AP® Physics B
2008 Scoring Guidelines

The College Board: Connecting Students to College Success

The College Board is a not-for-profit membership association whose mission is to connect students to college success and opportunity. Founded in 1900, the association is composed of more than 5,400 schools, colleges, universities, and other educational organizations. Each year, the College Board serves seven million students and their parents, 23,000 high schools, and 3,500 colleges through major programs and services in college admissions, guidance, assessment, financial aid, enrollment, and teaching and learning. Among its best-known programs are the SAT®, the PSAT/NMSQT®, and the Advanced Placement Program® (AP®). The College Board is committed to the principles of excellence and equity, and that commitment is embodied in all of its programs, services, activities, and concerns.

Visit the College Board on the Web: www.collegeboard.com.
AP Central is the online home for AP teachers: apcentral.collegeboard.com.

AP® PHYSICS
2008 SCORING GUIDELINES

General Notes About 2008 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 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 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. 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 $g = 9.8\ \text{m/s}^2$, but use of $10\ \text{m/s}^2$ 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

10 points total | **Distribution of points**

(a) 4 points

For the correct value of t_1, the time car *A* is accelerating — 1 point

$\upsilon_f = \upsilon_i + at_1$

$t_1 = \left(\upsilon_f - \upsilon_i\right)/a = (5.0 \text{ m/s} - 2.0 \text{ m/s})/(1.5 \text{ m/s})$

$t_1 = 2.0 \text{ s}$

For a correct value of x_1, the distance car *A* travels while accelerating — 1 point

$x_1 = \upsilon_i t_1 + \frac{1}{2}at_1^2$

$x_1 = (2.0 \text{ m/s})(2.0 \text{ s}) + \frac{1}{2}\left(1.5 \text{ m/s}^2\right)(2.0 \text{ s})^2$

$x_1 = 7.0 \text{ m}$

<u>Note</u>: The equation $\upsilon_f^2 = \upsilon_i^2 + 2ax_1$ could also be used.

For a correct value of $(x - x_1)$, the distance car *A* travels at constant velocity — 1 point

$(x - x_1) = (15.0 \text{ m} - 7.0 \text{ m}) = 8.0 \text{ m}$

For correctly calculating t_2, the time car *A* travels at constant velocity — 1 point

$x = x_1 + \upsilon_f t_2$

$t_2 = (x - x_1)/\upsilon_f = (15.0 \text{ m} - 7.0 \text{ m})/5.0 \text{ m/s}$

$t_2 = 1.6 \text{ s}$

$t_{tot} = t_1 + t_2 = 2.0 \text{ s} + 1.6 \text{ s}$

$t_{tot} = 3.6 \text{ s}$

(b)

(i) 2 points

For any clear statement that momentum is conserved — 1 point

$m_A\upsilon_{Ai} = m_A\upsilon_{Af} + m_B\upsilon_B$

$$\upsilon_{Af} = \frac{m_A\upsilon_{Ai} - m_B\upsilon_B}{m_A} = \frac{(250 \text{ kg})(5.0 \text{ m/s}) - (200 \text{ kg})(4.8 \text{ m/s})}{250 \text{ kg}}$$

For a correct answer — 1 point

$\upsilon_{Af} = 1.2 \text{ m/s}$

(ii) 1 point

For indicating a direction of car *A* after the collision that is consistent with the calculation of υ_{Af} — 1 point

<u>Note</u>: A correct calculation yields a direction to the right.

Question 1 (continued)

	Distribution of points
(c) 3 points	
For correctly indicating that the collision is <u>not</u> elastic	1 point
For a statement that kinetic energy is not conserved	1 point
For clearly showing that $K_f < K_i$, implying the collision is non-elastic	1 point

$$K_i = \frac{1}{2}m_A\upsilon_{Ai}^2 = \frac{1}{2}(250\ \text{kg})(5.0\ \text{m/s})^2$$

$$K_i = 3125\ \text{J}$$

$$K_f = \frac{1}{2}m_A\upsilon_{Af}^2 + \frac{1}{2}m_B\upsilon_B = \frac{1}{2}(250\ \text{kg})(1.2\ \text{m/s})^2 + \frac{1}{2}(200\ \text{kg})(4.8\ \text{m/s})^2$$

$$K_f = 2484\ \text{J}$$

Note: Two points were awarded for checking "yes" with a clear, correct explanation that it is a partially elastic collision.

Question 2

15 points total | **Distribution of points**

(a) 4 points

For a correct application of Newton's 2nd law for the two-block system — 1 point

$F = (m_A + m_B)a$

Note: Newton's 2nd law may be applied to each block separately to produce an equivalent solution.

For a correct determination of the acceleration — 1 point

$$a = \frac{F}{(m_A + m_B)} = \frac{4.0\text{ N}}{(2.0\text{ kg} + 8.0\text{ kg})}$$

$a = 0.40\ \text{m/s}^2$

For correct substitution of the acceleration into Newton's 2nd law for one of the blocks — 1 point

$F_{spring} = m_A a \quad (\text{or } F - F_{spring} = m_B a\,)$

For the correct solution (consistent with the value of the acceleration found above) — 1 point

$F_{spring} = (2.0\text{ kg})(0.40\ \text{m/s}^2) \qquad (\text{or } F_{spring} = 4.0\text{ N} - (8.0\text{ kg})(0.40\ \text{m/s}^2))$

$F_{spring} = 0.80\text{ N}$

Note: A correct free-body diagram for each block could earn 1 point each.

(b) 2 points

For a correct expression relating spring force to extension — 1 point

$F_{spring} = kx$

For the correct solution using the spring force from part (a) — 1 point

$$x = \frac{F_{spring}}{k} = \frac{0.80\text{ N}}{80\ \text{N/m}}$$

$x = 0.010\text{ m}$

(c) 3 points

For correctly indicating that the acceleration will be the same as before — 1 point

For a correct justification (only if the previous point was awarded) — 2 points

Examples:

- Explaining that in both cases there is a 4.0 N force pulling a combined mass of 10 kg, and hence the acceleration will be the same in the two cases.
  (Note: One point was awarded when the student noted that either the net force acting on the system of two blocks or the mass of the system is unchanged. For full credit, the student must have noted that both the force and mass are the same in the two cases.)
- Applying Newton's 2nd law to each block and calculating an acceleration with the same value as in part (a).

Question 2 (continued)

Distribution of points

(d) 3 points

For correctly indicating that the spring extension is greater than in part (b)	1 point
For a correct justification (only if the previous point was awarded)	2 points

Examples:

- The spring force on the 8.0 kg block produces the same acceleration as the spring force on the 2.0 kg block in part (a); hence the spring force is greater than in part (a) so the extension is greater.
- Applying Newton's 2nd law to show that the new spring extension is 0.040 m.

Notes:

- A partial justification worth a single point may note that the spring is pulling on a larger mass than before, or may note that the force exerted by the spring is larger than before (without explaining why this force is larger).
- Students who answered part (c) by saying that the acceleration is greater could earn 2 points here by noting that the force exerted by the spring on block B must be larger in order to give the larger mass a greater acceleration.

(e) 3 points

For indicating that, after block A impacts the wall, mechanical energy is conserved	1 point
For correctly applying conservation of energy, equating the energy immediately after block A hits the wall to the energy when the spring is at maximum compression	1 point

$$K_{before} + U_{before} = K_{after} + U_{after}$$

$$\frac{1}{2}m_B v^2 + 0 = 0 + \frac{1}{2}kx^2$$

For the correct solution	1 point

$$x = \sqrt{\frac{m_B v^2}{k}} = \sqrt{\frac{(8.0\text{ kg})(0.50\text{ m/s})^2}{80\text{ N/m}}}$$

$$x = 0.16\text{ m}$$

Question 3

15 points total **Distribution of points**

(a) 4 points

For using Ohm's law to find the total resistance of the circuit — 1 point

$\mathcal{E}/I = R_{\text{total}}$

$16\ \text{V}/4.0\ \text{A} = 4.0\ \Omega$

For a correct expression for the total resistance that has the internal resistance of the power supply in series with the wire's resistance — 1 point

$R_{\text{internal}} + R_{\text{wire}} = R_{\text{total}}$

$0.50\ \Omega + R_{\text{wire}} = 4.0\ \Omega$

$R_{\text{wire}} = 3.5\ \Omega$

An alternate solution is to use a circuit equation to determine the voltage across the wire for the first point, and then Ohm's law to determine its resistance for the second point.

$V_{\text{wire}} = V_{\text{term}} = \mathcal{E} - V_{\text{int}} = 16\ \text{V} - (4.0\ \text{A})(0.50\ \Omega) = 14\ \text{V}$

$R_{\text{wire}} = V/I = 14\ \text{V}/4.0\ \text{A} = 3.5\ \Omega$

Using the expression for the resistance of a wire in terms of its dimensions

$R_{\text{wire}} = \rho L/A$

$L = R_{\text{wire}}A/\rho$

For correct substitutions — 1 point

$L = (3.5\ \Omega)\left(3.5 \times 10^{-9}\ \text{m}^2\right)/\left(1.7 \times 10^{-8}\ \Omega\text{•m}\right)$

For a correct answer with correct units — 1 point

$L = 0.72\ \text{m}$

Note: The last 2 points could be earned for showing understanding of $R = \rho L/A$ by using it with the appropriate values of ρ and A and some value of resistance.

(b) 4 points

The force on the magnet is upwards.

Points are awarded for the justification as follows.

For indicating that the right-hand rule should be used — 1 point

For correctly identifying the direction of the magnetic field between the poles of the magnet as being to the right — 1 point

For obtaining a downward force on the wire using the right-hand rule — 1 point

Example for the above 3 points: The direction of the force on the wire is given by the right-hand rule. The current is into the page and the magnetic field is to the right. By the right-hand rule, the force on the wire is then downwards.

For using Newton's 3rd Law — 1 point

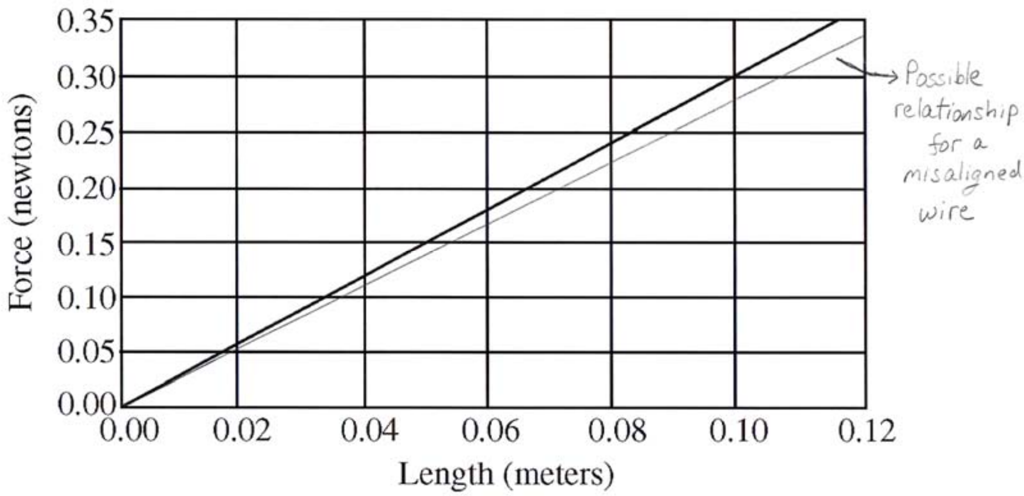
For example: The force on the wire is downwards, so the force on the magnet must be upwards.

Note: A student who checks "downward" can receive 3 of 4 points if they correctly use the right-hand rule to show that the force on the wire is downward. Just checking the box "upward" without justification received no points.

Question 3 (continued)

		Distribution of points
(c)	3 points	
	For simplifying the formula given in the equation table for the force on a current-carrying wire (or stating that $\theta = 90°$)	1 point
	$F = ILB$	
	For correct substitutions	1 point
	$B = \dfrac{F}{IL} = \dfrac{(0.060\text{ N})}{(4.0\text{ A})(0.020\text{ m})}$	
	For a correct answer with correct units	1 point
	$B = 0.75\text{ T}$	

(d) 3 points



For a straight-line relationship	1 point
For a relationship that passes through the origin	1 point
For a slope less than the original line but NOT zero	1 point

(e) 1 point

For a plausible source of error that would produce the plotted results	1 point

For example: The horizontal width of the wire approaches the width of the magnet. Near the edges of the magnet the strength of the magnetic field decreases. As the length of the wire increases, the magnetic field experienced by the ends of the wire decreases in strength, leading to a smaller magnetic force than expected.

Question 4

10 points total | **Distribution of points**

(a) 3 points

For a correct application of kinematics to the vertical motion — 1 point

$\upsilon_{yf}^2 = \upsilon_{y0}^2 - 2gh = 0$

$\upsilon_{y0}^2 = 2gh$

For correctly expressing the vertical component of the initial velocity — 1 point

$\upsilon_{y0} = \upsilon_0 \sin 50^\circ$

For a correct solution — 1 point

$\upsilon_0 \sin 50^\circ = \sqrt{2gh}$

$$\upsilon_0 = \frac{\sqrt{2gh}}{\sin 50^\circ} = \frac{\sqrt{2\left(9.8 \text{ m/s}^2\right)(0.150 \text{ m})}}{\sin 50^\circ}$$

$\upsilon_0 = 2.24 \text{ m/s}$ (or 2.26 m/s using $g = 10 \text{ m/s}^2$)

(b) 2 points

For a correct expression for the volume flow rate, using an area of πr_0^2 — 1 point

Volume flow rate $= A_0\upsilon_0 = \pi r_0^2 \upsilon_0$

For a correct solution with correct units, consistent with υ_0 found in part (a) — 1 point

Volume flow rate $= \pi\left(4.00 \times 10^{-3} \text{ m}\right)^2 (2.24 \text{ m/s})$

Volume flow rate $= 1.13 \times 10^{-4} \text{ m}^3/\text{s}$ (or $1.14 \times 10^{-4} \text{ m}^3/\text{s}$ using $g = 10 \text{ m/s}^2$)

Question 4 (continued)

Distribution of points

(c) 5 points

For a correct expression for the water velocity in the feeder pipe with substitutions consistent with previous work — 1 point

$A_0 \upsilon_0 = A_p \upsilon_p$

$\upsilon_p = \dfrac{A_0}{A_p}\upsilon_0 = \left(\dfrac{r_0}{r_p}\right)^2 \upsilon_0 = \left(\dfrac{4.00 \times 10^{-3} \text{ m}}{7.00 \times 10^{-3} \text{ m}}\right)^2 2.24 \text{ m/s}$

For a correctly calculated answer consistent with previous work — 1 point

$\upsilon_p = 0.731 \text{ m/s}$ (or $\upsilon_p = 0.738 \text{ m/s}$ using $g = 10 \text{ m/s}^2$)

For a correct expression of Bernoulli's equation — 1 point

$P_0 + \rho g h_0 + \frac{1}{2}\rho\upsilon_0^2 = P_p + \rho g h_p + \frac{1}{2}\rho\upsilon_p^2$

$P_p - P_0 = \rho g\left(h_0 - h_p\right) + \frac{1}{2}\rho\left(\upsilon_0^2 - \upsilon_p^2\right)$

For consistent/correct substitutions of heights and velocities — 1 point

$P_p - P_0 = \left(1.0 \times 10^3 \text{ kg/m}^3\right)\left(9.8 \text{ m/s}^2\right)(3.00 \text{ m})$

$\qquad + \frac{1}{2}\left(1.0 \times 10^3 \text{ kg/m}^3\right)\left[(2.24 \text{ m/s})^2 - (0.731 \text{ m/s})^2\right]$

For correctly accounting for atmospheric pressure (with no obvious algebraic errors) leading to an answer — 1 point

P_0 is atmospheric pressure, and $P_p = P_0 + P_{gauge}$

$P_{gauge} = P_p - P_0 = 3.16 \times 10^4 \text{ Pa}$ (or $3.23 \times 10^4 \text{ Pa}$ using $g = 10 \text{ m/s}^2$)

Question 5

10 points total — **Distribution of points**

(a) 3 points

Process	W	Q	ΔU
$A \rightarrow B$	0	+	+
$B \rightarrow C$	–	+	0
$C \rightarrow A$	+	–	–

For correctly identifying the signs of all three variables $(W,\ \Delta U,\ Q)$ for process $A \rightarrow B$ — 1 point

For correctly identifying the signs of all three variables $(W,\ \Delta U,\ Q)$ for process $B \rightarrow C$ — 1 point

For correctly identifying the signs of all three variables $(W,\ \Delta U,\ Q)$ for process $C \rightarrow A$ — 1 point

(b) 4 points

For a correct explanation of why zero work is done on the gas — 1 point

Examples of correct responses include:

- There is no area under the graph/curve.
- There is no volume change.
- The piston does not move.
- $W = -P\Delta V$, where $\Delta V = 0$.
- $W = 0$ by definition in an isochoric/isovolumetric process.

For a correct explanation of why ΔU is positive — 1 point

Examples of correct responses include:

- For a fixed number of moles of a sample, an increase in pressure at constant volume implies an increase in temperature, and an increased temperature implies an increase in internal energy (ΔU is positive).
- State B is on a higher isotherm than state A.
- $U = \dfrac{3}{2}nRT$; since T increases, ΔU is positive.
- $U = \dfrac{3}{2}PV$; since P increases at a constant V, ΔU is positive.
- A correct use of the first law of thermodynamics leading to ΔU being positive ($\Delta U = Q + W$, but $W = 0$ so $\Delta U = Q$; since Q is positive, ΔU must be also).

For a correct explanation of why Q is positive — 1 point

Examples of correct responses include:

- If pressure increases *and* volume is constant, heat must be added to system.
- If temperature increases *and* volume is constant, heat must be added to system.
- A correct use of the first law of thermodynamics leading to Q being positive ($\Delta U = Q + W$, but $W = 0$ so $\Delta U = Q$; since ΔU is positive, Q must be also).

For stating the first law of thermodynamics, whether used correctly or not, OR for correctly explaining all three variables without reference to the first law of thermodynamics — 1 point

Question 5 (continued)

Distribution of points

(c) 3 points

For correctly relating states B and C at a constant temperature, using either the ideal gas law or Boyle's Law — 1 point

$$\frac{P_B V_B}{T_B} = \frac{P_C V_C}{T_C} \quad \text{or} \quad P_B V_B = P_C V_C$$

For the correct substitution of the appropriate values — 1 point

$$V_C = \frac{P_B}{P_C} V_B = \left(\frac{5\ \text{atm}}{1\ \text{atm}}\right)\left(0.001\ \text{m}^3\right)$$

For the correct answer including units — 1 point

$$V_C = 0.005\ \text{m}^3$$

Alternate solution — *Alternate points*

For correctly relating states A and B at a constant volume, using the ideal gas law, to determine the temperature T_B — *1 point*

$$\frac{P_A V_A}{T_A} = \frac{P_B V_B}{T_B}$$

$$T_B = \frac{P_B}{P_A} T_A = \left(\frac{5\ \text{atm}}{1\ \text{atm}}\right)(400\ \text{K}) = 2000\ \text{K}$$

For realizing that $T_C = T_B$ *and correctly relating states A and C at constant pressure, using the value of* T_B *and the ideal gas law or Charles' Law to calculate* V_C. — *1 point*

$$\frac{P_A V_A}{T_A} = \frac{P_C V_C}{T_C} \quad \text{or} \quad \frac{V_A}{T_A} = \frac{V_C}{T_C}$$

$$V_C = \frac{T_C}{T_A} V_A = \frac{T_B}{T_A} V_A = \left(\frac{2000\ \text{K}}{400\ \text{K}}\right)\left(0.001\ \text{m}^3\right)$$

For the correct answer, including units — *1 point*

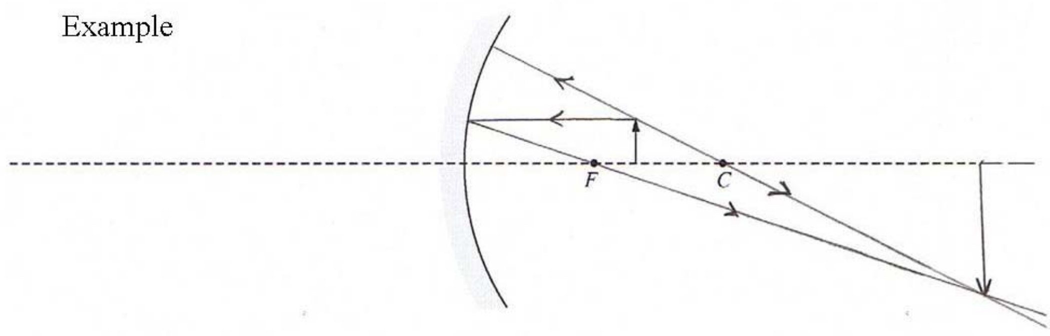
$$V_C = 0.005\ \text{m}^3$$

Another method is to use the ideal gas law to calculate T_B, *set* $T_C = T_B$, *and once again use the ideal gas law to calculate* V_C.

Question 6

10 points total | **Distribution of points**

(a) 3 points



For a correct ray, correctly drawn (must reflect off mirror and must extend below principal axis) — 1 point

For a second correct ray, correctly drawn (must reflect off mirror and must extend below principal axis) — 1 point

For an inverted image located to the right of C and at the location where the rays converge — 1 point

(b) 2 points

For correctly indicating that the image is real — 1 point

For a correct justification with no incorrect statements — 1 point

Examples of correct responses include:

- Image is inverted.
- Image is on the same side of the mirror as the object $(s_i > 0)$.
- Light from the object passes through the image point.
- Rays converge at the image.
- Image could be projected on a screen.
- Object is placed beyond the focal point of a converging mirror.

(c) 2 points

For a correct mirror equation and at least one step toward a correct solution — 1 point

$\frac{1}{s_i} + \frac{1}{s_o} = \frac{1}{f}$, leading to $\frac{1}{s_i} = \frac{1}{f} - \frac{1}{s_o}$, for example

Substituting into the second equation above

$$\frac{1}{s_i} = \frac{1}{6.0 \text{ cm}} - \frac{1}{8.0 \text{ cm}} = \frac{8-6}{48}\,\frac{1}{\text{cm}} = \frac{2}{48}\,\frac{1}{\text{cm}}$$

For a correct calculation with correct units, consistent with substitutions made — 1 point

$s_i = 24 \text{ cm}$

Question 6 (continued)

Distribution of points

(d) 3 points

For correctly indicating that the image is smaller than the object — 1 point
For a correct justification — 2 points

Numerical justification:

$$\frac{1}{s_i} = \frac{1}{f} - \frac{1}{s_o}$$

$$\frac{1}{s_i} = \frac{1}{-6.0\text{ cm}} - \frac{1}{8.0\text{ cm}} = -\frac{8+6}{48}\frac{1}{\text{cm}} = \frac{14}{48}\frac{1}{\text{cm}}$$

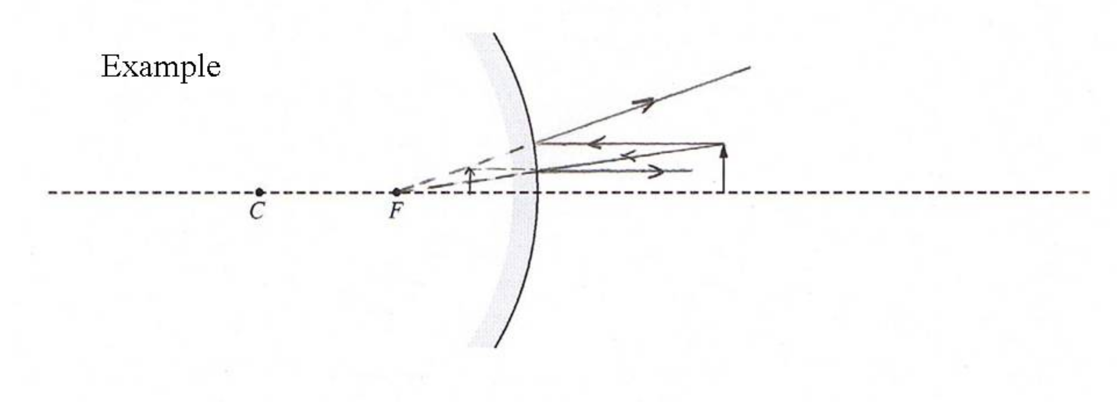
$$s_i = -3.4\text{ cm}$$

$$M = -\frac{s_i}{s_o} = -\frac{-3.4\text{ cm}}{8.0\text{ cm}} = 0.43$$

Qualitative justifications:

- Diverging mirrors always form an image that is smaller than the object.
- $s_i < s_o$ and so $h_i < h_o$. The student must prove the inequality with calculations or a diagram.

Ray diagram justification:



The ray diagram must contain at least two correct rays that show reflection and correctly show the image upright and smaller than the object, between the focal point and the mirror. The student must specifically indicate that his/her ray diagram is the justification to earn any points for it.
An incomplete but not incorrect justification earns 1 point.

Question 7

10 points total | **Distribution of points**

(a) 2 points

For correct substitutions into the relationship between the de Broglie wavelength and the momentum — 1 point

$$p = \frac{h}{\lambda}$$

$$p = \frac{6.63 \times 10^{-34}\ \text{J}\bullet\text{s}}{0.038 \times 10^{-9}\ \text{m}}$$

For a correct answer — 1 point

$$p = 1.74 \times 10^{-23}\ \frac{\text{kg}\bullet\text{m}}{\text{s}}$$

(b) 2 points

Calculating the speed of an electron

$$\upsilon = \frac{p}{m} = \frac{1.74 \times 10^{-23}\ \text{kg}\bullet\text{m/s}}{9.11 \times 10^{-31}\ \text{kg}} = 1.91 \times 10^{7}\ \text{m/s}$$

For correct substitutions into a correct expression for kinetic energy — 1 point

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

$$K = \frac{1}{2}\left(9.11 \times 10^{-31}\ \text{kg}\right)\left(1.91 \times 10^{7}\ \text{m/s}\right)^2$$

For a correct answer — 1 point

$$K = 1.66 \times 10^{-16}\ \text{J}$$

(c) 3 points

For any indication of conservation of energy — 1 point

$$K = qV$$

For correct substitutions into a correct expression — 1 point

$$V = \frac{K}{q} = \frac{\left(1.66 \times 10^{-16}\ \text{J}\right)}{\left(1.60 \times 10^{-19}\ \text{C}\right)}$$

For a correct answer — 1 point

$$V = 1.04 \times 10^{3}\ \text{V}$$

Question 7 (continued)

		Distribution of points
(d)	3 points	
	For any indication that this process is the photoelectric effect	1 point
	$K_{max} = hf - \phi$	
	For recognizing that $K_{max} = 0$	1 point
	$f = \dfrac{\phi}{h} = \dfrac{4.5 \text{ eV}}{4.14 \times 10^{-15} \text{ eV•s}}$	
	For a correct answer with units	1 point
	$f = 1.09 \times 10^{15} \text{ Hz}$	