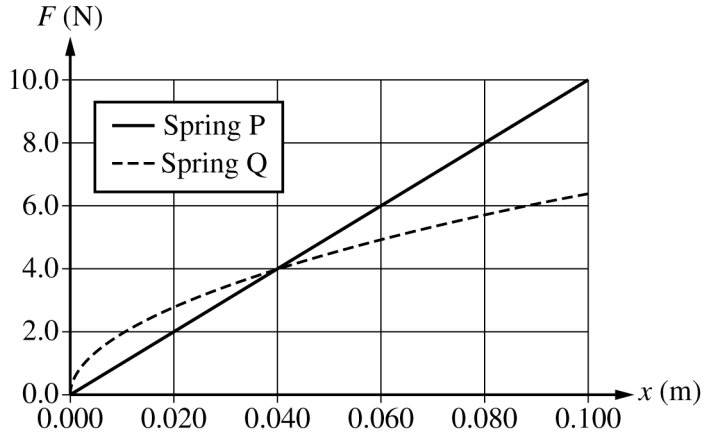
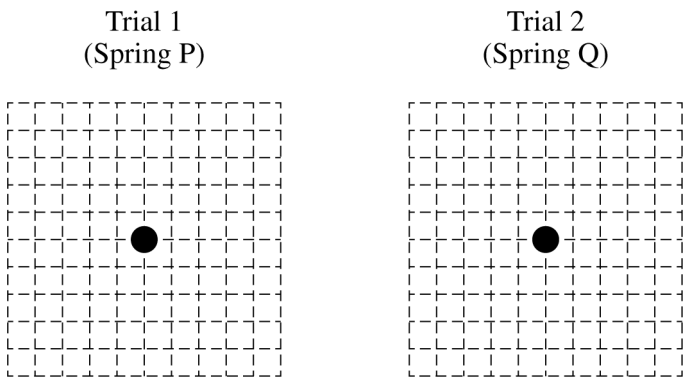



Figure 2

(a) For the experiment, the block is pushed against one of the springs, compressing the spring a distance $x = 0.010\,\text{m}$. The block is then released from rest. In Trial 1, Spring P is used, and in Trial 2, Spring Q is used. On the following dots, representing the block in Trials 1 and 2, draw and label the forces (not components) that are exerted on the block at the instant the block is released. Each force must be represented by a distinct arrow starting on, and pointing away from, the dot. The lengths of the horizontal vectors should represent the relative magnitude of the horizontal forces and the lengths of the vertical vectors should represent the relative magnitude of the vertical forces.

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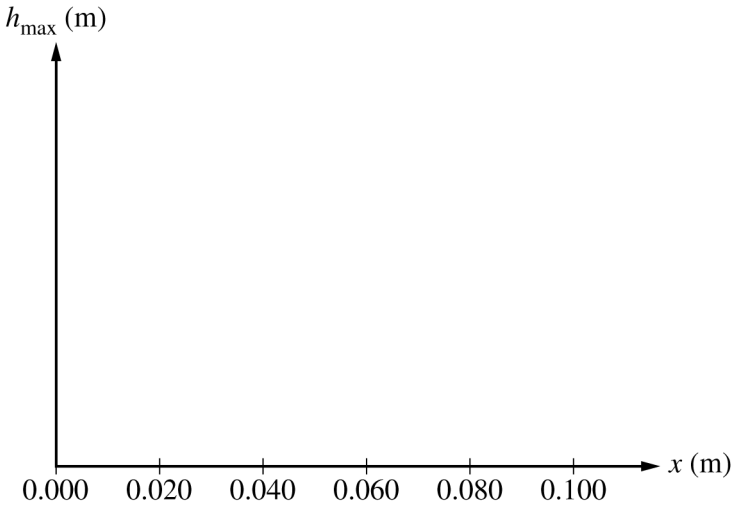
Continue your response to **QUESTION 1** on this page.

(b)

i. What feature(s) of the graph in Figure 2 could be used to estimate the work done on the block by each spring as each spring is compressed?

ii. There is one compression distance $x_0$ for which the maximum height $h_{max}$ reached by the block is the same regardless of which spring, Spring P or Spring Q, is used. Predict whether the value of $x_0$ is greater than, less than, or equal to $0.040\ \text{m}$. Use the graph in Figure 2 to justify your answer.

iii. On the axes provided, for both Spring P and Spring Q, sketch a graph of the maximum height $h_{max}$ reached by the block as a function of the distance each spring is compressed for values of $x$ ranging from 0 to $0.100\ \text{m}$. Clearly label the curve for Spring P and Spring Q.

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Continue your response to **QUESTION 1** on this page.

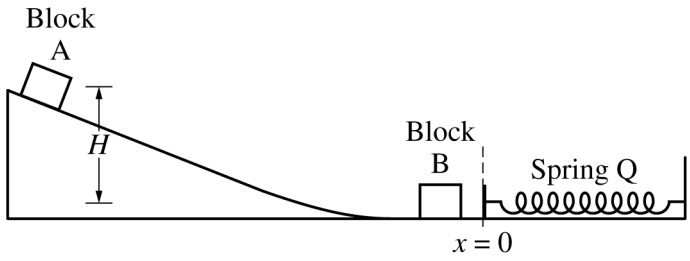


Figure 3

(c) Spring Q is attached to the wall and is at equilibrium, as shown in Figure 3. Block A has a mass of 0.120 kg and Block B has a mass of 0.070 kg. Block A is held at rest at the top of the ramp and Block B is at rest on the horizontal surface. The student releases Block A, and it moves down the ramp and collides with Block B. The change in vertical height of Block A is $H = 0.75$ m. After the collision, the blocks stick together and move to the right, compressing the spring. Frictional forces between the blocks and all surfaces are negligible.

i. Calculate the velocity of the two-block system immediately after the collision between Blocks A and B.

ii. Calculate the maximum compression of the spring.

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Continue your response to **QUESTION 1** on this page.

(d) Spring Q where $F_Q(x) = Cx^{1/2}$ is replaced by a different nonlinear spring, Spring R, and the procedure described in part (c) is repeated. For Spring R, $F_R(x) = Dx^{1/2}$. The maximum compression of Spring R is greater than the maximum compression of Spring Q. Which of the following correctly compares the constants $C$ and $D$ ?

_____ $C < D$ _____ $C > D$ _____ $C = D$

Briefly justify your answer.

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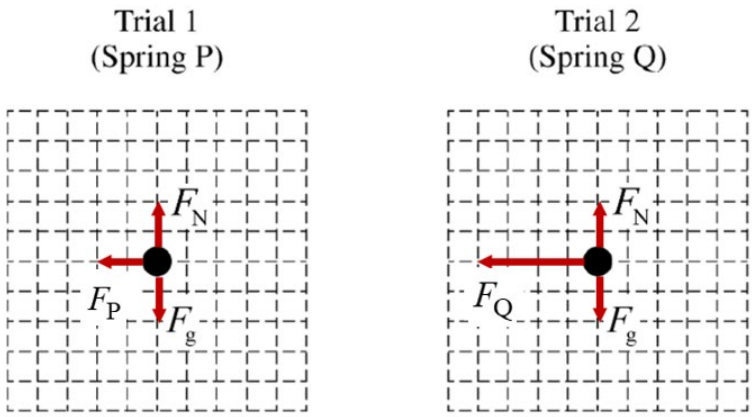
## Question 1: Free-Response Question — 15 points

**(a)** For correctly drawing and labeling the force of gravity and the normal force on both dots — **1 point**

For drawing and labeling the spring force to the left on both dots, where the force for Spring Q (Trial 2) is twice as long as the force for Spring P (Trial 1) — **1 point**

**Example Solution**




**Scoring Note:** Examples of appropriate labels for the force due to gravity include: $F_G$, $F_g$, $F_{grav}$, $W$, $mg$, $Mg$, "grav force", "F Earth on block", "F on block by Earth", $F_{\text{Earth on block}}$, $F_{E,Block}$. The labels $G$ and $g$ are not appropriate labels for the force due to gravity.
$F_n$, $F_N$, $N$, "normal force", "ground force", or similar labels may be used for the normal force.

**Scoring Note:** A response that includes extraneous vectors can earn a maximum of 1 point.

**Total for part (a)** — **2 points**

**(b)(i)** For a statement that the work is equal to the area under the curve — **1 point**

**(b)(ii)** For stating the spring compression will be greater than $0.040$ m with an attempt at a relevant justification — **1 point**

For a justification that indicates that the heights are equal when the area between each function and the horizontal axis are equal, which happens after $x = 0.040$ m — **1 point**

**Scoring Note:** While a mathematical solution is not required to earn credit for this point, students may reference a mathematical solution.

**Example Solution**

*The work done by each spring is equal to the area under their respective curves. This work is converted to the change in potential energy and therefore relates to the maximum height reached by the block. At $x = 0.040$ m, the area under the curve for Spring Q is greater than that of Spring P. Therefore, it is not until a compression greater than $x = 0.040$ m that the areas under the two curves are equal, have the same work, and convert to the same maximum height.*

| | | |
|---|---|---|
| **(d)** | For selecting $C > D$ with an attempt at a relevant justification | **1 point** |
| | For one of the following:<br>• a statement that correctly relates the total energy of the system, the maximum compression distance of the springs, and the spring constant<br>• a statement that correctly relates the force exerted on the blocks by the spring, the maximum compression distance of the springs, and the spring constant | **1 point** |

**Example Solutions**

*The energy of the two-block-spring system before the blocks compress the spring is the same in both procedures, so the total potential energy of both springs must be the same when each spring is at its maximum compression. Since Spring Q is compressed less than Spring R, C must be greater than D.*

**OR**

*The blocks are traveling at the same speed before colliding with the spring in each procedure. The maximum compression of Spring Q is less than Spring R, so the average force exerted on the blocks by Spring Q to stop the blocks must be greater than that of Spring R. Therefore, C must be greater than D.*

**Total for part (d) 2 points**

**Total for question 1 15 points**