General Notes About 2009 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 $g = 9.8\ \mathrm{m/s^2}$, but use of $10\ \mathrm{m/s^2}$ 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 2

15 points total **Distribution of points**

(a) 3 points

For correctly substituting the given values into the expression for resistance — 1 point

$R = \rho\ell/A$

$R = \left(4.5\times10^{-4}\ \Omega\text{•m}\right)(0.080\ \text{m})\Big/\left(5.0\times10^{-6}\ \text{m}^2\right) = 7.2\ \Omega$

For correctly combining $V = IR$ and $P = IV$ to get an expression for power in terms of voltage and resistance — 1 point

$P = V^2/R$

$P = (9.0\ \text{V})^2/7.2\ \Omega$

For the correct answer — 1 point

$P = 11\ \text{W}$

Alternate solution: *Alternate Points*

For correctly substituting the given values into the expression for resistance — *1 point*

$R = \rho\ell/A$

$R = \left(4.5\times10^{-4}\ \Omega\text{•m}\right)(0.080\ \text{m})\Big/\left(5.0\times10^{-6}\ \text{m}^2\right) = 7.2\ \Omega$

For correctly combining $V = IR$ and $P = IV$ to get an expression for power in terms of current and resistance — *1 point*

$P = I^2R$

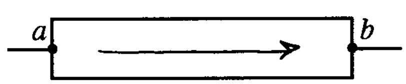
$I = 9.0\ \text{V}/7.2\ \Omega = 1.25\ \text{A}$

$P = (1.25\ \text{A})^2(7.2\ \Omega)$

For the correct answer — *1 point*

$P = 11\ \text{W}$

(b) 3 points



Side View

For an arrow directed from *a* to *b* — 1 point

For correctly indicating that the conventional current is from *a* to *b* OR that the electron current is from *b* to *a* — 1 point

For correctly indicating that the electric field is in the same direction as the conventional current OR in the opposite direction to the electron current — 1 point

Alternate solution: *Alternate Points*

For an arrow directed from a to b — *1 point*

For stating that point a is at a higher potential than point b — *1 point*

For stating that electric field points from higher to lower potential — *1 point*

Note: The third point could be earned for an incorrect field direction consistent with an incorrect current or potential drop direction.

Question 2 (continued)

Distribution of points

(c) 2 points

For recognizing that the electric field is uniform in the bar and stating the relationship between V and E for a uniform field — 1 point

$E = V/\ell$

$E = (9.0\text{ V})/(0.080\text{ m})$

For the correct answer — 1 point

$E = 110\ \text{V/m}$

Alternate solution: — *Alternate Points*

$E = \rho J$

For correctly calculating the current density — *1 point*

$J = I/A = 1.25\text{ A}/5.0\times10^{-6}\ \text{m}^2$

$J = 2.5\times10^{5}\ \text{A/m}^2$

$E = J = \left(4.5\times10^{-4}\ \Omega\text{•m}\right)\left(2.5\times10^{5}\ \text{A/m}^2\right)$

For the correct answer — *1 point*

$E = 110\ \text{V/m}$

(d) 2 points

For applying the equation for the magnetic force on a wire with current — 1 point

$F = I\ell B$

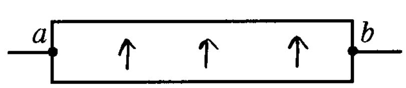
For substituting for current, in terms of either the given quantities or numerical values consistent with previous calculations, for example, the current determined in part (a) — 1 point

Examples: $F = (V/R)\ell B = V\ell B/R$ OR $F = I\ell B$

$F = (9.0\text{ V})(0.08\text{ m})(0.25\text{ T})/(7.2\ \Omega)$ OR $F = (1.25\text{ A})(0.080\text{ m})(0.25\text{ T})$

$F = 0.025\text{ N}$

(e) 1 point



Side View

For arrows indicating an electric field directed toward the top of the bar — 1 point

Question 2 (continued)

Distribution of points

(f) 3 points

For recognizing that when there is no longer deflection, the electric force is equal and opposite to the magnetic force — 1 point

$F_E = F_B$

For the correct expressions for the electric force and the magnetic force — 1 point

$F_E = qE$

$F_B = q\upsilon B$

$qE = q\upsilon B$

$E = \upsilon B$

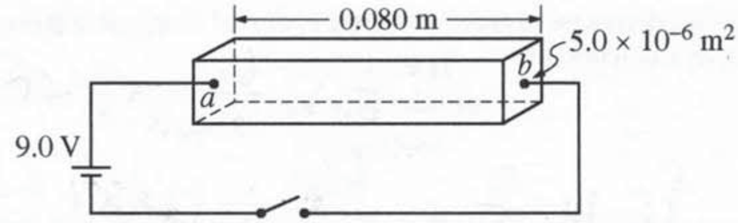
For correctly substituting values — 1 point

$E = \left(3.5 \times 10^{-3}\ \text{m/s}\right)\left(0.25\ \text{T}\right)$

$E = 8.8 \times 10^{-4}\ \text{V/m}$

Units point

For the correct units on at least two numerical answers — 1 point



E&M. 2.

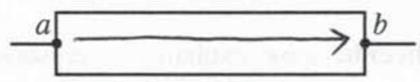
A 9.0 V battery is connected to a rectangular bar of length 0.080 m, uniform cross-sectional area $5.0 \times 10^{-6}\ \text{m}^2$, and resistivity $4.5 \times 10^{-4}\ \Omega\bullet\text{m}$, as shown above. Electrons are the sole charge carriers in the bar. The wires have negligible resistance. The switch in the circuit is closed at time $t = 0$.

(a) Calculate the power delivered to the circuit by the battery.

Resistance of the bar $= \dfrac{4.5 \times 10^{-4} \times 0.080}{5 \times 10^{-6}} = 7.2\,\Omega$

$P = VI = V\dfrac{V}{R} = \dfrac{V^2}{R} = \dfrac{9 \times 9}{7.2} = 11.25\,W$ power is 11.25W

(b) On the diagram below, indicate the direction of the electric field in the bar.



Side View

Explain your answer.

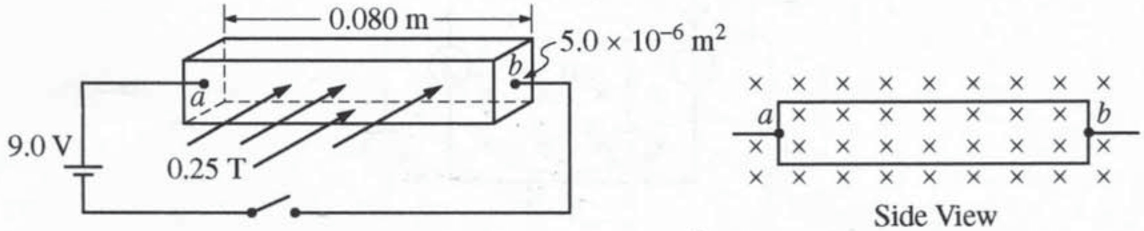
~~ele~~ Electrons gather on b side gradually so a side becomes more and more positive and b side becomes more and more negative. And electric field points from positive to negative, so electric field points from a to b.

(c) Calculate the strength of the electric field in the bar.

$V = E \cdot d$

$9V = E(0.08m)$ $\boxed{E = 112.5\ N/C}$

A uniform magnetic field of magnitude 0.25 T perpendicular to the bar is added to the region around the bar, as shown below.



(d) Calculate the magnetic force on the bar.

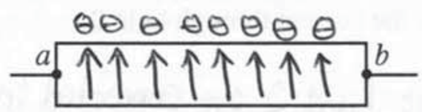
$$F = \int I\,dl \times B = (1.25A)(0.08m)(0.25) = \boxed{0.025\,N}$$

$R = 7.2\Omega$

$V = 9V$

$I = \frac{V}{R} = \frac{9V}{7.2\Omega} = 1.25A \qquad l = 0.08m$

(e) The electrons moving through the bar are initially deflected by the external magnetic field. On the diagram below, indicate the direction of the additional electric field that is created in the bar by the deflected electrons.



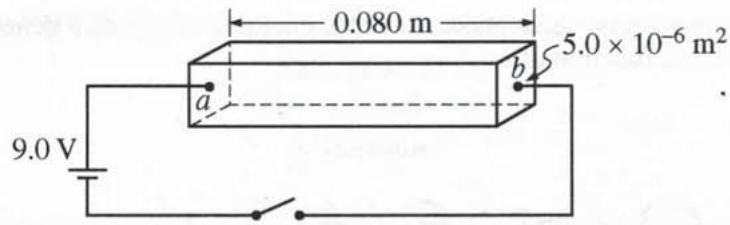
Side View

(f) The electrons eventually experience no deflection and move through the bar at an average speed of 3.5×10^{-3} m/s . Calculate the strength of the additional electric field indicated in part (e).

$F = BqV = Eq$

$(0.25T)\cancel{(1.6\times10^{-19}\,C)}(3.5\times10^{-3}\,m/s) = E\cancel{(1.6\times10^{-19}\,C)}$

$E = 0.25 \times 3.5 \times 10^{-3} = \boxed{8.75\times10^{-4}\,N/C}$



E&M. 2.

A 9.0 V battery is connected to a rectangular bar of length 0.080 m, uniform cross-sectional area 5.0×10^{-6} m^2, and resistivity 4.5×10^{-4} $\Omega \bullet$m, as shown above. Electrons are the sole charge carriers in the bar. The wires have negligible resistance. The switch in the circuit is closed at time $t = 0$.

(a) Calculate the power delivered to the circuit by the battery.

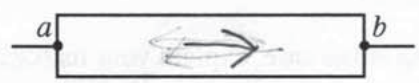
$P = IV$ $\quad$ $P = \frac{9^2}{R}$ $\quad$ $R = \frac{\rho l}{A}$

$V = IR$ $\quad$ $R = \frac{4.5 \times 10^{-4} (.08)}{5 \times 10^{-6} m^2}$

$I = \frac{V}{R}$ $\quad$ $P = \frac{9^2}{7.2}$

$P = \frac{V^2}{R}$ $\quad$ $P = 11.25$ W $\quad$ $R = 7.2\,\Omega$

(b) On the diagram below, indicate the direction of the electric field in the bar.



Side View

Explain your answer.

$E = \rho J$, $E = F/q$, $\oint E\,dA = \frac{Q}{\varepsilon_0}$ $\quad$ $E = \frac{-dV}{dr}$

J is a vector and ρ is scalar so E must be in the direction of J which follows conventional current in the positive direction.

(c) Calculate the strength of the electric field in the bar.

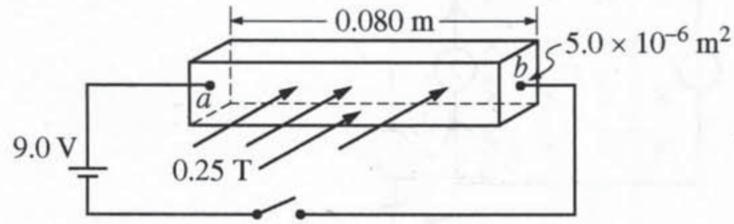
$$E = -\frac{dV}{dr} = -\frac{\Delta V}{\Delta r} = -\frac{9V}{.08m} = -112.5 \text{ V/m}$$

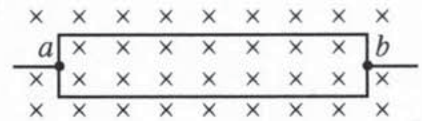
$E = F/q$

$E = \rho J$

$\oint E \cdot dA = \frac{Q}{\varepsilon_0}$

A uniform magnetic field of magnitude 0.25 T perpendicular to the bar is added to the region around the bar, as shown below.





Side View

(d) Calculate the magnetic force on the bar.

$$F = \int I \, dl \times B$$

$$F = I l \times B$$

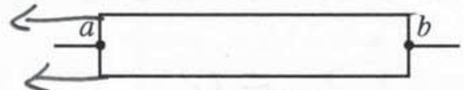
$$F = \frac{P}{V} l \times B$$

$$F = \frac{P}{V} l B \sin 90$$

$$F = \frac{11.25\,\mathrm{W}}{9} (.08) .25 \sin 90$$

$$F = .025\ \mathrm{N}.$$

(e) The electrons moving through the bar are initially deflected by the external magnetic field. On the diagram below, indicate the direction of the additional electric field that is created in the bar by the deflected electrons.



Side View

(f) The electrons eventually experience no deflection and move through the bar at an average speed of 3.5×10^{-3} m/s . Calculate the strength of the additional electric field indicated in part (e).

$F = \frac{k q_1 q_2}{r^2}$ $\quad I = \frac{dQ}{dt}$ $\quad F_m = qV \times B$

$E = \frac{F}{q}$ $\quad U_c = \frac{1}{2} QV = \frac{1}{2} CV^2$ $\quad \oint B \cdot dl = \mu_0 I$

$\oint E \, dA = \frac{Q}{\varepsilon_0}$ $\quad R = \frac{\rho l}{A}$ $\quad dB = \frac{\mu_0}{4\pi} \frac{I \, dl \times r}{r^3}$

$E = -\frac{dV}{dr}$ $\quad E = \rho J$ $\quad B_s = \mu_0 n I$ $\quad U_L = \frac{1}{2} L I^2$

$V = k \sum \frac{q}{r}$ $\quad I = N e V_d A$ $\quad F = \int I \, dl \times B$

$U_{E} = qV = \frac{k q_1 q_2}{r}$ $\quad V = IR$ $\quad \Phi_m = \int B \cdot dA$

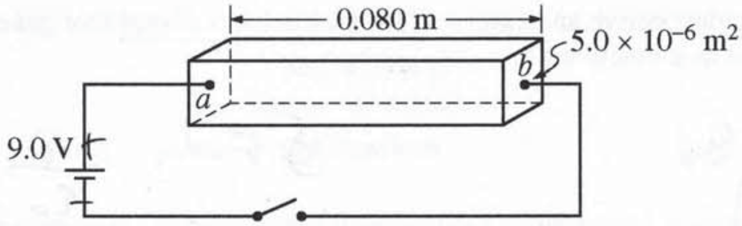
$R = \sum R_i$

$C = \frac{Q}{V}$ $\quad R_s = \sum R_i$ $\quad \mathcal{E} = -\frac{d\Phi_m}{dt}$

$C = \frac{K \varepsilon_0 A}{d}$ $\quad \frac{1}{R_p} = \sum \frac{1}{R_i}$ $\quad \mathcal{E} = -L \frac{dI}{dt}$

$C_p = \sum C_i$

$\frac{1}{C_s} = \sum \frac{1}{C_i}$ $\quad P = IV$



E&M. 2.

A 9.0 V battery is connected to a rectangular bar of length 0.080 m, uniform cross-sectional area 5.0×10^{-6} m^2, and resistivity 4.5×10^{-4} $\Omega \bullet$m, as shown above. Electrons are the sole charge carriers in the bar. The wires have negligible resistance. The switch in the circuit is closed at time $t = 0$.

(a) Calculate the power delivered to the circuit by the battery.

$P = IV$ $\quad R = \frac{\rho l}{A}$ $\quad R = \frac{(4.5e^{-4})(.08)}{5e^{-6}}$

$P = (1.25)(9)$ $\quad V = IR$ $\quad \boxed{R = 7.2\Omega}$

$= \boxed{11.25\text{W}}$ $\quad I = V/R$

$I = 9/7.2 = \boxed{1.25A}$

(b) On the diagram below, indicate the direction of the electric field in the bar.

Side View

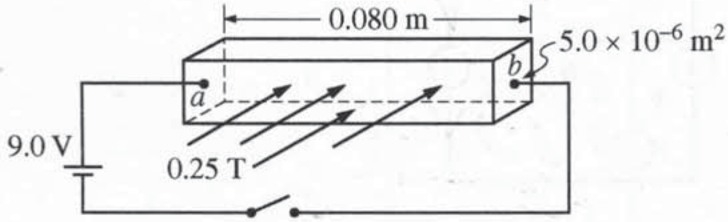
Explain your answer. Current →

The electric field is to the right with the current of the circuit.

(c) Calculate the strength of the electric field in the bar.

$\oint E\,dA = \frac{q}{\varepsilon_0}$

A uniform magnetic field of magnitude 0.25 T perpendicular to the bar is added to the region around the bar, as shown below.



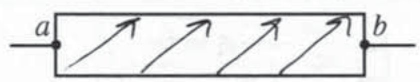
Side View

(d) Calculate the magnetic force on the bar.

$F_m = qvb$

$F_m = eIb$

(e) The electrons moving through the bar are initially deflected by the external magnetic field. On the diagram below, indicate the direction of the additional electric field that is created in the bar by the deflected electrons.



Side View

(f) The electrons eventually experience no deflection and move through the bar at an average speed of 3.5×10^{-3} m/s . Calculate the strength of the additional electric field indicated in part (e).

$v = 3.5e^{-7}$

Question 2

Overview

This question assessed students' understanding of (1) a simple circuit containing a bar-shaped resistor of given length, cross section, and resistivity; (2) the electric field inside the resistor; and (3) the consequences of imposing a uniform external magnetic field.

Sample: CE-2A
Score: 15

This is a very well-done response, neat and clear and easy to read, and earned the maximum number of points. The student starts with basic equations and shows all the relevant work. Part (b) has a correct explanation based on charge rather than directly referring to current or potential.

Sample: CE-2B
Score: 11

The response earned the maximum available points in parts (a) through (d), as well as the units point. However, no points were earned in part (e) since the arrow is in the wrong direction. No points were earned for the long list of equations in part (f). According to the scoring guidelines, the student would have received 1 point for writing both $F_E = qE$ and $F_B = qvB$. However, including all the other equations indicates a lack of understanding and thus this part of the response earned no points.

Sample: CE-2C
Score: 6

The response earned 3 points in part (a) and 3 points in part (b). In part (b) the student shows the arrow for the correct direction of the current and then states that the electric field points in the same direction as the current. No points were earned for the remaining parts or the units. The student writes $F = \ell IB$ in part (d) but never uses it, and since the student also writes $F = qvB$ it is not clear which equation the student thinks is appropriate. Finally, there is only one answer with units.