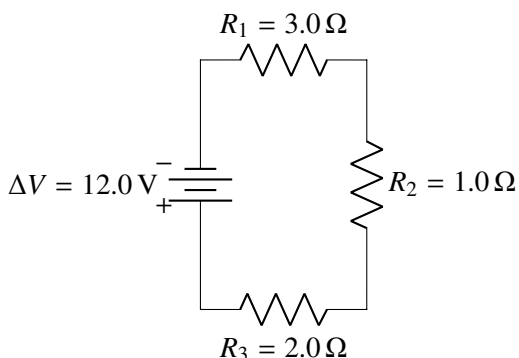


**AP PHYSICS C: CIRCUIT ANALYSIS**

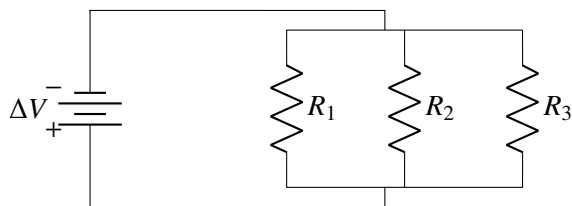
**Directions:** Each of the questions or incomplete statements below is followed by five suggested answers or completions. Select the one that is best in each case and place the letter of your choice in the corresponding box on the student answer sheet.

**Note:** To simplify calculations, you may use  $g = 10 \text{ m/s}^2$  in all problems.

**Questions 1 to 4**

1. What is the current flowing through the circuit shown in the diagram?  
(A) 1 A  
(B) 2 A  
(C) 4 A  
(D) 6 A  
(E) 12 A
2. Which of the following statements is true about the circuit shown in the diagram?  
(A) The voltage drop is greatest across  $R_1$ , but  $R_1$  has the least amount of current flowing through it.  
(B) The voltage drop is greatest across  $R_2$ , but  $R_2$  has the least amount of current flowing through it.  
(C) The voltage drop is greatest across  $R_3$ , but  $R_3$  has the least amount of current flowing through it.  
(D) The voltage drops and current are equal across all resistors.  
(E) The voltage drop is greatest across  $R_1$ , but the current is equal at all points in the circuit.
3. In this diagram, what is the power dissipated by all of the resistors in the circuit?  
(A) 2 W  
(B) 6 W  
(C) 12 W  
(D) 24 W  
(E) 48 W
4. In the diagram, what is the voltage drop across the third resistor ( $R_3$ )?  
(A) 2 V  
(B) 3 V  
(C) 4 V  
(D) 6 V  
(E) 12 V
5. Which of the following statements best summarizes a series circuit with three different resistances?  
(A) In all parts of the circuit, the resistances are different, the voltage drops are the same, and the current is different.  
(B) In all parts of the circuit, the resistances are the same, the voltage drops are the same, and the current is different.  
(C) In all parts of the circuit, the resistances are different, the voltage drops are different, and the current is the same.  
(D) In all parts of the circuit, the resistances are different, the voltage drops are the same, and the current is the same.  
(E) In all parts of the circuit, the resistances are the same, the voltage drops are the same, and the current is the same.

## Questions 6-9



$$\Delta V = 12.0 \text{ V}, R_1 = 10.0 \Omega, \\ R_2 = 6.0 \Omega, R_3 = 8.0 \Omega$$

6. For the circuit in the diagram, which of the following expressions will describe the amount of current flowing through the resistors?

(A)  $I_1 = I_2 = I_3$   
(B)  $I_3 > I_2 > I_1$   
(C)  $I_1 > I_2 < I_3$   
(D)  $I_2 > I_1 > I_3$   
(E)  $I_1 < I_2 < I_3$

7. For the circuit in the diagram, what is the equivalent resistance?

(A)  $0.040 \Omega$   
(B)  $0.40 \Omega$   
(C)  $1.0 \Omega$   
(D)  $2.6 \Omega$   
(E)  $24 \Omega$

8. For the circuit in the diagram, what is the total current?

(A)  $0.5 \text{ A}$   
(B)  $4.6 \text{ A}$   
(C)  $12 \text{ A}$   
(D)  $30 \text{ A}$   
(E)  $300 \text{ A}$

9. For the circuit in the diagram, the third resistor ( $R_3$ ) dissipates how much energy each second?

(A)  $12 \text{ W}$   
(B)  $14 \text{ W}$   
(C)  $46 \text{ W}$   
(D)  $212 \text{ W}$   
(E)  $300 \text{ W}$

## Questions 11 and 12

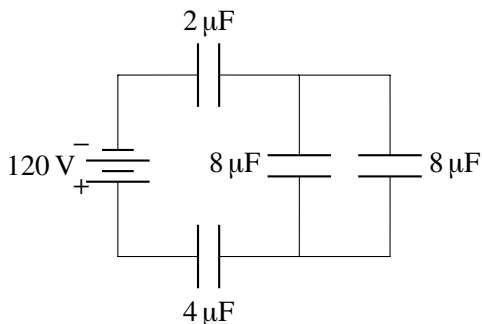
10. Which is the correct ranking of the currents for the resistors?

(A)  $I_A = I_B = I_C$   
(B)  $I_A > I_B > I_C$   
(C)  $I_C > I_A = I_B$   
(D)  $I_C > I_B > I_A$   
(E)  $I_C < I_B < I_A$

11. Which is the correct ranking of the potential differences of the resistors?

(A)  $V_A = V_B = V_C$   
(B)  $V_A > V_B > V_C$   
(C)  $V_A = V_B > V_C$   
(D)  $V_C > V_B > V_A$   
(E)  $V_C < V_B < V_A$

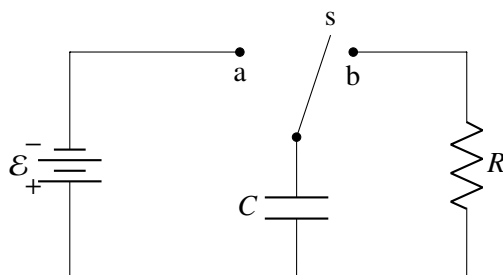
## Questions 13-14



12. The equivalent capacitance of this circuit is
- $7/4 \mu\text{F}$
  - $4/7 \mu\text{F}$
  - $21/16 \mu\text{F}$
  - $10 \mu\text{F}$
  - $22 \mu\text{F}$
13. The charge stored on the  $2 \mu\text{F}$  capacitor is most nearly
- $6 \mu\text{C}$
  - $12 \mu\text{C}$
  - $22 \mu\text{C}$
  - $36 \mu\text{C}$
  - $120 \mu\text{C}$
14. A capacitor  $C_0$  is connected to a battery and stores charge. If the space between the capacitor plates is filled with oil, which of the following quantities increase?
- Capacitance and voltage across the plates
  - Charge and voltage across the plates
  - Capacitance and electric field between the plates
  - Capacitance and charge on the plates
  - Electric field between the plates and voltage across the plates

## Question 16-17

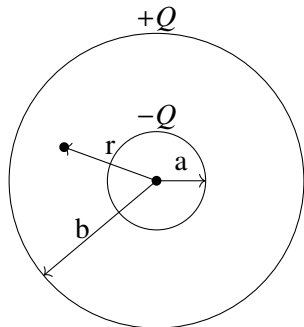
The circuit shows a capacitor, a battery, and a resistor. Switch  $S$  is first connected to point  $a$  to charge the capacitor, then a long time later switched to point  $b$  to discharge the capacitor through the resistor.



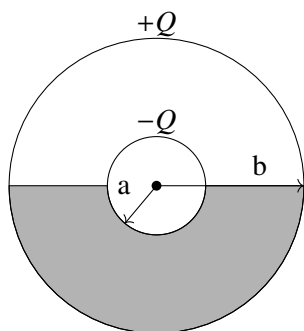
15. The time constant  $\tau$  for discharging the capacitor through the resistor could be decreased (faster discharge) by
- placing another resistor in series with the first resistor
  - placing another resistor in parallel with the first resistor
  - placing another capacitor in parallel with the first capacitor
  - placing another battery in series in the same direction with the first battery
  - increasing both  $R$  and  $C$
16. The maximum current through the resistor is
- $\mathcal{E}/2R$
  - $\mathcal{E}/R$
  - $\mathcal{E}/RC$
  - $\mathcal{E}/2RC$
  - $C\mathcal{E}/R$

**Questions 18–20**

17. The spherical capacitor shown consists of a conducting shell of radius  $a$  inside a larger conducting shell of radius  $b$ . A charge  $-Q$  is placed on the inner sphere and a charge  $+Q$  is placed on the outer shell. The capacitance of the capacitor is  $C_0$ . The magnitude of the electric field  $E$  at a distance  $r$  between the spheres is

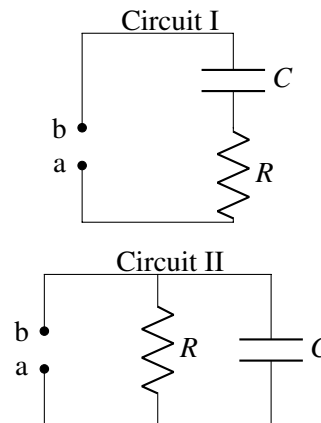


- (A)  $\frac{Q}{4\pi\epsilon_0 r^2}$   
 (B)  $\frac{Q}{4\pi\epsilon_0 r}$   
 (C)  $\frac{Q}{4\pi\epsilon_0 a^2}$   
 (D)  $\frac{Q}{4\pi\epsilon_0 b^2}$   
 (E) zero
18. The bottom half of the space between the spheres is filled with oil of dielectric constant  $\kappa = 3$ , creating two capacitors connected to each other. Which of the following is true of the two capacitors?



- (A) They are connected in series.  
 (B) They are connected in parallel.  
 (C) The total capacitance has not changed.  
 (D) The total capacitance of the spheres has decreased.  
 (E) The total capacitance is now zero.

19. With the bottom half of the space between the spheres having been filled with oil of dielectric constant  $\kappa = 3$ , the new capacitance of the spheres is
- (A) zero  
 (B)  $C_0$   
 (C)  $2C_0$   
 (D)  $3C_0$   
 (E)  $4C_0$
20. A battery of voltage  $V_0$  is attached to two parallel conducting plates. Charge is distributed on the plates, and then the battery is removed. A dielectric is then inserted between the plates, filling the space. Which of the following decreases after the battery is removed and the dielectric is inserted to fill the space between the plates?
- (A) Capacitance  
 (B) Charge on the plates  
 (C) Net electric field between the plates  
 (D) Area of the plates  
 (E) Separation distance between the plates
21. Circuit I and Circuit II shown each consist of a capacitor and a resistor. A battery is connected across a and b, and then removed. Which of the following statements is true of the circuits?

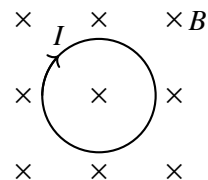


- (A) Circuit I and Circuit II will both retain stored energy when the battery is removed.  
 (B) Neither Circuit I nor Circuit II will retain stored energy when the battery is removed.  
 (C) Only Circuit I will retain stored energy when the battery is removed.  
 (D) Only Circuit II will retain stored energy when the battery is removed.

- (E) Current will continue to flow in both circuits after the battery is removed.

**Questions 25–26** Two wires are parallel to each other, one carrying twice the current as the other. The two currents flow in the same direction.

22. Which of the following is true of the forces the wires exert on each other?
- (A) The wire with the larger current exerts a greater force on the other wire.
  - (B) The wire with the smaller current exerts a greater force on the other wire.
  - (C) The wires exert equal and opposite forces on each other.
  - (D) The wires exert equal forces on each other, but in the same direction.
  - (E) The net force between the wires is zero.
23. The direction of the force between the wires is
- (A) repulsive
  - (B) attractive
  - (C) zero
  - (D) into the page
  - (E) out of the page
24. A loop of wire in the plane of the page carries a clockwise current  $I$  and is placed in a magnetic field that is directed into the page as shown. Which of the following will happen as a result of the wire loop being in the magnetic field?



- (A) The wire loop will rotate clockwise.
- (B) The wire loop will rotate counterclockwise.
- (C) The wire loop will flip on a horizontal axis through its center.
- (D) The wire loop will expand in size.
- (E) The wire loop will contract in size.

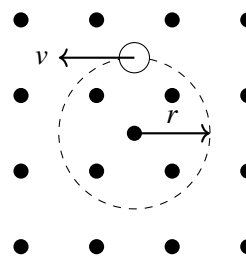
25. A thin sheet of copper is placed in a uniform magnetic field. A battery is connected to the top and bottom ends of the copper sheet, so that conventional current flows from the top to the bottom of the sheet. Points X and Y are on the left and right sides of the sheet, respectively. Which of the following statements is true?

(A) Point X is at a higher potential than point Y.  
 (B) Point Y is at a higher potential than point X.  
 (C) Point X and point Y are at equal potential.  
 (D) Point X is at zero potential, and point Y has a positive potential.  
 (E) Point Y is at zero potential, and point X has a negative potential.

26. A very long conducting slab of copper of height  $a$  and width  $b$  carries a current  $I$  throughout its cross-sectional area. The current density  $j$  is constant throughout the slab, and is directed out of the page through the facing area of the slab. Points X and Y are marked on the facing area of the slab. The current density  $j$  can be expressed by the expression

(A)  $\frac{I}{a^2}$   
 (B)  $\frac{I}{b^2}$   
 (C)  $\frac{I}{(ab)^2}$   
 (D)  $\frac{I}{ab}$   
 (E)  $\frac{I}{a+b}$

**Questions 30–31** A negatively charged particle of mass  $m$  and charge  $q$  in a uniform magnetic field  $B$  travels in a circular path of radius  $r$ .



27. In terms of the other given quantities, the charge-to-mass ratio  $q/m$  of the particle is

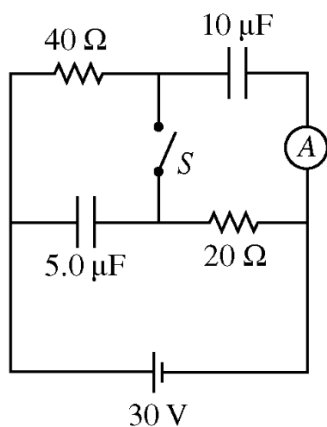
(A)  $\frac{Bv}{r}$   
 (B)  $\frac{rv}{B}$   
 (C)  $\frac{B}{rv}$   
 (D)  $\frac{rvB}{v}$   
 (E)  $\frac{v}{rB}$

28. The work done by the magnetic field after two full revolutions of the charge is

(A) zero  
 (B)  $-qvB/rm$   
 (C)  $qvm/Br$   
 (D)  $-mBr/qv$   
 (E)  $-mqvBr$

**AP PHYSICS C: CIRCUIT ANALYSIS****SECTION II****4 Questions**

**Directions:** Answer all questions. The parts within a question may not have equal weight. All final numerical answers should include appropriate units. Credit depends on the quality of your solutions and explanations, so you should show your work. Credit also depends on demonstrating that you know which physical principles would be appropriate to apply in a particular situation. Therefore, you should clearly indicate which part of a question your work is for.

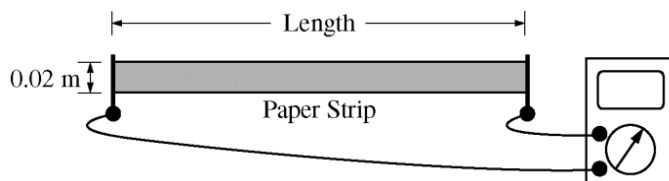


1. In the circuit illustrated above, switch  $S$  is initially open and the battery has been connected for a long time.

- (a) What is the steady-state current through the ammeter?
- (b) Calculate the charge on the  $10\ \mu\text{F}$  capacitor.
- (c) Calculate the energy stored in the  $5.0\ \mu\text{F}$  capacitor.

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

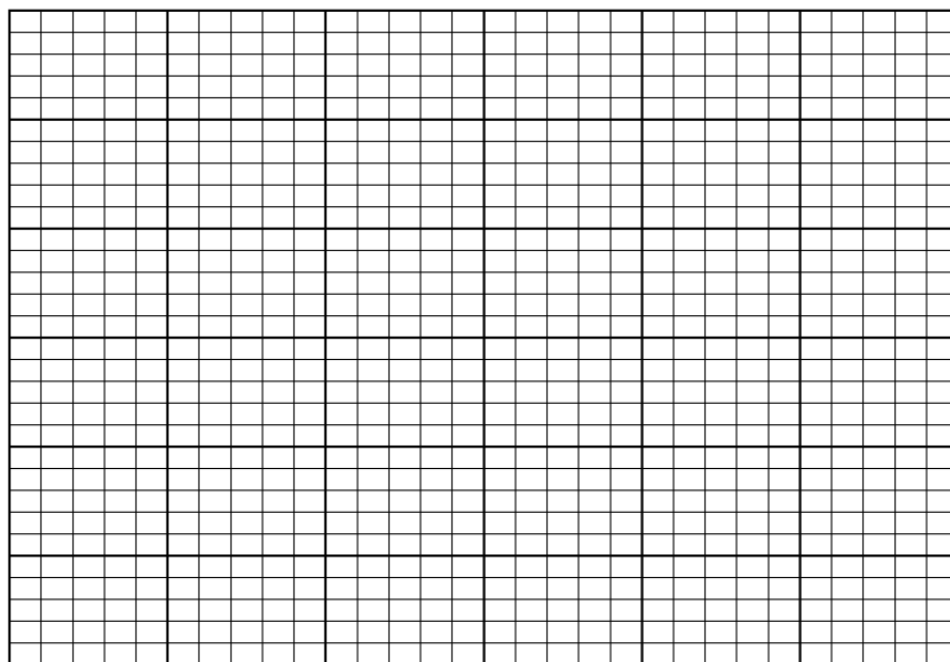
- (d) Calculate the steady-state current through the battery.
- (e) Calculate the final charge on the  $5.0\ \mu\text{F}$  capacitor.
- (f) Calculate the energy dissipated as heat in the  $40\ \Omega$  resistor in one minute once the circuit has reached steady state.



2. A physics student wishes to measure the resistivity of slightly conductive paper that has a thickness of  $1.0 \times 10^{-4}$  m. The student cuts a sheet of the conductive paper into strips of width 0.02 m and varying lengths, making five resistors labeled R1 to R5. Using an ohmmeter, the student measures the resistance of each strip, as shown above. The data are recorded below.

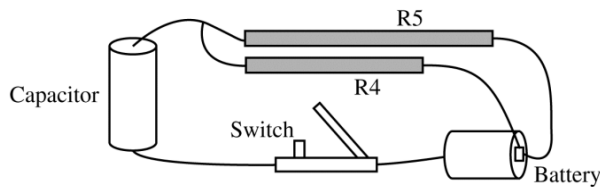
Resistor	R1	R2	R3	R4	R5
Length (m)	0.020	0.040	0.060	0.080	0.100
Resistance ( $\Omega$ )	80,000	180,000	260,000	370,000	440,000

- (a) Use the grid below to plot a linear graph of the data points from which the resistivity of the paper can be determined. Include labels and scales for both axes. Draw the straight line that best represents the data.



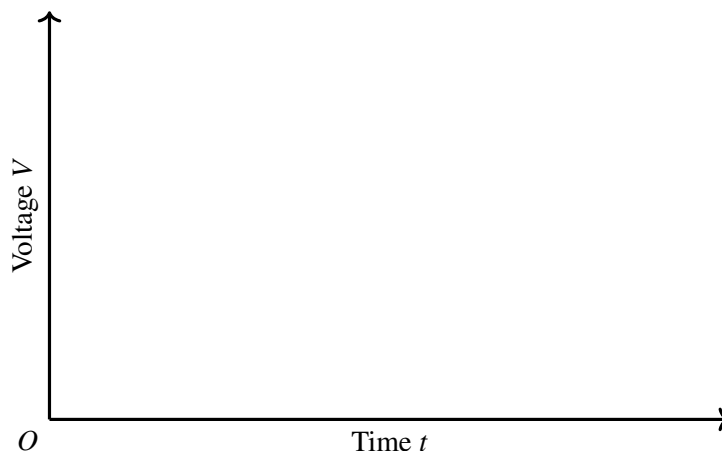
- (b) Using the graph, calculate the resistivity of the paper.



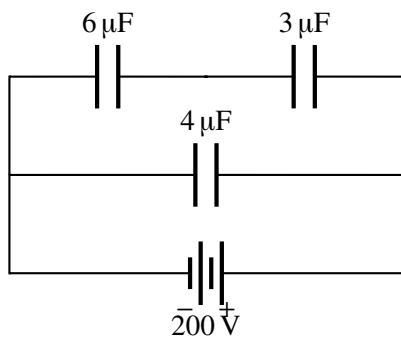


The student uses resistors  $R_4$  and  $R_5$  to build a circuit using wire, a 1.5 V battery, an uncharged  $10\ \mu\text{F}$  capacitor, and an open switch, as shown above.

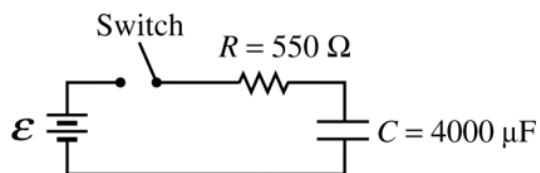
- (c) Calculate the time constant of the circuit.
- (d) At time  $t = 0$ , the student closes the switch. On the axes below, sketch the magnitude of the voltage  $V_c$  across the capacitor and the magnitudes of the voltages  $V_{R4}$  and  $V_{R5}$  across each resistor as functions of time  $t$ . Clearly label each curve according to the circuit element it represents. On the axes, explicitly label any intercepts, asymptotes, maxima, or minima with values or expressions, as appropriate.



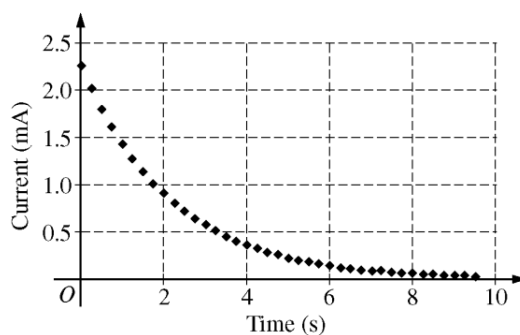
3. The circuit in the figure consists of three capacitors ( $3\ \mu\text{F}$ ,  $4\ \mu\text{F}$ , and  $6\ \mu\text{F}$ ) connected to a 200 V battery.



- (a) Calculate the equivalent capacitance of the combined three capacitors.
- (b) Calculate the total energy stored in the  $6\ \mu\text{F}$  and  $3\ \mu\text{F}$  capacitor combination.

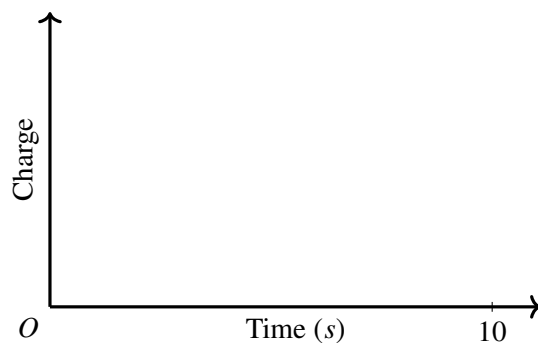


4. A student sets up the circuit above in the lab. The values of the resistance and capacitance are as shown, but the constant voltage  $E$  delivered by the ideal battery is unknown. At time  $t = 0$ , the capacitor is uncharged and the student closes the switch. The current as a function of time is measured using a computer system, and the following graph is obtained.



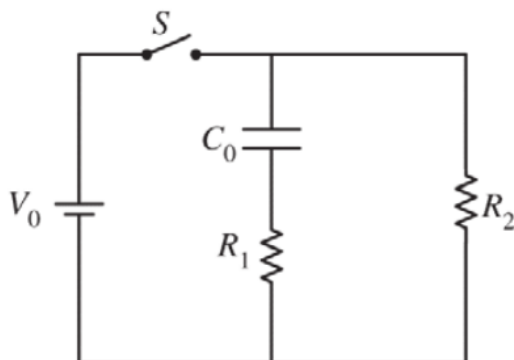
- Using the data above, calculate the battery voltage  $e$ .
- Calculate the voltage across the capacitor at time  $t = 4.0$  s.
- Calculate the charge on the capacitor at  $t = 4.0$  s.

- (d) On the axes below, sketch a graph of the charge on the capacitor as a function of time.



- (e) Calculate the power being dissipated as heat in the resistor at  $t = 4.0$  s.
- (f) The capacitor is now discharged, its dielectric of constant  $\kappa = 1$  is replaced by a dielectric of constant  $\kappa = 3$ , and the procedure is repeated. Is the amount of charge on one plate of the capacitor at  $t = 4.0$  s now greater than, less than, or the same as before? Justify your answer.

\_\_\_\_ Greater than      \_\_\_\_ Less than      \_\_\_\_ The same



5. In the circuit above, an ideal battery of voltage  $V_0$  is connected to a capacitor with capacitance  $C_0$  and resistors with resistances  $R_1$  and  $R_2$ , with  $R_1 > R_2$ . The switch  $S$  is open, and the capacitor is initially uncharged.
- (a) The switch is closed at time  $t = 0$ . On the axes below, sketch the charge  $q$  on the capacitor as a function of time  $t$ . Explicitly label any intercepts, asymptotes, maxima, or minima with numerical values or algebraic expressions, as appropriate.



- (b) On the axes below, sketch the current  $I$  through each resistor as a function of time  $t$ . Clearly label the two curves as  $I_1$  and  $I_2$ , the currents through resistors  $R_1$  and  $R_2$ , respectively. Explicitly label any intercepts, asymptotes, maxima, or minima with numerical values or algebraic expressions, as appropriate.



The circuit is constructed using an ideal 1.5 V battery, an  $80\text{ }\mu\text{F}$  capacitor, and resistors  $R_1 = 150\text{ }\Omega$  and  $R_2 = 100\text{ }\Omega$ . The switch is closed, allowing the capacitor to fully charge. The switch is then opened, allowing the capacitor to discharge.

- (c) The time it takes to charge the capacitor to 50 % of its maximum charge is  $\Delta t_C$ . The time it takes for the capacitor to discharge to 50 % of its maximum charge is  $\Delta t_D$ . Which of the following correctly relates the two time intervals?

\_\_\_\_  $\Delta t_C > \Delta t_D$       \_\_\_\_  $\Delta t_C = \Delta t_D$       \_\_\_\_  $\Delta t_C < \Delta t_D$

Justify your answer.

- (d) i. Calculate the current through resistor  $R_2$  immediately after the switch is opened.  
 ii. Is the current through resistor  $R_2$  increasing, decreasing, or constant immediately after the switch is opened?

\_\_\_\_ Increasing      \_\_\_\_ Decreasing      \_\_\_\_ Constant

Justify your answer.

- (e) i. Calculate the energy stored in the capacitor immediately after the switch is opened.  
 ii. Calculate the energy dissipated by resistor  $R_1$  as the capacitor completely discharges.