CollegeBoard
Advanced Placement Program

AP® Physics B
2006 Scoring Guidelines

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General Notes About 2006 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 awarded. 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 receive credit. For example, if use of the equation expressing a particular concept is worth 1 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 awarded. 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. See pages 21–22 of the *AP Physics Course Description* for a description of the use of such terms as "derive" and "calculate" on the exams, and what is expected for each.

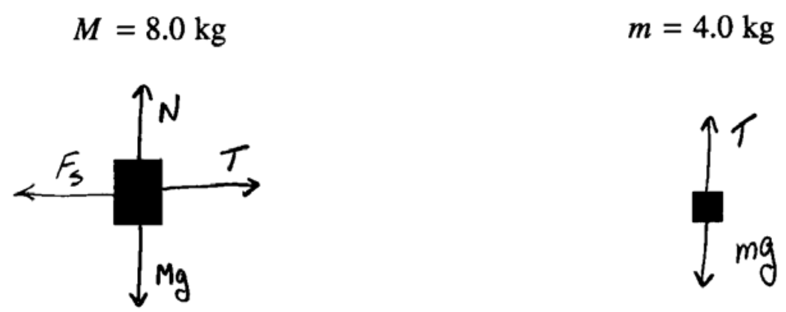
4. The scoring guidelines typically show numerical results using the value $g = 9.8 \text{ m/s}^2$, but use of 10 m/s^2 is of course also acceptable. Solutions usually show numerical answers using both values when they are significantly different.

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 receive 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) 3 points



For the 4 kg mass:
For two correctly labeled vertical vectors, one up and one down, and no horizontal vectors — 1 point
For the 8 kg mass:
For two correctly labeled vertical vectors, one up and one down — 1 point
For two correctly labeled horizontal vectors, one left and one right — 1 point

<u>Note</u>: *Labels could be in words, symbols, or correct numerical values. The two masses were considered independently. It was not necessary to indicate that the tension forces had the same magnitudes or that the weights were different.*

(b) 2 points

For a correct approach using Newton's 2nd law and the static equilibrium condition for the 4 kg mass that leads to a relationship between tension and weight — 1 point

$T = mg$

$T = (4.0\text{ kg})\left(9.8\text{ m/s}^2\right)$

For the correct answer — 1 point

$T = 39\text{ N}$ (40 N using $g = 10\text{ m/s}^2$)

(c) 3 points

For a correct application of Newton's 2nd law and the static equilibrium condition for the 8 kg mass leading to a relationship between tension from part (b) and spring force — 1 point

$T = F_S = k\Delta x$

$k = T/\Delta x$

For using the correct displacement of the spring from equilibrium — 1 point

$\Delta x = 0.25\text{ m} - 0.20\text{ m} = 0.05\text{ m}$

For a correct calculation leading to a positive value of k using the tension from (b) — 1 point

$k = 39\text{ N}/0.05\text{ m}$

$k = 780\text{ N/m}$ (800 N/m using 40 N from part (b))

Question 1 (continued)

	Distribution of points
(d) 2 points	
For a correct kinematic approach for an accelerating system applied to the 4 kg mass	1 point
$y = \frac{1}{2}gt^2$	
$t = \sqrt{2y/g}$	
$t = \sqrt{2(0.70\text{ m})/(9.8\text{ m/s}^2)}$	
For the correct answer	1 point
$t = 0.38\text{ s}$ (0.37 s using $g = 10\text{ m/s}^2$)	
<u>Note</u>: *An alternate approach using conservation of energy to determine the speed at the bottom and then use of a kinematic equation for time could also earn full credit.*	
(e) 2 points	
For a correct approach to calculating the frequency (*f* or ω) of a mass-spring system	1 point
$f = \frac{1}{T} = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$ OR $\omega = \sqrt{\frac{k}{m}}$	
$f = \frac{1}{2\pi}\sqrt{\frac{780\text{ N/m}}{8.0\text{ kg}}}$ OR $\omega = \sqrt{\frac{780\text{ N/m}}{8.0\text{ kg}}}$	
For a correct value of frequency (*f* or ω) consistent with the value of *k* from part (c)	1 point
$f = 1.6\text{ Hz}$ OR $\omega = 10\text{ rad/s}$	
(f) 2 points	
For using conservation of energy, setting the spring potential energy equal to the kinetic energy of the block	1 point
$\frac{1}{2}mv^2 = \frac{1}{2}kA^2$	
$v = \sqrt{\frac{k}{m}}A$	
$v = \sqrt{\frac{780\text{ N/m}}{8.0\text{ kg}}}(0.05\text{ m})$	
For a correct calculation of speed consistent with the value of *k* from part (c) and the correct displacement from equilibrium	1 point
$v = 0.49\text{ m/s}$ (0.50 m/s using 800 N/m from part (c))	
(Global) 1 point	
For correct units and a reasonable number of digits in all numerical answers obtained (must have at least one final numerical answer to earn this point)	1 point

Question 2

15 points total **Distribution of points**

Two general approaches were used by most of the students.

Approach A: Spread the students out every 10 meters or so. The students each start their stopwatches as the runner starts and measure the time for the runner to reach their positions.

Analysis variant 1: Make a position vs. time graph. Fit the parabolic and linear parts of the graph and establish the position and time at which the parabola makes the transition to the straight line.

Analysis variant 2: Use the position and time measurements to determine a series of average velocities ($\upsilon_{avg} = \Delta x/\Delta t$) for the intervals. Graph these velocities vs. time to obtain a horizontal line and a line with positive slope. Establish the position and time at which the sloped and horizontal lines intersect.

Analysis variant 3: Use the position and time measurements to determine a series of average accelerations $\left(\Delta x = \upsilon_0 t - at^2/2\right)$. Graph these accelerations vs. time to obtain two horizontal lines, one with a nonzero value and one at zero acceleration. Establish the position and time at which the acceleration drops to zero.

Approach B: Concentrate the students at intervals at the end of the run, in order to get a very precise value of the constant speed υ_f, or at the beginning in order to get a precise value for a_u. The total distance *D* is given by $D = \left(a_u t_u^2/2\right) + \upsilon_f\left(T - t_u\right)$, where *T* is the total measured run time. In addition, $\upsilon_f = a_u t_u$. These equations can be solved for a_u and t_u (if υ_f is measured directly) or υ_f and t_u (if a_u is measured directly). Students may have also defined and used distances, speeds, and times for the accelerated and constant-speed portions of the run in deriving these relationships.

(a) 2 points

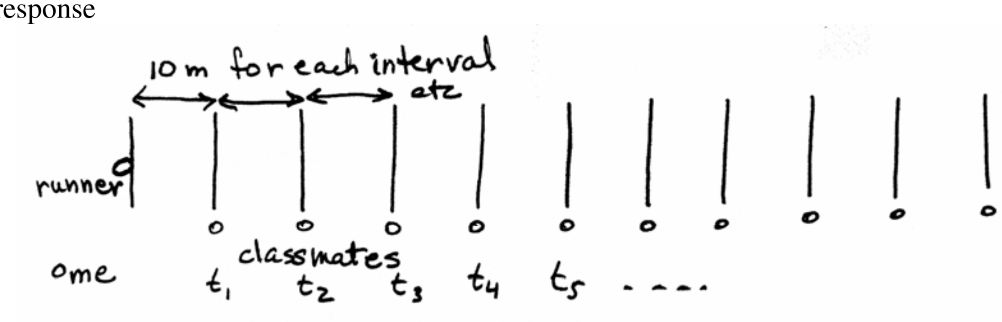
For checking off a distance-measuring device and describing its use in part (b)	1 point
For checking off a stopwatch and describing its use in part (b)	1 point

Question 2 (continued)

Distribution of points

(b) 6 points

Sample response



Use the tape measure and chalk to mark off the 100 meters in 10 meter lengths. Set a classmate with a stopwatch at marks as shown. Use the starter's pistol to signal the runner to run and the classmates to start their stopwatches. Each person turns off the stopwatch when the runner reaches his or her mark. You then have measurements of the time to reach each increment of 10 meters.

For taking distance measurements for 8 to 11 distinct fixed positions per run	1 point
For measuring time for the same 8 to 11 distinct fixed positions, consistent with the description of the experimental setup	1 point
For an experimental technique consistent with being able to determine the requested quantities	2 points
For a diagram of the experimental setup with clear labels and consistent with the technique described (awarded even if the technique is wrong)	1 point
For a technique that allows data for all positions to be taken in a single run	1 point

(c) 7 points

<u>Approach A</u>

For a clear and detailed explanation of the data analysis process	3 points
<u>Note</u>: *This part of the solution was graded holistically and students could earn between 0 and 3 points depending on the clarity and completeness of their explanation.*	
For equations or clear prose and use of the data to identify the two distinct regions of motion (constant acceleration and constant velocity)	1 point
For clearly and correctly identifying t_u	1 point
For clearly and correctly identifying a_u	1 point
For having the final answers correct and no incorrect statements or calculations among the correct ones	1 point

Question 2 (continued)

	Distribution of points
(c) (continued)	
Approach B	
Students needed to clearly indicate which variable was used (acceleration or final velocity) by including the following.	
For a description or diagram that clearly defines all the variables being used	1 point
For a description or diagram showing how the needed variable (acceleration or final velocity) will be determined	1 point
For a successful transformation of the above description into equation form	2 points
For correctly solving the equations obtained	1 point
For work that would determine a correct value of a_u	1 point
For work that would determine a correct value of t_u	1 point

Question 3

15 points total | **Distribution of points**

(a) 2 points

For checking "Positive" — 1 point
For a correct justification (point only awarded if "Positive" checked) — 1 point
Example: At point *P*, the electric field due to charge q_1 points to the right because electric fields point toward negative charges. The field from q_2 must point to the left, i.e., away from the charge, to cancel the field from q_1. So q_2 must be positive.
Point is not awarded if the justification is "*charges cancel each other out.*"

(b) 4 points

For a correct equation for electric field strength of a point charge — 1 point

$$E = \frac{1}{4\pi\epsilon_0}\frac{q_i}{r_i^2}$$

For showing that the sum of the electric fields at *P* is zero — 1 point

$$0 = \frac{1}{4\pi\epsilon_0}\frac{q_1}{d_1^2} + \frac{1}{4\pi\epsilon_0}\frac{q_2}{d_2^2}$$

$$\frac{1}{4\pi\epsilon_0}\frac{q_2}{d_2^2} = -\frac{1}{4\pi\epsilon_0}\frac{q_1}{d_1^2}$$

$$q_2 = -\frac{d_2^2}{d_1^2}q_1$$

For correct substitution of values — 1 point

$$q_2 = -\frac{(0.40\text{ m})^2}{(0.10\text{ m})^2}\left(-3.0\times10^{-9}\text{ C}\right)$$

For the correct answer — 1 point

$$q_2 = +4.8\times10^{-8}\text{ C}$$

(c) 3 points

For writing Coulomb's law — 1 point

$$F = \frac{1}{4\pi\epsilon_0}\frac{q_1 q_2}{r^2}$$

For correct substitution of given values and the charge found in part (b) — 1 point

$$F_2 = \left(9.0\times10^9\text{ N}\cdot\text{m}^2/\text{C}^2\right)\frac{\left(3.0\times10^{-9}\text{ C}\right)\left(48\times10^{-9}\text{ C}\right)}{(0.30\text{ m})^2}$$

$$F_2 = 1.4\times10^{-5}\text{ N}$$

For a direction consistent with the answer to part (a) — 1 point
The electric force on q_2 is to the left (or to the right if the answer to part (a) is "Negative")

Question 3 (continued)

Distribution of points

(d) 4 points

For showing that the sum of the potentials is zero — 1 point

$V_1 + V_2 = 0$

For using the point charge formula for electric potential — 1 point

$V = \dfrac{q}{4\pi\epsilon_0 r}$ OR $V = k\dfrac{q}{r}$

$\dfrac{1}{4\pi\epsilon_0}\dfrac{q_1}{r_1} + \dfrac{1}{4\pi\epsilon_0}\dfrac{q_2}{r_2} = 0$

For correctly substituting values into the equation above, including q_1, the value of q_2 from part (b), and distances in the denominators that sum to 0.3 m and include a valid distance variable — 1 point

Example:

$\dfrac{1}{4\pi\epsilon_0}\dfrac{-3.0\times10^{-9}\text{ C}}{(0.30\text{ m} - d)} + \dfrac{1}{4\pi\epsilon_0}\dfrac{48\times10^{-9}\text{ C}}{d} = 0$

$d\left(-3.0\times10^{-9}\text{ C}\right) = -(0.30\text{ m} - d)\left(48\times10^{-9}\text{ C}\right)$

$d\left(3.0\times10^{-9}\text{ C}\right) = (0.30\text{ m} - d)\left(48\times10^{-9}\text{ C}\right)$

$\left(48\times10^{-9}\text{ C} + 3.0\times10^{-9}\text{ C}\right)d = (0.30\text{ m})\left(48\times10^{-9}\text{ C}\right)$

$d = \dfrac{(0.30\text{ m})\left(48\times10^{-9}\text{ C}\right)}{\left(48\times10^{-9}\text{ C} + 3.0\times10^{-9}\text{ C}\right)}$

$d = 0.28\text{ m}$

For finding a value for x within the range $-0.1\text{ m} < x < 0.2\text{ m}$ — 1 point

<u>Note</u>: This point was only awarded if the substitution point was awarded

$x = 0.20\text{ m} - 0.28\text{ m} = -0.08$

(e) 2 points

For stating that net work done is zero — 1 point

For a correct justification — 1 point

Example:

$W = \Delta U = q\,\Delta V$. Since the potential is zero at infinity and is also zero at the final position, $\Delta V = 0$. Therefore $W = 0$.

Question 4

15 points total **Distribution of points**

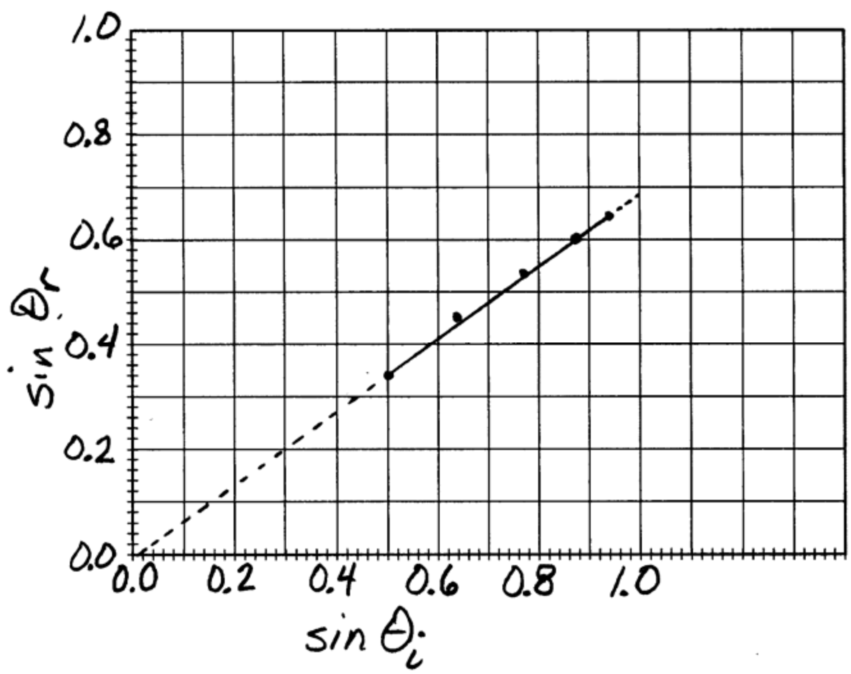
(a) 2 points

Trial	θ_i	θ_r	$\sin\theta_i$	$\sin\theta_r$
1	30°	20°	0.50	0.34
2	40°	27°	0.64	0.45
3	50°	32°	0.77	0.53
4	60°	37°	0.87	0.60
5	70°	40°	0.94	0.64

For identifying that both quantities to be graphed are the sines of the angles — 1 point
For correctly calculating the sines using degrees — 1 point

(b) 4 points

Example:



For correctly labeling both axes with the sines of the angles — 1 point
For correctly labeling both axes with appropriate numerical scales — 1 point
For plotting the five points — 1 point
For correctly drawing a best fit line that includes the entire range of data points and may extend beyond them — 1 point

Question 4 (continued)

		Distribution of points
(c)	4 points	
	For a statement or implicit use of Snell's Law $n_1 \sin\theta_i = n_2 \sin\theta_r$ (or $\sin\theta_i = n_2 \sin\theta_r$ since $n_1 = n_{air} = 1$)	1 point
	For indicating that the index of refraction *n* can be obtained from the slope or inverse of the slope depending on choice of variable plotted on each axis Example using graph above $n = \frac{\sin\theta_i}{\sin\theta_r} = \frac{1}{\text{slope}}$	1 point
	For using two sets of points directly from the line to find the slope $\text{slope} = \frac{0.53 - 0.41}{0.78 - 0.60} = 0.67$	1 point
	For a correct calculation of the index of refraction consistent with the slope of the graph $n = 1/0.67 = 1.5$	1 point
(d)	1 point	
	For checking "The air-oil interface only"	1 point
(e)	4 points	
	For indicating that the optical path difference between the waves reflecting off the air-oil interface and the oil-water interface is one-half wavelength $\Delta\ell = \lambda/2$	1 point
	For indicating that the wave reflecting off the oil-water interface travels a distance equal to twice the thickness of the oil $\Delta\ell = 2t$	1 point
	For indicating that the wavelength of the light in the oil film is different from the wavelength of the light in air $\lambda_{film} = \lambda_{air}/n_{film}$	1 point
	The three equations above are combined to relate the film thickness to the wavelength. $2t = \lambda_{film}/2 = \lambda_{air}/2n_{film}$ $t = \lambda_{air}/4n_{film}$ $t = 6.0 \times 10^{-7}\,\text{m}/4(1.43)$	
	For the correct answer with appropriate units $t = 1.05 \times 10^{-7}\,\text{m} = 105\text{ nm}$	1 point

Notes:

A student who checked "The oil-water interface only" *in part (d) and then correctly calculated a wavelength of 105 nm for the thickness of the oil was awarded full credit.*

A student who checked "Both interfaces" *or* "Neither interface" *in part (d) and then correctly calculated a wavelength of 210 nm for the thickness of the oil was awarded full credit.*

Question 5

10 points total | **Distribution of points**

(a)

(i) 2 points

From the ideal gas law

$PV = nRT$

For recognizing that $\frac{PV}{T}$ is constant throughout the cycle — 1 point

Using the fact that pressure is the same for states 1 and 2

$\frac{V_1}{T_1} = \frac{V_2}{T_2}$

$T_2 = \frac{V_2 T_1}{V_1}$

For substituting correct values into a correct expression — 1 point

$T_2 = \left(0.50\ \text{m}^3\right)(373\ \text{K})\Big/\left(0.25\ \text{m}^3\right)$

$T_2 = 746\ \text{K}$

<u>Note</u>: *Some students earned the first point by correctly calculating the value of n or the product nR using the given conditions in state 1. The student could have then proceeded to the correct substitutions in both parts (i) and (ii).*

(ii) 1 point

Using the fact that volume is the same for states 1 and 3

$\frac{P_1}{T_1} = \frac{P_3}{T_3}$

$T_3 = \frac{P_3 T_1}{P_1}$

For substituting correct values into a correct expression — 1 point

$T_3 = \left(1.5 \times 10^5\ \text{Pa}\right)(373\ \text{K})\Big/\left(1.0 \times 10^5\ \text{Pa}\right)$

$T_3 = 560\ \text{K}$

Question 5 (continued)

Distribution of points

(b) 4 points

Calculate the work done on the gas in each of the three processes making up the cycle.

For calculating the work done from state 1 to state 2 given constant pressure — 1 point

$W_{1\rightarrow 2} = -P\Delta V = -(1.0 \times 10^5 \text{ Pa})(0.25 \text{ m}^3) = -25000 \text{ J}$ (negative sign not required)

For calculating the work done from state 2 to state 3 using average pressure — 1 point

$W_{2\rightarrow 3} = -P_{avg}\Delta V = -(1.25 \times 10^5 \text{ Pa})(\text{-}0.25 \text{ m}^3) = +31250 \text{ J}$ (positive sign not required)

Note: *A student that correctly calculated the area under the curve for either process earned the point for that process.*

For noting that no work is done going from state 1 to state 3 or for indicating net work is only contributed in going from state 1 to 2 and state 2 to 3 — 1 point

$W_{3\rightarrow 1} = 0$ or $W_{net} = W_{1\rightarrow 2} + W_{2\rightarrow 3}$

For the correct answer with the correct sign — 1 point

$W_{net} = +6250 \text{ J}$

Alternate solution — *Alternate points*

For stating that the net work done is the area of the triangle or for implying such by using the expression for the area of a triangle, $A = \frac{1}{2}\text{base}\bullet\text{height}$ — *1 point*

For correctly substituting the base value from the graph — *1 point*

For correctly substituting the height value from the graph — *1 point*

$W = \frac{1}{2}\left(1.5 \times 10^5 \text{ Pa} - 1.0 \times 10^5 \text{ Pa}\right)\left(0.50 \text{ m}^3 - 0.25 \text{ m}^3\right)$

For the correct answer with the correct sign — *1 point*

$W_{net} = +6250 \text{ J}$

(c) 3 points

For checking "Removed" — 1 point

Note: *Checking the box consistent with the sign of the net work calculated in part (b) earned full credit, but checking the incorrect option resulted in no additional credit.*

For referring to the first law of thermodynamics implicitly or explicitly — 1 point

$\Delta U = Q + W$

For noting that the consequence of the closed thermodynamic cycle is that the internal energy does not change (since the gas ends at the same temperature at which it started), and/or that the heat transferred equals the opposite of the work done on gas — 1 point

$\Delta U = 0$ or $Q = -W$

This can also be expressed in words.

Example: Work is done on the gas, which would add energy to the gas. Heat must be removed in order for the internal energy to be unchanged after one cycle.

Question 6

10 points total	**Distribution of points**

(a) 3 points

For correctly expressing frequency in terms of speed of light and wavelength, either with symbols or numerical values — 1 point

$$f = \frac{c}{\lambda} = \frac{3.0 \times 10^8 \text{ m/s}}{1.5 \times 10^{-8} \text{ m}} = 2.0 \times 10^{16} \text{ Hz}$$

For substituting the expression for frequency into the equation for the energy of a photon — 1 point

$$E = hf = (6.63 \times 10^{-34} \text{ J} \cdot \text{s})(2.0 \times 10^{16} \text{ Hz})$$

For the correct answer with correct units — 1 point

$$E = 1.33 \times 10^{-17} \text{ J} = 82.7 \text{ eV}$$

Alternate solution — *Alternate points*

For correctly expressing the momentum of the photon in terms of Planck's constant and the wavelength, either with symbols or numerical values — *1 point*

$$\lambda = \frac{h}{p} \quad \text{or} \quad p = \frac{h}{\lambda} = \frac{6.63 \times 10^{-34} \text{ J} \cdot \text{s}}{1.5 \times 10^{-8} \text{ m}} = 4.42 \times 10^{-26} \text{ kg•m/s}$$

For substituting the expression for the momentum into the energy-momentum relationship for a photon — *1 point*

$$E = pc = (4.42 \times 10^{-26} \text{ N} \cdot \text{s})(3.0 \times 10^8 \text{ m/s})$$

For the correct answer with correct units — *1 point*

$$E = 1.33 \times 10^{-17} \text{ J} = 82.7 \text{ eV}$$

(b) 4 points

The kinetic energy of a massive particle is given by

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

For substituting the energy in joules from part (a) as the kinetic energy to calculate the speed of the electron — 1 point

$$1.33 \times 10^{-17} \text{ J} = \frac{1}{2}(9.11 \times 10^{-31} \text{ kg}) v^2$$

$$v = 5.4 \times 10^6 \text{ m/s}$$

For calculating the momentum of the electron using the speed calculated above — 1 point

$$p = mv = (9.11 \times 10^{-31} \text{ kg})(5.4 \times 10^6 \text{ m/s})$$

For substituting the momentum into the equation for the deBroglie wavelength — 1 point

$$\lambda = \frac{h}{p} = \frac{h}{mv} = \frac{6.63 \times 10^{-34} \text{ J•s}}{(9.11 \times 10^{-31} \text{ kg})(5.4 \times 10^6 \text{ m/s})}$$

For the correct answer with correct units — 1 point

$$\lambda = 1.35 \times 10^{-10} \text{ m}$$

Question 6 (continued)

		Distribution of points
(c)	3 points	
	The expected answer is a description of an experiment in which a beam of electrons is aimed at either a single slit, a double slit, a diffraction grating, or a crystal. The student must also describe the interference pattern of maxima and minima appearing on a screen as evidence of the wave nature of the electron.	
	For using a beam of electrons (NOT a single electron)	1 point
	For aiming the electron beam at one of the objects noted above	1 point
	For indicating that the resultant is an interference pattern (a drawing was acceptable)	1 point

<u>*Notes*</u>*:*

If the experiment description is completely correct except that it includes a beam of light instead of electrons, it earned two of the three possible points.

No points were earned for merely naming an experiment, either in reference to commonly known experimenters ("Davisson–Germer experiment") or pieces of equipment ("double-slit experiment").