Solutions: AP Physics 1 Practice Exam 1, Section II (Free-Response)

Obviously your solutions will not be word-for-word identical to what is written below. Award points for your answer as long as it contains the correct physics, and as long as it does not contain incorrect physics.

Question 1

Part (a)

1 point for a correct circle on the diagram.

1 point for a correct explanation: When the carts collide, the moving cart must lose speed. The vertical axis of the velocity-time graph indicates speed. The circled portion of the graph is the only place where the vertical axis value drops rapidly, as the cart’s speed must drop in the collision.

(i) 1 point for answer: 0.60 m/s (or thereabouts—anywhere between, say, 0.55 m/s and 0.60 m/s is fine.)

(ii) 1 point for answer: 0.25 m/s (or thereabouts—anything between, say, 0.22 m/s and 0.29 m/s is fine.)

Part (b)

(i) 1 point: The easiest answer is to put the speed of Cart A before collision on the vertical axis; and to put the speed of Cart A after collision on the horizontal axis. There are other answers that will work.

(ii) 3 points: Award one or two points of partial credit for correct but incomplete physics. For example, writing and using an expression for momentum conservation should earn a point, even if the rest of the explanation doesn’t follow properly.

Conservation of momentum means the total momentum before the collision equals the total momentum after the collision. Before the collision, the total momentum is that of Cart A: \( m_A v_A \).

After the collision, the total momentum is \( (m_A + m_B)v' \) where \( v' \) is the speed of Cart A (and, because they stick together, the speed of Cart B, too). Set these momentum expressions equal:

\[
m_{AVA} = (m_A + m_B)v'.
\]

This equation can be solved for the \( y \)-axis variable divided by the \( x \)-axis variable:

\[
\frac{v_A}{v'} = \frac{m_A + m_B}{m_A}.
\]
So, to get the mass of Cart B, I’d determine the slope of the line on the graph, and set that equal to 
\[
\frac{(m_A + m_B)}{m_A}.
\]
The mass of Cart A is given as 500 g, so I’d plug that in and solve for \(m_B\).

Part (c)

(i) **2 points:** Award one point for a partially correct description, two points for a complete and correct description.

Three ideas occur, but many are possible:

- Measure the distance that Cart B has to travel to the end of the track. When the carts collide, start a stopwatch; when Cart B hits the end of the track, stop the stopwatch. The speed of Cart B is the distance you measured divided by the time on the stopwatch.
- After the collision, when the detector has already read the speed of Cart A but before Cart B reaches the end of the track, lift up Cart A. Now the detector can read Cart B’s speed.
- Let Cart B roll off the end of the track and fall to the floor as a projectile. Measure the vertical height \(y\) of the track off the ground; the time \(t\) that the cart was in the air is given by \(y = \frac{1}{2}gt^2\), where \(g\) is 10 m/s per second. Measure the horizontal distance from the track’s edge to the spot where the cart landed. Then the speed of the cart is this horizontal distance divided by the calculated time of flight.

(ii) **2 points:** Award one point for a partially correct description, two points for a complete and correct description.

“Elastic” means that the total kinetic energy of the two carts was the same before and after collision. Before the collision, the only kinetic energy is that of Cart A: \(\frac{1}{2}m_Av_A^2\). After the collision, the total kinetic energy is the sum of the kinetic energy of both carts, where each cart’s kinetic energy is given by \(\frac{1}{2}mv^2\). Compare the total kinetic energy after collision to Cart A’s kinetic energy before collision. If these values are equal, the collision was elastic. If the kinetic energy after the collision is less than the kinetic energy before collision, the collision was not elastic.

**Question 2**

Part (a) **2 points:** Award one point for a partially correct description, two points for a complete and correct description. Consider the center of the meterstick as the fulcrum; then the weight of the meterstick provides no torque. The oppositely directed torques applied by each scale must be equal, because the meterstick is in equilibrium. Torque is force times distance from the fulcrum; since the right-hand scale’s torque calculation includes a smaller distance from the fulcrum, the right-hand scale must apply more force in order to multiply to the same torque.

Part (b) **4 points:** Full credit for a complete and correct answer. Award three points partial credit for a correct approach with incorrect answers. Award two points for a correct approach and correct answer for one of the scales, but not the other. Award at least one point if the answer involved some use of torque equilibrium.

For this calculation, consider the left-hand scale as the fulcrum—that way, the left-hand scale provides no torque, and we only have to solve for one unknown variable. Set counterclockwise torques equal to clockwise torques, with \(T_2\) the reading in the right-hand scale.
The weight of the meterstick provides the clockwise torque; the right-hand scale provides the counterclockwise torque.

\[ ** (T_2)(50 \text{ cm}) = (1.5 \text{ N})(30 \text{ cm}) \]

Solve for \( T_2 \) to get \( T_2 = 0.9 \text{ N} \)

Next, the sum of the scale readings has to be the 1.5 N weight of the meterstick:

\[ 0.9 \text{ N} + T_1 = 1.5 \text{ N} \]

Giving \( T_1 = 0.6 \text{ N} \)

Part (c)

(i) **2 points:** Award one point for a partially correct description, two points for a complete and correct description.

Look at the starred calculation in Part (b). By moving the right-hand scale closer to the center, the scale will be less than 50 cm from the left-hand scale; but the meterstick’s center will still be 30 cm from the fulcrum. So when we solve for \( T_2 \), we’re dividing \((1.5 \text{ N})(30 \text{ cm})\) by a smaller value, giving a bigger \( T_2 \) reading.

But the question asks for the reading in the left-hand scale, which adds to \( T_2 \) to the same 1.5 N. A bigger \( T_2 \) adds to a smaller \( T_1 \) to get 1.5 N. Answer: decrease.

(ii) **2 points:** Award one point for a partially correct description, two points for a complete and correct description.

See Part (i): \( T_2 \), the reading in the right-hand scale, will increase.

Part (d)

**2 points:** Award one point for a partially correct description, two points for a complete and correct description.

Again, start from the equilibrium of torques using the left-hand scale as the fulcrum:

\[ (T_2)(50 \text{ cm}) = (1.5 \text{ N})(30 \text{ cm}) \]

Hanging a 0.2-N weight would provide a clockwise torque that would add to the torque applied by the meterstick’s weight on the right of this equation. Algebraically, \( T_2 \) is increased by adding to the numerator of the right side of this equation. We want to add the biggest possible torque.

Torque is force times distance from the fulcrum. We want, then, the largest possible distance from the fulcrum, which would be the right-hand edge of the meterstick, 80 cm from the left-hand scale.

**Question 3**

Part (a)

**1 point** for both a correct answer and a correct justification.

Probe A. The probe’s speed is the circumference of its circular motion divided by its period of revolution. We already established that the period is the same for each. Probe A has a bigger orbital radius, meaning a larger circumference of its circular motion, meaning a greater speed.

Part (b)
2 points: Award one point for the correct answer with a partially correct justification; award both points for the fully correct answer and justification.

Probe A. The centripetal acceleration is \( \frac{v^2}{r} \). The problem is that Probe A has both a larger speed \( v \) and a larger orbital radius \( r \). In order to answer the question, it’s necessary to replace the speed \( v \) by circumference over period, \( v = \frac{2\pi r}{T} \). Now the acceleration is \( \frac{\left( \frac{2\pi r}{T} \right)^2}{r} = \frac{4\pi^2 r}{T^2} \). Okay, now we know: both probes have the same orbital period \( T \), and \( r \) is in the numerator. The bigger-radius orbit—Probe A—has the greater acceleration.

Part (c)
(i) 1 point for correct ranking

(Greatest 2 = 4 > 1 = 3 > 5 = 6 Least)

(ii) 3 points: Award one point for justifying all three sets of force pairs set equal. Award one more point for justifying at least one correct portion of the ranking. Award the third point for justifying a second correct portion of the ranking.

By Newton’s third law, the three force pairs can be immediately set equal: that’s #1 with #3, #2 with #4, and #5 with #6. Next, we know that the force of Mars on either probe is given by \( F = G \frac{Mm}{r^2} \), where \( M \) and \( m \) are the masses of Mars and the probe, respectively. Since the probes are identical, the numerator is the same for both #1 and #2, but the distance of the probe from Mars’ center is smaller for Probe B. Therefore, Probe B experiences more force, and force #2 is greater than force #1. As for force #5, Mars is an enormous planet, many times more massive than Earth even. There’s no way that the product of the space probes’ masses can ever approach Mars’ mass, meaning that the numerator of the force equation must be way smaller for force #5.

Question 4

The paragraph response must discuss kinetic energy, total mechanical energy, and linear momentum for each of the two systems. For each of these three quantities in each system, award one point for correctly explaining whether it is conserved and correctly justifying why it is or isn’t conserved. For example:

1 point: In system A, kinetic energy is not conserved. When the blocks are released, Block A speeds up away from Block B. Kinetic energy depends on mass and speed only. Since Block A’s speed increases without changing its mass, kinetic energy cannot remain constant.

1 point: In system A, total mechanical energy is not conserved. Since the system consists only of Block A, there is no interaction with another object that would allow for the storage of potential energy. The force of the spring on Block A would be a force external to the system, and the spring does work on Block A because Block A moves parallel to the spring force; when a net force external to the system does work, mechanical energy is not conserved.

1 point: In system A, linear momentum is not conserved. Either the reasoning for system A’s kinetic energy or total mechanical energy can be extended here. Linear momentum depends on mass and speed, and Block A’s speed changes without changing mass. Or, the spring force is
external to the system, and momentum is only conserved in systems on which no net external force acts.

1 point: In system B, kinetic energy is \textit{not} conserved. Kinetic energy is a scalar, so kinetic energy of a system of objects is just the addition of the kinetic energies of all the objects in the system. Both blocks speed up, so both blocks are increasing their kinetic energy, increasing the system’s kinetic energy.

1 point: In system B, total mechanical energy \textit{is} conserved. No force external to the spring-blocks system does work, so mechanical energy is conserved. The kinetic energy gained by the blocks was converted from potential energy stored in the spring.

1 point: In system B, linear momentum \textit{is} conserved. No force external to the spring-blocks system acts, so linear momentum is conserved. Here even though Block B gains linear momentum, momentum is a vector—its gain of momentum is canceled by the momentum gained by Block A in the opposite direction.

\textbf{Add 1 point} if the paragraph correctly states whether each quantity is conserved in each system, regardless of whether the justifications are legitimate.

\textbf{Question 5}

Part (a)
1 point\textbf{ for correctly identifying and justifying Bulb 1’s current increase and 1 point} for correctly identifying and justifying Bulb 3’s decreased current.

Initially, the circuit is just Bulbs 1 and 3 in series. When Bulb 2 is added, the voltage from the battery is unchanged. Yet the total resistance of the circuit decreases, because an additional parallel path is added. Therefore, by \( V = IR \) with constant \( V \), the total current in the circuit increases.

Bulb 1 takes the total current, so Bulb 1’s current increases. For Bulb 1 \textit{only}, the resistance is a property of the bulb and thus doesn’t change. So by \( V = IR \) with constant \( R \), Bulb 1 takes an increased voltage, too.

Then by Kirchoff’s loop rule, an increase voltage across Bulb 1 means a decreased voltage across Bulb 3. And for Bulb 3 only, by \( V = IR \) with constant \( R \), Bulb 3’s current also decreases. (Obviously Bulb 2’s current increases from nothing to something.)

Part (b)
1 point\textbf{ for either a correct answer with correct justification; or, for an answer consistent with the answers to Part (a) with reference to the power dissipated by the bulbs.}

All bulbs have an unchanging resistance. Brightness depends on power, which is \( I^2R \). With constant \( R \), a bigger current means more brightness; a smaller current means less brightness. So Bulb 1 gets brighter and Bulb 3 gets dimmer.

Part (c)
2 points\textbf{ for a fully correct answer with justification. One of these two points can be earned for a partially correct justification, or for an incorrect answer that is justified consistently with the answers to (A) or (B).}

For the whole circuit, use power = \( V^2/R \). The voltage of the battery is unchanged because it’s still the same battery. The resistance of the circuit decreases because of the extra parallel path. Decreasing the denominator increases the entire value of the equation, so power increases.

Part (d)
2 points for a complete and correct explanation. One of these two points can be earned by a partially correct, or an incomplete, justification.

Conservation of charge in circuits is expressed in Kirchoff’s junction rule—the current entering a junction equals the current leaving the junction. At any given moment of time, the junction rule holds. Now, when the switch is closed, more current flows from the battery than before. That’s not a violation of charge conservation, because the materials in the battery contain way more charged particles than are ever flowing through the wires. After the switch is closed, more current flows into the junction right before the switch than before, but more current also flows out of that junction than before. Charge conservation doesn’t mean that the same current must always flow in a circuit, it just says that whatever charge does flow in a circuit must flow along the wires.

Scoring the Practice Exam

Remember that the raw percentage score necessary to obtain a 5, 4, 3, or 2 is not a fixed number. The scores are scaled each year so, regardless of whether the questions on that year’s exam are hard or easy, the meaning of each score is similar year after year after year. What you see below is merely my best educated guess at a reasonable score conversion. I’ll even use this very score conversion in my own classes. But I don’t guarantee the accuracy of the chart any more than I guarantee Arsenal to win the Premier League.

Multiple-Choice Raw Score: Number Correct ______ (50 points maximum)

Free Response:  Problem 1______(12 points maximum)
  Problem 2______(12 points maximum)
  Problem 3______(7 points maximum)
  Problem 4______(7 points maximum)
  Problem 5______(7 points maximum)

Free response total:______(45 points maximum)

The final score is equal to (1.11 × the free response score) + (the multiple choice score)

Total score:______(100 points maximum)

Approximate Score Conversion Chart (only a guesstimate, see above)

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