AP® PHYSICS
2011 SCORING GUIDELINES

General Notes About 2011 AP Physics Scoring Guidelines

1. The solutions contain the most common method of solving the free-response questions and the allocation of points for this solution. Some also contain a common alternate solution. Other methods of solution also receive appropriate credit for correct work.

2. Generally, double penalty for errors is avoided. For example, if an incorrect answer to part (a) is correctly substituted into an otherwise correct solution to part (b), full credit will usually be earned. One exception to this may be cases when the numerical answer to a later part should be easily recognized as wrong, e.g., a speed faster than the speed of light in vacuum.

3. Implicit statements of concepts normally earn credit. For example, if use of the equation expressing a particular concept is worth one point, and a student's solution contains the application of that equation to the problem but the student does not write the basic equation, the point is still earned. However, when students are asked to derive an expression it is normally expected that they will begin by writing one or more fundamental equations, such as those given on the AP Physics exam equation sheet. For a description of the use of such terms as "derive" and "calculate" on the exams, and what is expected for each, see "The Free-Response Sections — Student Presentation" in the *AP Physics Course Description*.

4. The scoring guidelines typically show numerical results using the value $g = 9.8\ \mathrm{m/s^2}$, but use of $10\ \mathrm{m/s^2}$ is also acceptable. Solutions usually show numerical answers using both values when they are significantly different.

5. Strict rules regarding significant digits are usually not applied to numerical answers. However, in some cases answers containing too many digits may be penalized. In general, two to four significant digits are acceptable. Numerical answers that differ from the published answer due to differences in rounding throughout the question typically earn full credit. Exceptions to these guidelines usually occur when rounding makes a difference in obtaining a reasonable answer. For example, suppose a solution requires subtracting two numbers that should have five significant figures and that differ starting with the fourth digit (e.g., 20.295 and 20.278). Rounding to three digits will lose the accuracy required to determine the difference in the numbers, and some credit may be lost.

Question 1

15 points total | **Distribution of points**

(a) 2 points

$\mathbf{J} = \int \mathbf{F}\, dt$

For a correct equation relating the given force, time and impulse — 1 point

$J_p = F_{avg}\Delta t$

For the correct answer — 1 point

$\Delta t = J_p / F_{avg}$

Alternate solution — *Alternate points*

For using both kinematics and Newton's second law — *1 point*

$\upsilon_x = 0 + a_{avg}\Delta t$

$\mathbf{F}_{avg} = m\mathbf{a}_{avg}$

Combining the above equations

$F_{avg} = m\left(\frac{\upsilon_x}{\Delta t}\right)$

$F_{avg}\Delta t = m\upsilon_x = J_p$

For the correct answer — *1 point*

$\Delta t = J_p / F_{avg}$

(b) 2 points

For the correct relationship between impulse and the change in momentum — 1 point

$\mathbf{J} = \Delta\mathbf{p} = m\Delta\mathbf{v}$

$J_p = m(\upsilon_x - 0) = m\upsilon_x$

For the correct answer — 1 point

$m = J_p / \upsilon_x$

Note: A correct kinematics and Newton's laws approach is also acceptable.

Question 1 (continued)

Distribution of points

(c) 3 points

For using the work-energy theorem — 1 point

$W = \Delta K$

$W = 0 - \frac{1}{2}m\upsilon_x^2$

For substituting the expression for m from part (b) — 1 point

$W = -\frac{1}{2}\frac{J_p}{\upsilon_x}\upsilon_x^2$

$W = -\frac{1}{2}J_p\upsilon_x$

For an indication that the work done is negative — 1 point

Alternate Solution — *Alternate points*

Using kinematics and Newton's second law to determine the average net force

$\upsilon_f^2 - \upsilon_i^2 = 2a_{avg}d$

$-\upsilon_x^2 = 2a_{avg}d$

$a_{avg} = -\frac{\upsilon_x^2}{2d}$

$\mathbf{F}_{avg} = m\mathbf{a}_{avg}$

$F_{net} = m\left(-\frac{\upsilon_x^2}{2d}\right)$

For substituting this expression for the force into the equation for work — *1 point*

$W = \int \mathbf{F} \bullet d\mathbf{r} = F_{avg}d = m\left(-\frac{\upsilon_x^2}{2d}\right)d$

$W = -m\frac{\upsilon_x^2}{2}$

For substituting the expression for m from part (b) — *1 point*

$W = -\frac{J_p}{\upsilon_x}\frac{\upsilon_x^2}{2}$

$W = -\frac{1}{2}J_p\upsilon_x$

For an indication that the work done is negative — *1 point*

Question 1 (continued)

Distribution of points

(d) 2 points

$W = \int \mathbf{F} \cdot d\mathbf{r} = \mathbf{F}_{avg} \cdot \mathbf{r}$

For using F_b as the average force in the equation for work — 1 point

$W = F_b d$

$F_b = \dfrac{W}{d}$

For substituting the expression for W from part (c), with or without a negative sign — 1 point

$F_b = \dfrac{J_p v_x}{2d}$

(e) 4 points

Applying the work-energy relationship

$K_i + W = K_f$

For correctly relating the initial kinetic energy of the projectile with the work done by the block on the projectile and the work done on the block by friction with the table — 1 point

$K_i + W_{block} + W_{friction} = 0$

For substituting for the work done by the block on the projectile (i.e., the energy lost to heat in the block-projectile collision) — 1 point

$K_i - F_b d_n + W_{friction} = 0$

For substituting the work done on the block by friction with the table (i.e., the energy lost to heat as the block slides to rest on the table) — 1 point

$K_i - F_b d_n - f_T D = 0$

The initial kinetic energy of the projectile is the same as in the first case when the block was clamped. Therefore, it can be equated to the work done in stopping the projectile from part (d).

For substituting $F_b d$ for the initial kinetic energy of the block — 1 point

$F_b d - F_b d_n - f_T D = 0$

$F_b d_n = F_b d - f_T D$

Full credit could not be earned for just writing this equation. The student needed to have some indication that the work-energy relationship was being applied, and that F_d was associated with the initial kinetic energy.

$d_n = \dfrac{F_b d - f_T D}{F_b}$

$d_n = d - \dfrac{f_T}{F_b} D$

Question 1 (continued)

	Distribution of points
(f) 2 points	
For a correct application of conservation of momentum to the block-projectile collision	1 point

$mv_x = (M+m)V$

$V = \dfrac{m}{(M+m)} v_x$

The kinetic energy of the block/projectile system immediately after the collision is equal to the work done by friction in stopping it.

$\frac{1}{2}(M+m)V^2 = f_T D$

For substituting for V — 1 point

$\frac{1}{2}(M+m)\left(\dfrac{m}{(M+m)} v_x\right)^2 = f_T D$

$\dfrac{1}{2}\dfrac{m^2 v_x^2}{(M+m)} = f_T D$

$\dfrac{m}{M+m}\left(\dfrac{1}{2} m v_x^2\right) = f_T D$

From part (c) the kinetic energy factor in the equation above is equal to the total work done. From part (d) that work is equal to $F_b d$.

$\dfrac{m}{M+m} F_b d = f_T D$

Using the expression $F_b d_n = F_b d - f_T D$ from part (e) to substitute for $f_T D$

$\dfrac{m}{M+m} F_b d = F_b d - F_b d_n$

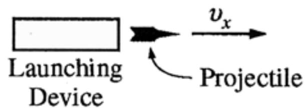
$\dfrac{m}{M+m} d = d - d_n$

$d_n = d\left(1 - \dfrac{m}{M+m}\right)$

Note: Because the work for parts (e) and (f) is interrelated, the two parts are scored as a whole. Credit is earned for work related to part (f) even when it is shown in part (e) and vice versa.

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, NOT in the green insert.



Mech. 1.

A projectile is fired horizontally from a launching device, exiting with a speed v_x. While the projectile is in the launching device, the impulse imparted to it is J_p, and the average force on it is F_{avg}. Assume the force becomes zero just as the projectile reaches the end of the launching device. Express your answers to parts (a) and (b) in terms of v_x, J_p, F_{avg}, and fundamental constants, as appropriate.

(a) Determine an expression for the time required for the projectile to travel the length of the launching device.

$$J_p = \int F\,dt = F_{avg} \cdot t$$

$$t = \frac{J_p}{F_{avg}}$$

(b) Determine an expression for the mass of the projectile.

$$\begin{cases} J_p = mV_x - mV_0 \\ V_0 = 0 \end{cases}$$

$$J_p = mV_x$$

$$m = \frac{J_p}{V_x}$$

GO ON TO THE NEXT PAGE.

The projectile is fired horizontally into a block of wood that is clamped to a tabletop so that it cannot move. The projectile travels a distance d into the block before it stops. Express all algebraic answers to the following in terms of d and the given quantities previously indicated, as appropriate.

(c) Derive an expression for the work done in stopping the projectile.

$$Work = E_{kine} - E_{kineo} = 0 - \frac{1}{2}mV_x^2 \quad m = \frac{J_p}{V_x}$$

$$\text{so} \quad work = -\frac{J_pV_x}{2} = -\frac{1}{2}J_pV_x$$

(d) Derive an expression for the average force F_b exerted on the projectile as it comes to rest in the block.

$$work = -\frac{1}{2}J_pV_x = \int \cancel{F_b\,dx} = F_b \cdot d$$

$$F_b = -\frac{J_pV_x}{2d}$$

"−" means ~~Fb the direction of~~ $\vec{F_b}$ points to the opposite direction to that of $\vec{V_x}$

Now a new projectile and block are used, identical to the first ones, but the block is not clamped to the table. The projectile is again fired into the block of wood and travels a new distance d_n into the block while the block slides across the table a short distance D. Assume the following: the projectile enters the block with speed v_x, the average force F_b between the projectile and the block has the same value as determined in part (d), the average force of friction between the table and the block is f_T, and the collision is instantaneous so the frictional force is negligible during the collision.

(e) Derive an expression for d_n in terms of d, D, f_T, and F_b, as appropriate.

~~$0 - mV_x = F_b\,d_n$~~

the initial energy of the projectile is $\frac{1}{2}J_pV_x = F_b \cdot d$

the energy reserves, so $F_b \cdot d = F_b \cdot d_n + f_T \cdot D$

$$d_n = d - \frac{f_T}{f_b} \cdot D$$

(f) Derive an expression for d_n in terms of d, the mass m of the projectile, and the mass M of the block.

the linear momentum reserves when the collision happens

$$mV_x = (m+M)u \quad ①$$

$$\cancel{\tfrac{1}{2}(m+M)u^2} = f_T \cdot D = \frac{1}{2}(m+M)u^2 \quad ②$$

$$J_p = mV_x \quad ③$$

according to (e)

$$d_n = d - \frac{f_T \cdot D}{f_b} = d - \frac{\frac{1}{2}(m+M)u^2}{-\frac{J_pV_x}{2d}} = d - \frac{\frac{1}{2}\frac{m^2V_x^2}{m+M}}{\frac{mV_x^2}{2d}} = d - \frac{m}{m+M}d = \frac{M}{m+M}d$$

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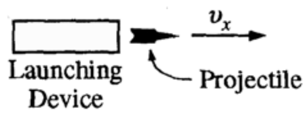

Mech. 1.

A projectile is fired horizontally from a launching device, exiting with a speed v_x. While the projectile is in the launching device, the impulse imparted to it is J_p, and the average force on it is F_{avg}. Assume the force becomes zero just as the projectile reaches the end of the launching device. Express your answers to parts (a) and (b) in terms of v_x, J_p, F_{avg}, and fundamental constants, as appropriate.

(a) Determine an expression for the time required for the projectile to travel the length of the launching device.

$$J_p = F_{avg} t \Rightarrow t = \frac{J_p}{F_{avg}}$$

(b) Determine an expression for the mass of the projectile.

$$J_p = \Delta P = mV_f - mV_i$$

$$\Rightarrow J_p = mV_x - 0$$

$$\Rightarrow m = \frac{J_p}{V_x}$$

The projectile is fired horizontally into a block of wood that is clamped to a tabletop so that it cannot move. The projectile travels a distance d into the block before it stops. Express all algebraic answers to the following in terms of d and the given quantities previously indicated, as appropriate.

(c) Derive an expression for the work done in stopping the projectile.

$$W = K_E = \frac{1}{2} m V_x^2 = \frac{1}{2} \cdot \frac{J_P}{V_x} \cdot V_x^2 = \frac{1}{2} J_P V_x$$

(d) Derive an expression for the average force F_b exerted on the projectile as it comes to rest in the block.

$$W = F_b d = \frac{1}{2} J_P V_x$$

$$\Rightarrow F_b = \frac{J_P V_x}{2d}$$

Now a new projectile and block are used, identical to the first ones, but the block is <u>not</u> clamped to the table. The projectile is again fired into the block of wood and travels a new distance d_n into the block while the block slides across the table a short distance D. Assume the following: the projectile enters the block with speed v_x, the average force F_b between the projectile and the block has the same value as determined in part (d), the average force of friction between the table and the block is f_T, and the collision is instantaneous so the frictional force is negligible during the collision.

(e) Derive an expression for d_n in terms of d, D, f_T, and F_b, as appropriate.

$$P_i = P_f$$

m

(f) Derive an expression for d_n in terms of d, the mass m of the projectile, and the mass M of the block.

$$P_i = P_f$$

$$m V_x = (M+m) V'$$

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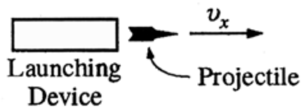


$J = \Delta P$

Mech. 1.

A projectile is fired horizontally from a launching device, exiting with a speed v_x. While the projectile is in the launching device, the impulse imparted to it is J_p, and the average force on it is F_{avg}. Assume the force becomes zero just as the projectile reaches the end of the launching device. Express your answers to parts (a) and (b) in terms of v_x, J_p, F_{avg}, and fundamental constants, as appropriate.

(a) Determine an expression for the time required for the projectile to travel the length of the launching device.

$\cancel{J_p = \Delta p}$

$\cancel{J_p = mv_2 - mv_1 \quad v_1 = 0 \quad v_2 = v_x}$

$\cancel{J_p = mv_x}$

$\cancel{Ft_{exit} = mv_x}$

$\boxed{t_{ext} = J_p / F_{avg}}$

$J_p = \int F\,dt$

$J_p = \int F_{avg}\,dt$

$J_p = Ft\Big|_0^{t_{exit}}$

$J_p = F\,t_{exit}$

(b) Determine an expression for the mass of the projectile.

$J_p = \Delta P$

$v_1 = 0$

$v_2 = v_x$

$J_p = mv_2 - mv_1$

$J_p = mv_x$

$\boxed{m = J_p / v_x}$

GO ON TO THE NEXT PAGE.

The projectile is fired horizontally into a block of wood that is clamped to a tabletop so that it cannot move. The projectile travels a distance d into the block before it stops. Express all algebraic answers to the following in terms of d and the given quantities previously indicated, as appropriate.

MV $m\,a\,d$

(c) Derive an expression for the work done in stopping the projectile.

$W = FD$ $W = \int F\,dr$

$J = \frac{kgm}{s}$

$W = \frac{Km^2}{s^2}$

$\boxed{W = J_p V_x}$

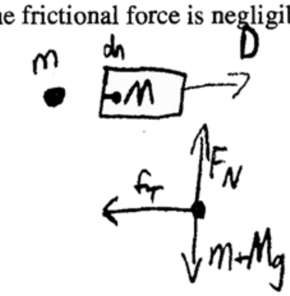
(d) Derive an expression for the average force F_b exerted on the projectile as it comes to rest in the block.

$W = F_b D$

$F_b = W/D$

$\boxed{F_b = \frac{J_p U_x}{D}}$

Now a new projectile and block are used, identical to the first ones, but the block is not clamped to the table. The projectile is again fired into the block of wood and travels a new distance d_n into the block while the block slides across the table a short distance D. Assume the following: the projectile enters the block with speed v_x, the average force F_b between the projectile and the block has the same value as determined in part (d), the average force of friction between the table and the block is f_T, and the collision is instantaneous so the frictional force is negligible during the collision.



(e) Derive an expression for d_n in terms of d, D, f_T, and F_b, as appropriate.

$P_{in} = m v_x$ $W = F_b d_n$

(f) Derive an expression for d_n in terms of d, the mass m of the projectile, and the mass M of the block.

$P_i = mV_x$

$K = \frac{1}{2} m v_x^2$

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Question 1

Overview

This question assessed students' understanding of impulse, momentum, work, kinetic energy, and the relationship between net work and the change in kinetic energy. It tested the application of these concepts in one-dimensional situations involving collisions between a projectile and a fixed block, and a projectile and a block that is allowed to move along a horizontal surface with friction. Parts (e) and (f) required students to distinguish the details regarding work and energy before, during and after the collision. The problem could also be addressed using combinations of kinematics and Newton's second law.

Sample: M1A
Score: 15

This response earned full credit for all parts. In part (d) the student explains the meaning of the negative sign, but that was not required. In part (e) the student uses $\frac{1}{2}J_p v_x$ as the kinetic energy of the projectile just before it strikes the block rather than $\frac{1}{2}mv_x^2$. This was given full credit as well, based on the understanding of its relationship to kinetic energy shown in part (c).

Sample: M1B
Score: 9

Parts (a) and (b) earned full credit. Part (c) did not earn the point because it did not indicate that the work is negative. Part (d) earned full credit. Part (e) earned no credit, and part (f) earned 1 point for the correct conservation of momentum equation.

Sample: M1C
Score: 6

The response earned full credit for parts (a) and (b), but no credit for part (c). Full credit was earned for part (d): The answer is incorrect, but the student correctly substitutes the incorrect answer from part (c). No credit was earned for parts (e) and (f).