# AP® PHYSICS C: ELECTRICITY AND MAGNETISM
# 2010 SCORING GUIDELINES

## General Notes

1. The solutions contain the most common method of solving the free-response questions and the allocation of points for the 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 — for example, 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 Exams 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 2

| **15 points total** | **Distribution of points** |
| --- | --- |
| (a) 2 points | |
| For correctly stating that there is no current in the steady state | 2 points |
| $I = 0\ \text{A}$ | |
| (b) 2 points | |
| $Q = CV$ | |
| For correct substitution of capacitance into the equation above | 1 point |
| $Q = (10\ \mu\text{F})(30\ \text{V})$ | |
| For a correct numerical answer with units | 1 point |
| $Q = 300\ \mu\text{C}$ | |
| (c) 3 points | |
| $U = \frac{1}{2}CV^2$ | |
| For substitution of the correct capacitance (in units of $\mu\text{F}$ or F) into the correct expression for energy | 1 point |
| For substitution of the battery voltage into the correct expression for energy | 1 point |
| $U = \frac{1}{2}(5\ \mu\text{F})(30\ \text{V})^2$ | |
| For correct units on a numerical answer | 1 point |
| $U = 2250\ \mu\text{J}$ | |
| (d) 2 points | |
| For recognizing the two resistors are now in series and correctly calculating the equivalent resistance | 1 point |
| $R_T = 20\ \Omega + 40\ \Omega = 60\ \Omega$ | |
| $V = IR$ | |
| $I = V/R$ | |
| For substitution of the correct voltage and the calculated equivalent resistance into Ohm's law | 1 point |
| $I = 30\ \text{V}/60\ \Omega$ | |
| $I = 0.5\ \text{A}$ | |

**Question 2 (continued)**

**Distribution of points**

(e) 3 points

For recognizing that the voltage across the $5.0\ \mu\text{F}$ capacitor is the same as that for the $40\ \Omega$ resistor and calculating that voltage — 1 point

$V_{40\ \Omega} = (0.5\ \text{A})(40\ \Omega) = 20\ \text{V}$

$Q = CV$

For correctly substituting the value of the capacitance into the above equation — 1 point

$Q = (5.0\ \mu\text{F})(20\ \text{V})$

For the correct answer — 1 point

$Q = 100\ \mu\text{C}$

*Alternate solution* — *Alternate points*

*For correctly applying the loop equation to the loop that includes the* $5.0\ \mu\text{F}$ *capacitor, the* $20\ \Omega$ *resistor and the* $30\ \text{V}$ *battery* — *1 point*

$$V - IR - \frac{Q}{C} = 0$$

$Q = (C)(V - IR)$

*For correctly substituting the current and the resistances* — *1 point*

$Q = (5.0\ \mu\text{F})[(30\ \text{V}) - (0.5\ \text{A})(20\ \Omega)]$

*For the correct answer* — *1 point*

$Q = 100\ \mu\text{C}$

(f) 3 points

$P = I^2R$

For correct substitution of the total current from part (d) and the resistance into the above equation for power (or substituting correct values into $P = V^2/R$ or $P = IV$ ) — 1 point

$P = (0.5\ \text{A})^2(40\ \Omega) = 10\ \text{W}$

For correctly substituting the power into an equation for energy — 1 point

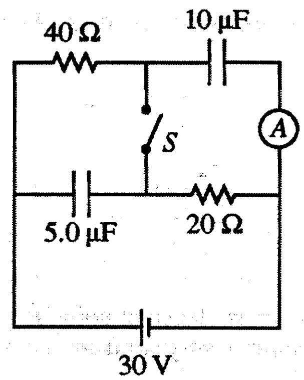
For correctly substituting the time in seconds into an equation for energy — 1 point

$E = Pt$

$E = (10\ \text{W})(60\ \text{s})$

$E = 600\ \text{J}$

Note: If time is not substituted using seconds, the units on the final answer must be consistent with the substitution.




E&M. 2.

**In the circuit illustrated above, switch $S$ is initially open and the battery has been connected for a long time.**

**(a) What is the steady-state current through the ammeter?**

Zero, because the capacitors would be fully charged in the current's steady state. This means no current would flow thru a capacitor, and thus, none would flow thru the ammeter

**(b) Calculate the charge on the $10\ \mu F$ capacitor.**

The 10 μF capacitor must have a potential difference of 30 V.

Therefore: $10\ \mu F = \frac{Q}{30\ V}$

$Q = 300\ \mu C$

**(c) Calculate the energy stored in the $5.0\ \mu F$ capacitor.**

$$U_c = \frac{1}{2} C V^2$$

$$= \frac{1}{2}(5 \mu F)(30 V)^2$$

$$= 2.25 \times 10^{-3}\ J$$

The switch is now closed, and the circuit comes to a new steady state.

(d) Calculate the steady-state current through the battery.

No current flows thru capacitors, resistors become resistors in series

$30\text{ V} = I(20\Omega + 40\Omega)$

$I = .5\text{ Amps}$

(e) Calculate the final charge on the 5.0 μF capacitor.

$V = (40\Omega)(.5\text{ Amps})$

$= 20\text{ Volts}$

$5\mu F = \frac{q}{20V}$

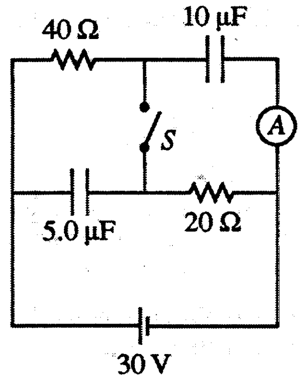
$q = 1 \times 10^{-4}\text{ C}$

(f) Calculate the energy dissipated as heat in the 40 Ω resistor in one minute once the circuit has reached steady state.

$P = I^2 R$

$\text{Energy} = (.5\text{ Amps})^2 (40\Omega)(60\text{ sec})$

$= 600\text{ J}$




E2-B-1

E&M. 2.

**In the circuit illustrated above, switch *S* is initially open and the battery has been connected for a long time.**

**(a) What is the steady-state current through the ammeter?**

$\mathcal{E} = IR_{total}$  $\boxed{I = 0\ A}$

**(b) Calculate the charge on the 10 μF capacitor.**

$q = CV$  V through 20Ω = $V_{10\mu F}$ capacitor

$= 15\ V$

$q = C(V) = 10\mu F(10V)$

$= \boxed{1.5\times10^{-4}\ C}$

**(c) Calculate the energy stored in the 5.0 μF capacitor.**

$V_c = V_{40\Omega}$ resistor $= 15V$

$\text{Energy} = \frac{1}{2}CV^2$

$= \frac{1}{2}(5\times10^{-6})(15)^2 = \boxed{5.625\times10^{-4}\ J}$

The switch is now closed, and the circuit comes to a new steady state.

E2-B-2

(d) Calculate the steady-state current through the battery.

$\mathcal{E} = IR_{total}$ $\quad R = 20 + 40 = 60\,\Omega$

$I = \frac{\mathcal{E}}{R} = \frac{30}{60} = \boxed{0.5A}$

(e) Calculate the final charge on the 5.0 μF capacitor.

$q = CV$ $\quad V_{through\ 5\mu F} = V_{40\Omega} = 0.5(40) = 20V$

$q = (5\times10^{-6}F)(20V) = \boxed{10^{-4}C}$

(f) Calculate the energy dissipated as heat in the 40 Ω resistor in one minute once the circuit has reached steady state.

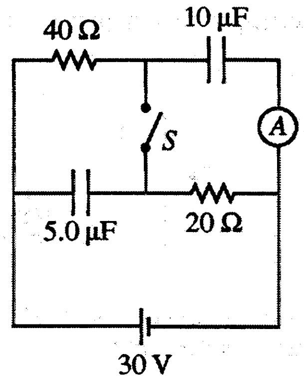
$P = I^2R$

$I = 0.5A$

$R = 40\Omega$

$P = (0.5A)^2(40\Omega) = 10\,W$

$\boxed{P = 10W}$




E2-C-1

E&M. 2.

**In the circuit illustrated above, switch $S$ is initially open and the battery has been connected for a long time.**

**(a) What is the steady-state current through the ammeter?**

Ohm's Law

Total resistance $= \dfrac{1}{\frac{1}{40} + \frac{1}{20}} = 13.33$

$V = IR$

$\dfrac{30}{13.33} = I = \boxed{2.25 (A)}$

**(b) Calculate the charge on the 10 μF capacitor.**

$Q = CV$

$Q = (10\mu F)(30V)$

$= 10 \times 10^{-6}(30)$

$= \boxed{3 \times 10^{-4} (C)}$

**(c) Calculate the energy stored in the 5.0 μF capacitor.**

$U_c = \frac{1}{2} QV = \frac{1}{2} CV^2$

$= \frac{1}{2}(10 \times 10^{-6})(30^2)$

$= \boxed{.0045 (J)}$

The switch is now closed, and the circuit comes to a new steady state.

E2-C-2

(d) Calculate the steady-state current through the battery.

Total resistance $= \dfrac{1}{\frac{1}{40}+\frac{1}{20}} = 13.33$

Ohm's Law: $V = IR$

$\dfrac{30}{13.33} = I = \boxed{2.25(A)}$

(e) Calculate the final charge on the 5.0 μF capacitor.

$Q = CV$

voltages are same across parallel

$15 + 15 = 30$

$Q = (5\times10^{-6})(15)$

$Q = \boxed{7.5\times10^{-5}(C)}$

(f) Calculate the energy dissipated as heat in the 40 Ω resistor in one minute once the circuit has reached steady state.

$V = V_0 \cdot e^{-t/RC}$

$V = 30 \cdot e^{-60/400}$

$V = 25.82$

$U = \frac{1}{2}CV_0^2$

$= \frac{1}{2}(10\mu F)(30^2)$

$= .0045 J$

$U = \frac{1}{2}CV^2$

$= \frac{1}{2}(10\mu F)(25.82)^2$

$= .0033 J$

$\boxed{.0012 J}$

## Question 2

### Overview

This question tested students' ability to apply basic circuit rules and equations to a DC circuit containing both capacitors and resistors in steady state.

**Sample: E2-A**
**Score: 15**

Even though they were not required, this response has nice explanations for parts (a) and (d). The answers throughout are circled and easy to find. The response alternates between the use of microcoulombs and coulombs; either choice was acceptable.

**Sample: E2-B**
**Score: 11**

This response earned full credit for part (a). In part (b) an incorrect voltage is used, so 1 point for the final answer was lost. Part (c) again uses an incorrect voltage and also lost 1 point. Parts (d) and (e) earned full credit. In part (f) only the power is calculated, so only 1 point was earned.

**Sample: E2-C**
**Score: 6**

Part (a) earned no credit, but part (b) earned full credit. Part (c) lost 1 point for using the incorrect capacitance. Part (d) lost 1 point for incorrectly calculating the equivalent resistance. Part (e) earned only 1 point, for substituting the correct capacitance. No credit was earned for part (f).