Electric Current & DC Circuits

PSI AP Physics 2

Name__________________________

Multiple-Choice

1. The length and radius of an aluminum wire is quadrupled. By which factor does the resistance change?
(A) 2  (B) 1/2  (C) 1/4  (D) 1

\[ R = \frac{\rho L}{A} = \frac{\rho L}{\pi r^2} = \frac{4}{16} = \frac{1}{4} \]

2. A copper wire has a length L and cross-sectional area A. What happens to the resistivity of the wire if the length is doubled and cross-sectional area halved?
(A) Four times as large  (B) Stays the same  (C) Half as large  (D) Quarter as large

\[ \rho = \frac{RA}{L \times \pi} \]

3. Which circuit has greater resistance between the terminals?
(A) A  (B) B  (C) C  (D) D

4. Which circuits have the same resistance between the terminals?
(A) A and B  (B) B and C  (C) C and D  (D) A and D

5. In the circuit shown above, what is the value of the net resistance?
(A) 0.75 \( \Omega \)  (B) 4.5 \( \Omega \)  (C) 6 \( \Omega \)  (D) 13 \( \Omega \)

\[ \begin{align*}
\text{L} & = 6 \Omega \\
\text{M} & = 4 \Omega \\
\text{3\Omega} & = 3 \Omega \\
\text{12V} & = V
\end{align*} \]

\[ \frac{1}{\frac{1}{6} + \frac{1}{3}} = \frac{1}{R_{eq}} \]

\[ R_{eq} = 2 \Omega \]

6. What is the current in 4 \( \Omega \) resistor?
(A) 2A  (B) 3A  (C) 9A  (D) 12A

7. What is the voltage between points L and M?
(A) 2V  (B) 4V  (C) 8V  (D) 12V

\[ V_{LM} = 2V \left( 2 \Omega \right) = 4V \]

8. A lamp L1, a voltmeter V, an ammeter A, and a battery with zero internal resistance are connected as shown above. Connecting another lamp L2 in series with the first lamp as shown by the dashed lines would

(A) Increase the ammeter reading  (C) Decrease the ammeter reading
(B) Increase the voltmeter reading  (D) Decrease the voltmeter reading

Series \[ \uparrow \quad R \quad \downarrow \quad I \]

P8 2
9. The four resistors shown below have the lengths and cross-sectional areas indicated and are made of material with the same resistivity. Which has the smallest resistance?

\[ R = \frac{P \cdot L}{\pi r^2} \]

\[ \begin{align*}
\text{A} & \quad \text{L} \\
\text{B} & \quad \text{L/2} \\
\text{C} & \quad \text{A/2} \\
\text{D} & \quad \text{2L}
\end{align*} \]

(A) A  (B) B  (C) C  (D) D

11. The equivalent resistance between the junction points of the above circuit shown on the diagram is:

(A) 2 \( \Omega \)  (B) 6 \( \Omega \)  (C) 9 \( \Omega \)  (D) 18 \( \Omega \)

12. A heating spiral of resistance \( R \) converts electrical energy into thermal energy that is transferred to the liquid in which the spiral is immersed. If the voltage across the spiral is \( V \), the thermal energy transferred to the liquid in time \( t \) is:

\[ P = \frac{E}{\Delta t} \]

\[ P = \frac{V^2}{R} \]

13. In the circuit two identical resistors \( R \) are connected in series with 8-\( \Omega \) resistor and 12-V battery. What is the value of \( R \) if the current in the circuit \( I = 1 \) A?

(A) 2 \( \Omega \)  (B) 4 \( \Omega \)  (C) 8 \( \Omega \)  (D) 12 \( \Omega \)

\[ P = VI \]

\[ V = \frac{P}{I} \]

\[ V = \frac{40}{5} \]

\[ V = 8 \]

\[ 12V = 8R + 8R \]

\[ R = 2\Omega \]
Questions 14-16 relate to the following circuit diagram which shows a battery with an internal resistance of 2.0 ohms connected to an 8-ohm and a 10-ohm resistor in series. The current in the 10-ohm resistor is 0.2 amperes.

14. What is the emf of the battery?
(A) 0.4 V  (B) 3.6 V  (C) 4.0 V  (D) 12 V

15. What is the potential difference across the terminals A and B of the battery?
(A) 1.2 V  (B) 2.4 V  (C) 3.6 V  (D) 12.2 V

16. What power is dissipated by the 2-ohm internal resistance of the battery?
(A) 0.08 W  (B) 0.8 W  (C) 1.2 W  (D) 6.5 W

17. In the diagrams above, resistors \( R_1 \) and \( R_2 \) are shown in two different connections to the same source of emf \( \varepsilon \) that has no internal resistance. How does the power dissipated by the resistors in these two cases compare?
(A) It is greater for the series connection.
(B) It is greater for the parallel connection.
(C) It is the same for both connections.
(D) One must know the values of \( R_1 \) and \( R_2 \) to know which is greater.

18. The product 3 amperes x 3 volts x 3 seconds is equal to
(A) 27 C  (B) 27 N  (C) 27 J  (D) 27 W

Questions 19-20 refer to the following diagram that shows part of a closed electrical circuit.

19. The electrical resistance of the part of the circuit shown between point X and point Y is
(A) 1.4 \( \Omega \)  (B) 2.5 \( \Omega \)  (C) 6.2 \( \Omega \)  (D) 10 \( \Omega \)

20. When there is a steady current in the circuit, the amount of charge passing a point per unit of time is:
(A) the same everywhere in the circuit
(B) greater at point X than at point Y
(C) greater in the 2 \( \Omega \) resistor than in the 5 \( \Omega \) resistor
(D) the same in the 2 \( \Omega \) resistor as in the 5 \( \Omega \) resistor

21. A certain coffeepot draws 2.0 A of current when it is operated on 110 V household lines. If electrical energy costs 10 cents per kilowatt-hour, how much does it cost to operate the coffeepot for 5 hours?
(A) 2.4 cents  (B) 4.8 cents  (C) 8.0 cents  (D) 11 cents

\[
p = \frac{\text{cost}}{\text{kwh}} \times \text{kwh} = \frac{11 \text{ cents}}{\text{kwh}} \times 5 \text{ kwh}
\]

\[
p = \frac{55}{\text{kwh}} = \frac{\text{cost}}{\text{kw-hr}}
\]

\[
p = 2.2 \text{ kw-hr}
\]
Questions 22-24

Five identical light bulbs are connected to a 120 V power supply. Each light bulb has a resistance of 15 Ω. The switch is closed.

22. What is the net resistance of the circuit?
   (A) 3 Ω  (B) 30.1 Ω  (C) 40 Ω  (D) 75 Ω

23. What is the current in the light bulb L₁?
   (A) 1.6 A  (B) 3 A  (C) 8 A  (D) 40 A

24. Which light bulb or bulbs could burn out without causing any others to go out?
   (A) Only L₁  (B) Only L₂  (C) Only L₄  (D) Only L₅

A circuit, shown above, has three resistors R₁ = 60 Ω, R₂ = 300 Ω, and R₃ = 200 Ω, and a 120V battery with an internal resistance r = 4Ω. Use this circuit to answer questions 25 – 27.

25. What is the relationship between the three labeled currents?
   (A) i₁ < i₂ < i₃  (B) i₁ + i₂ = i₃  (C) i₂ + i₃ = i₁  (D) i₁ + i₂ = i₃

26. If V₁ represents the potential difference across the first resistor, V₂ across the second resistor, V₃ across the third resistor and V the terminal voltage in the battery. What is the relationship between the V₁, V₂, V₃, and V?
   (A) V₁ = V₂ = V₃ = V  (B) V₁ + V₂ + V₃ = V  (C) V₃ < V₁ < V₂  (D) V = V₁ + V₂ + V₃

27. What is the ratio of current i₁ in resistor R₁ to the current in i₂ in resistor R₂?
   (A) \( \frac{i_1}{i_2} = \frac{1}{3} \)  (B) \( \frac{i_1}{i_2} = \frac{1}{1} \)  (C) \( \frac{i_1}{i_2} = \frac{1}{2} \)  (D) \( \frac{i_1}{i_2} = \frac{1}{5} \)

28. A battery has an emf of \( \varepsilon \) and an internal resistance of \( r \). What resistance \( R \), when connected across the terminals of the battery will make the terminal voltage to be \( \frac{1}{3} \varepsilon \)?
   (A) \( \frac{1}{3} r \)  (B) \( 2r \)  (C) \( r \)  (D) \( 4r \)

\[ V_T = \frac{1}{3} \varepsilon \]
Multi-correct Section: For each question or incomplete statement, two of the answers are correct. For each question you must select both answers.

37. In reference to the circuit above, which of the following statements are true? Choose two answers.
   (A) The current in R₁ must be the same as the current in R₂.
   (B) The voltage across R₁ must be the same as the voltage across the battery.
   (C) The voltage across R₁ must be the same as the voltage across R₂.
   (D) The voltage across R₂ must be the same as the voltage across R₃.

38. A single resistor is connected across the terminals of a battery. Which of the following will leave the power output unaffected? Choose two answers.
   (A) Reducing both the resistance and the voltage by a factor of 4.
   (B) Reducing the resistance by a factor of 4 and the voltage by a factor of 2.
   (C) Doubling both the resistance and the voltage.
   (D) Doubling the voltage and increasing the resistance by a factor of 4.

39. The diagrams above show four light bulbs of the same type. Two are in series and two are in parallel. Which of the following statements are true? Choose two answers.
   (A) The light bulbs in the series circuit are brightest since they get the total current.
   (B) The light bulbs in the parallel circuit draw more power than in the series circuit.
   (C) The series circuit has more total resistance than the parallel circuit.
   (D) The parallel circuit has the less total current than the series circuit.

40. The following diagrams show resistors in four different circuits. Which two have the same total resistance? Choose two answers.

Ohms Law!!
4. Four resistors are connected in a circuit. The circuit is connected to a battery with emf \( \varepsilon \) and negligible internal resistance. The current through 9.6 \( \Omega \) resistor is 0.25 A.

   a. What is the net resistance of the circuit?
   b. What is the voltage drop across 6 \( \Omega \) resistor?
   c. What is the current in 4 \( \Omega \) resistor?
   d. What is the emf of the battery?
   e. What is the net power dissipation?

5. Five resistors are connected to a battery with an emf of 12 V and an internal resistance of 1 \( \Omega \).

   a. Calculate the external resistance of the circuit.
   b. Calculate the current in the battery.
   c. Calculate the terminal voltage of the battery.
   d. Calculate the power dissipation in the 3 \( \Omega \) resistor.
   e. Calculate the power dissipation in the internal resistance.

6. Students in the physics lab have a 30W light bulb and a 40W light bulb. Both are meant to be used in a 120V outlet. They experiment connecting the bulbs in series and in parallel to 120V.

   The first student thinks that the 40W bulb will be brighter than the 30W bulb regardless of the connection since brightness depends on the power output and the 40W bulb has a lower resistance therefore a higher power output.

   The second student thinks that the 30W bulb will be brighter in either case because, for the same current, the greater the resistance, the greater the power output and the 30W bulb has the greater resistance.

   a. Ignoring if the prediction is correct, what aspect of the first student’s argument is correct and incorrect? Explain your reasoning.
   b. Ignoring if the prediction is correct, what aspect of the second student’s argument is correct and incorrect? Explain your reasoning.
   c. Rank the following light bulbs from 1 to 4, 1 being the brightest and 4 being the least bright. Justify your answer.

   ____ the 30W bulb in parallel
   ____ the 40W bulb in parallel
   ____ the 30W bulb in series
   ____ the 40W bulb in series
Why in Parallel: \[ P = \frac{V^2}{R} \]

In Parallel:
\[ \frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} \]

Series:
\[ P = \frac{V^2}{R} \]

More Resistance = Smaller Resistance
\[ R_{eq} = R_1, R_2 \]

(b) Terminal Battery
\[ E - Ir = V_T \]
\[ 12V - 1.3A \times 3.5 = V_T \]
\[ V_T = 11.35V \]

(c) Rate of Energy Delivered by System (Use EMF formula power)
\[ P = \frac{V^2}{R} \]
\[ R_{eq} = 9.2 \Omega \]
\[ R_{eq} = \frac{(12)^2}{9.2\Omega} = 15.7 \text{W} \]

\[ P = \frac{E}{\Delta t} \]
\[ E = 15.7W \times \frac{5\text{min}}{60\text{sec}} = 4710J \]
2. Electric motor resistance: \( R_{em} = \frac{6V}{0.5A} = 12 \Omega \)

1. Need 12 \( \Omega \)’s to work
   \[ R_0 = 12 = 6\Omega + 6\Omega \]

   \[ I_c = \frac{V_3}{R_0} = \frac{12V}{24\Omega} = 0.5A \]

2. Net resistance
   \[ R_f = 6\Omega + 6\Omega + 12\Omega = 24\Omega \]

3. Power
   \[ P = VI = 12V \times 0.5A = 6W \]

\[ \text{End worksheet} \]
Free-Response Problems

1. A physics student has an assignment to make an electrical heating system with the set of materials listed below:

   - Ammeter
   - Voltmeter
   - Connecting Wires
   - Switch

   a. In a space below draw a diagram showing all the elements connected in one electrical circuit that can provide the maximum rate of heat produced. Use two meters in your circuit, they will help to measure the heat rate.

   ![Diagram](image)

   The battery has an emf of 12 V and an internal resistance of 0.5 Ω and each heating coil has a resistance of 17.3 Ω.

   b. When the switch is closed, what is the current running through the battery?
   c. What is the terminal voltage on the battery?
   d. What is the rate of energy delivered by the heating system?
   e. If the switch is closed for 5 min, what is the total energy dissipated in the coils?

   ![Equations](image)

   See worksheets

   pg 13

2. An electric motor in a toy car can operate when connected to a 6 V battery and has a current of 0.5 A. A physics student wants to run the toy car but unfortunately he could only find a 12 V battery in the physics lab. The student also found a box with a set of five 6-Ω resistors.
   a. Use the given materials to design an electric circuit in which the electric motor will operate properly.
   i. Draw the circuit including all devices.
   ii. Explain your reasoning in designing this particular circuit.
   b. Calculate the net resistance of the circuit.
   c. Calculate the power dissipated in the circuit.

   See worksheets

3. Three light bulbs are connected in the circuit shown on the diagram. Each light bulb can develop a maximum power of 75 W when connected to a 120-V power supply. The circuit of three light bulbs is connected to a 120 V power supply.

   a. What is the resistance of the circuit?
   b. What is the power dissipated by the circuit?
   c. How would you compare this power to the power when all bulbs are connected in parallel?
   d. What is the current in light bulb \( L_1 \)?
   e. What is the voltage across light bulb \( L_1 \)?
   f. What is the voltage across light bulb \( L_2 \)?

   ![Equations](image)

   See worksheets

   pg 13
(a) \[ \frac{1}{R_L} = \frac{1}{6} + \frac{1}{4} = \frac{2}{12} + \frac{3}{12} = \frac{5}{12} \]
\[ R_L = \frac{12}{5} = 2.4\,\Omega \]

(b) \[ V_{6\Omega} = 2\]
\[ V_{6\Omega} = 0.6\,\text{V} \]

(c) \[ I = 4\Omega \]
\[ V_{4\Omega} = V_{2.4\Omega} = \sqrt{V_{6\Omega}} = 0.6\,\text{V} \]
\[ I_{4\Omega} = \frac{0.6\,\text{V}}{4\Omega} = 0.15\,\text{A} \]
\[ I_{4\Omega} = 0.15\,\text{A} \]

(d) What is the EMF of battery?
\[ \varepsilon = 6\,\text{V} \]

(e) What is the net power dissipation?
\[ P = VI = 6\,\text{V} \times 0.75 = 1.5\,\text{W} \]
\[ P = 1.5\,\text{W} \]
c. \[ V_T = E - I_L R_B \]
\[ V_T = 12 \varepsilon - 1.3 \Omega \]
\[ V_T = 10.7 \Omega \]

d. 3 \Omega \text{ Power}
\[ V_{2R} = 2 \varepsilon (1.53) \]
\[ V_{2R,2P} = 2.6 \]
\[ \Rightarrow \text{Volt drop on } 2\Omega \]

e. \text{Power } R_B
\[ P = I_L^2 R \]
\[ P = (1.3)^2 (1) \]
\[ P = 1.7 \text{W} \]
40Ω has a lower resistance but the power output is different depending on circuit arrangement. The only time voltage is the same for both is in parallel. In series more voltage drop across $R_{30}$ ($V = IR_{30} > V = IR_{40}$).

Not necessarily true. In parallel, $I_{30} = \frac{V}{R_{30}} < I_{40} = \frac{V}{R_{40}}$.

#2
\[ P = \frac{V^2}{R_{30}} \] 30Ω
\[ P = \frac{V^2}{R_{40}} \] 40Ω
\[ P = I^2 R_{30} \text{ series} \] 9.4W
\[ P = I^2 R_{40} \text{ parallel} \] 7.1W

#3
\[ I_L = \frac{120}{840} \]
\[ I_L = 0.142 \]
(7)

\[ \begin{align*}
\text{(a)} & \quad \text{Switch open} \\
& \quad \boxed{R_{eq} = 6 \Omega} \\
\text{(b)} & \quad \text{Current through } 2 \Omega \text{ resistor} \\
& \quad I_{2\Omega} = \boxed{I_L = 3 \frac{V}{\Omega}} \\
\text{(c)} & \quad \text{Current through } 3 \Omega \text{ resistor} \\
& \quad I_{3\Omega} = 3 \frac{V}{\Omega} \text{(3-9 reduction)} \\
\end{align*} \]

\[ V_{4\Omega \text{eL}} = I_L \cdot R_{eq} \]

\[ V_{4\Omega \text{eL}} = 3 \cdot (4\Omega) \]

\[ V_{3\Omega} = V_{4\Omega \text{eL}} = 12 \frac{V}{\Omega} \]

\[ I_{9\Omega} = I_{3\Omega} \text{ (series)} \]

\[ V_{9\Omega+3\Omega} = 12 \frac{V}{\Omega} = I_{9\Omega} \cdot (12 \Omega) \]

\[ I_L = 1 \frac{V}{\Omega} \Rightarrow I_{3\Omega} = 1 \frac{V}{\Omega} \]
(d) Switch closed and reached constant value

\[ Q = C \cdot V \] some voltage \( V \) across \( R \) resistor

\[ V_{\text{on}} = I_{\text{on}} (R_{\text{on}}) \]

\[ V_{\text{on}} = 19 (92) = 180 \]

\[ \downarrow \]

From page 11 C

\[ Q = 2 \times 10^{-6} \text{ F} (9V) \]

\[ Q = 1.8 \times 10^{-5} \text{ C} \]

\[ \boxed{Q = 18 \mu \text{ C}} \]

(e)

\[ U_{eq} = \frac{Q^2}{2C} \]

\[ U_{eq} = \left( \frac{18 \times 10^{-6} \text{ C}}{2 (2 \times 10^{-6} \text{ F})} \right)^2 \]

\[ \boxed{U_{eq} = 81 \mu \text{ J}} \]
① set up circuit as indicated above.
② close switch record gaps and resistance of resistor.
③ complete step 2 using 4 additional resistors.
④ Graph \( \frac{1}{I_L} \) vs. \( R_{total} \).
⑤ using graph solve for \( E \).
⑥ using \( V_T = E - I_R A \) solve for \( R_A \).
⑦ see answer key.

\[ E = \frac{1}{slope} \]

\[ \frac{1}{I_L} = \frac{R_L}{E} + \left( \frac{R_A}{E} \right) \]

\[ E = I_L (R_L + R_A) \]

\[ V = I_L R \]

\[ V = I \]
d. \text{slope} = \frac{1}{\epsilon} \\
\epsilon = \frac{1}{.0163} = 61 V \\
I_L R_C = \epsilon - I_L R_B \\
I_L R_B = \epsilon - I_L R_L \\
\frac{R_B}{I_L} = \frac{\epsilon - I_L R_L}{I_L} \\
R_B = 3.85 \Omega \\

or use graph \Rightarrow \\
y = .0163x + .0617 \\
\text{y intercept} \ x = 0 \\
y = .0617 \\
\frac{1}{I_L} = .0617 \\
\frac{\epsilon}{I_L} = .0617 \\
\epsilon = I_L (.0617) \\
\epsilon = 3.85 \epsilon \\

\text{Remember:} \\
\frac{1}{I_L} = \frac{R_B}{\epsilon} + \frac{\epsilon}{\epsilon} \\
\epsilon = \text{intercept} \\

\text{Intercept is current with no load resistance} \\
(\text{i.e. where the resistance starts!!}) \\

1. Step up circuit as shown \\
2. record \( R_C \) and \( R_L \) readings and the \( R_B \) resistor \\
3. Adjust \( \epsilon \) at 4 voltages and measure \\
4. Graph to determine if \( V \) is a linear line.
Multiple Choice Answers


Free Response Answers

1. a) Heating coils in parallel, voltmeter in parallel, ammeter in series.
b) 1.3 A
c) 11.35 V
d) 15.7 W
e) 4470 J

2. a) Two resistors in series with the motor. This reduces the currents to the required 0.5 A.
b) 24Ω
c) 6W

3. a) 268Ω b) 50W c) 10.7V d) 0.15 A e) 80V f) 40V

4. a) 24Ω b) 0.6V c) 0.15 A d) 6V e) 1.5W

5. a) 8Ω b) 1.3A c) 10.7V d) 2.25W e) 1.7W

6. a) The 40W bulb does have a lower resistance than the 30W bulb so when the voltage across each is the same, the lower the resistance the higher the power. However the voltage is only the same for each bulb when they are connected in parallel.
b) The 30W bulb does have a higher resistance than the 40W bulb so when the current though each light bulb is the same the higher the resistance, the higher the power. However, they will only have the same current when they are connected in series.
c) Ranking: 2, 1, 3, 4
Corresponding powers: 40W, 30W, 9.4W, 7.1W

7. a) 8Ω b) 3A c) 1A d) 18Ω e) 61J

8. a) Connect the first resistor in series with the ammeter and the battery. Record the current and the external resistance. Repeat for all the other resistors.
b) \(V_L = \varepsilon - Ir\)
\(I = \frac{\varepsilon}{R + r}\)
c) 

\[\text{Slope} = \frac{1}{r} = 0.0163 \quad \varepsilon = \frac{1}{r0.0163} = 61V\]
\(\text{Intercept} = \frac{\varepsilon}{r} = 0.0617 \quad r = (\varepsilon)\text{(intercept)} = (61)(0.0617) = 3.8\Omega\)

f) They should set up the circuit as shown and measure the current and the voltage. Then repeat for all of the known resistors. Then they should graph current verses voltage. If the relationship is linear, the resistor is Ohmic.

\[\text{Diagram}\]

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AP2 Circuits

1. Answer the following questions based on the schematic in Fig. 2, which shows a 3 μF and 6 μF capacitor connected in series, with a 2 μF capacitor connected in parallel to them. The system of capacitors is connected to a battery of voltage, V.

(a) Rank the potential differences across each capacitor and the battery (1 indicating greatest potential). Give the same rank value for any that have the same potential difference.

\[
\begin{align*}
\text{V}_{\text{bat}} & = \frac{3 \text{ V}_{\text{bat}}}{6} \quad \frac{3 \text{ V}_{\text{bat}}}{6}, \frac{4 \text{ V}_{\text{bat}}}{6}, \frac{1 \text{ V}_{\text{bat}}}{6} \quad \text{Charge sharing} \\
\text{Q} = \frac{Q_{\text{bat}}}{3} & = \frac{Q_{\text{bat}}}{3}, \frac{Q_{\text{bat}}}{4}, \frac{Q_{\text{bat}}}{1} \quad \text{Charge sharing} \\
\text{V} & = \frac{\text{V}_{\text{bat}}}{3} \quad \frac{\text{V}_{\text{bat}}}{3}, \frac{\text{V}_{\text{bat}}}{4}, \frac{\text{V}_{\text{bat}}}{1} \quad \text{Charge sharing}
\end{align*}
\]

(b) The capacitor Q_{bat} is the same as the voltage Q_{bat}.

(c) The ratio of the energy stored in the 2 μF capacitor to that of the 3 μF capacitor.

\[
\begin{align*}
\text{U} & = \frac{Q_{\text{bat}}^2}{2} \quad \frac{Q_{\text{bat}}^2}{2}, \frac{Q_{\text{bat}}^2}{4}, \frac{Q_{\text{bat}}^2}{1} \\
\text{V} & = \frac{\text{V}_{\text{bat}}}{3} \quad \frac{\text{V}_{\text{bat}}}{3}, \frac{\text{V}_{\text{bat}}}{4}, \frac{\text{V}_{\text{bat}}}{1} \\
\text{Answer:} & \quad \text{true because any capacitor in parallel has same potential as source (assuming no other caps in series).}
\end{align*}
\]

AP2 Circuits

2. A 2 μF, 3 μF, and 6 μF capacitor are connected in series to a 220-volt source. When completely charged, which of the following statements are true? Select two answers.

(A) The change in the 3 μF capacitor is equal to 440 μC.
(B) The change in the 3 μF capacitor is equal to 220 μC.
(C) The change in all three capacitors is the same.
(D) The voltage drop across the 3 μF capacitor is equal to 220 V.

\[
\begin{align*}
Q_{\text{CF}} & = \frac{1}{2} \times \left( \frac{1}{3} + \frac{1}{2} + \frac{1}{1} \right) \times 4 \mu F = 6 \mu F \\
Q & = \frac{Q_{\text{CF}}}{1} \quad \frac{Q_{\text{CF}}}{1}, \frac{Q_{\text{CF}}}{2}, \frac{Q_{\text{CF}}}{3} \\
V & = \frac{Q}{2} \quad \frac{Q}{2}, \frac{Q}{4}, \frac{Q}{1} \\
Q_{\text{bat}} & = \frac{Q}{1} \quad \frac{Q}{1}, \frac{Q}{2}, \frac{Q}{3}
\end{align*}
\]

Answers: (B) and (C)

\[
\begin{align*}
\text{EKT:} & \quad 4.5 \text{ The values of currents and electric potential differences in an electric circuit are determined by the properties and arrangement of the individual circuit elements such as sources of emf, resistors, and capacitors. S.B.9 Kirchhoff's loop rule describes conservation of energy in electrical circuits. S.C.3 Kirchhoff's junction rule describes the conservation of electric charge in electrical circuits. Since charge is conserved, current must be conserved at each junction in the circuit.}
\end{align*}
\]

SP: 1.4 Student can use representations and models to analyze situations or solve problems qualitatively and quantitatively. 3.2 Student can apply mathematical routines to quantities that describe natural phenomena. 6.4 The student can make claims and predictions about natural phenomena based on scientific theories and models.

LO: 4.5.1 The student is able to make and justify a quantitative prediction of the effect of a change in values or arrangements of one or two circuit elements on the currents and potential differences in a circuit containing a small number of sources of emf, resistors, capacitors, and switches in series and/or parallel.

Difficulty: 2
3. Capacitors X, Y, and Z are connected in series to a voltage source and each has a capacitance of 3C, 2C, and 4C, respectively. When completely charged, which of the following choices gives the correct relationships among the stored energy in the capacitors?

(A) \( U_x = 2U_y = 4U_z \)
(B) \( 4U_x = 2U_y = U_z \)
(C) \( U_x = 2U_y = 4U_z \)
(D) \( U_x = 4U_y = 16U_z \)

Answer: (A) \( U_x = 2U_y = 4U_z \), because in a series configuration, the energy is inversely proportional to the capacitance.

EK: 4.E.5 The values of currents and electric potential differences in an electric circuit are determined by the properties and arrangement of the individual circuit elements such as sources of emf, resistors, and capacitors.

SP: 1.4 The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively. 2.2 The student can apply mathematical routines to quantities that describe natural phenomena. 6.4 The student can make claims and predictions about natural phenomena based on scientific theories and models.

LO: 4.E.5.2 The student is able to make and justify a qualitative prediction of the effect of a change in values or arrangements of one or two circuit elements on currents and potential differences in a circuit containing a small number of sources of emf, resistors, capacitors, and switches in series and/or parallel.

Difficulty: 3

Page 3

4. Determine the effective capacitance of the circuit shown.

(A) 19 F
(B) 31 F
(C) 6 F
(D) (18/41) F

Answer: (C) 6 F. The two 4F capacitors in series reduce to 2F, added to the 8F capacitor in parallel gives 10F, 10F & 15F in series gives a total equivalent capacitance of 6F.

EK: 4.E.5 The values of currents and electric potential differences in an electric circuit are determined by the properties and arrangement of the individual circuit elements such as sources of emf, resistors, and capacitors.

SP: 1.4 The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively. 2.2 The student can apply mathematical routines to quantities that describe natural phenomena.

LO: 4.E.5.1 The student is able to make and justify a qualitative prediction of the effect of a change in values or arrangements of one or two circuit elements on currents and potential differences in a circuit containing a small number of sources of emf, resistors, capacitors, and switches in series and/or parallel.

Page 4

Difficulty: 1
AP2 Circuits

7. The circuits below depict identical batteries, resistors, and capacitors in various configurations. The circuits are initially open, and are all closed at the same time.

A) Rank the current through the battery immediately after the switch is closed from greatest to least.
\[ I = \frac{E}{R} \]

B) Rank the current through the battery a long time after the switch is closed from greatest to least.
\[ I = \frac{E}{R} \]

Answers: A) B-D, A-C, E; B) D, B-C, A-E. Note that when the switch is first closed, the capacitor acts like a wire. After a long time, the capacitor acts like an open.

8. The circuit depicted at right shows a battery, two identical resistors, and a capacitor. At time t=0 the switch is closed. The graphs below represent various circuit characteristics as a function of time.

A) Which graph best represents the potential difference across R1?
B) Which graph best represents the current through R1?
C) Which graph best represents the potential difference across R2?
D) Which graph best represents the current through R2?
E) Which graph best represents the potential difference across the capacitor?
F) Which graph best represents the current flow in the capacitor?

Answers:
A) D
B) D
C) A
D) A
E) C
F) A

EK: 4.E.4 The resistance of a resistor, and the capacitance of a capacitor, can be understood from the basic properties of electric fields and forces, as well as the properties of materials and their geometry. 4.E.5 The values of currents and electric potential differences in an electric circuit are determined by the properties and arrangement of the individual circuit elements such as sources of emf, resistors, and capacitors.

SP: 1.4 The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively. 2.2 The student can apply mathematical routines to quantities that describe natural phenomena. 6.4 The student can make claims and predictions about natural phenomena based on scientific theories and models.

LO: 4.E.5.2 The student is able to make and justify a qualitative prediction of the effect of a change in values or arrangements of one or two circuit elements on currents and potential differences in a circuit containing a small number of sources of emf, resistors, capacitors, and switches in series and/or parallel.

Difficulty: 2
Capacitor X with a capacitance C is connected to a battery of voltage V. Capacitor Y of capacitance 2C is connected to another battery of voltage 4V. Both capacitors are then disconnected from the batteries and connected to each other in parallel.

5. (a) What is the overall charge on both capacitors in terms of C and V?
(b) What is the potential difference across the capacitors?
(c) Using your answers from part (b), write an expression for the charge on each capacitor.
(d) How does the energy stored in the capacitors before they were connected in parallel compare to the energy stored after they are connected in parallel? Justify your answer.

Answers:
(a) Charge is conserved when the battery is disconnected, so when in parallel, \( Q_{total} = Q_x + Q_y = CV + 2CV = 3CV \)
(b) When disconnected, the charges will redistribute such that the potential across each is the same, but different than their original values. \( V_x = \frac{Q_x}{C} = \frac{3CV}{C} = 3V \) (3 times the original voltage, V)
(c) \( Q_x = CV, V_x = 3V \) \( Q_y = 2CV, V_y = 2V \) \( Q_{total} = Q_x + Q_y = 3CV + 2CV = 5CV \)
(d) \( U_x = \frac{1}{2}CQ_x^2 \) \( U_y = \frac{1}{2}CQ_y^2 \) \( U_{total} = \frac{1}{2}C(3V)^2 + \frac{1}{2}C(2V)^2 = 16.5CV^2 \)

EKF: 1. B. 1 Electric charge is conserved. The net charge of a system is equal to the sum of the charges of all the objects in the system.

4. F. 4 The resistance of a resistor, and the capacitance of a capacitor, can be understood from the basic properties of electric fields and forces, as well as the properties of materials and their geometry.

SP: 4. C. The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively.

6. A. The student can justify claims with evidence.

4. C. The student can make claims and predictions about natural phenomena based on scientific theories and models.

LO: 1. B. 1.2 The student is able to make predictions, using the conservation of electric charge, about the sign and relative quantity of net charge of objects or systems after various charging processes, including conservation of charge in simple circuits.

4. E. 4.1 The student is able to make predictions about the properties of resistors and capacitors when placed in a simple circuit, based on the geometry of the circuit element and supported by scientific theories and mathematical relationships.

Difficulty: 3

Q_x = CV = \frac{C}{3V} \Rightarrow 3CV = 3CV
Q_y = 2CV = 6CV

\( Q_{total} = 3CV + 6CV = 9CV \)

V_x = 3V
V_y = 2V
V_{total} = 9V

Answers: (B) & (C) The potential across R_y is completely controlled by V_y. Therefore, to increase the current across R_y you can either increase V_y or decrease the resistance of R_y.

EKF: 4. E. 5 The values of currents and electric potential differences in an electric circuit are determined by the properties and arrangement of the individual circuit elements such as sources of emf, resistors, and capacitors.

SP: 4. C. The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively.

2. C. The student can apply mathematical routines to quantities that describe natural phenomena.

LO: 4. E. 5.2 The student is able to make and justify a qualitative prediction of the effect of a change in values or arrangements of one or two circuit elements on currents and potential differences in a circuit containing a small number of sources of emf, resistors, capacitors, and switches in series and/or parallel.
AP Physics 2

Quiz #2 DC Circuits

Name: ________________________

Multiple Choice Section

1. Two resistors, A and B, are in series in a circuit. If the resistance of A is 4 times greater than the resistance of B, what is the current through the resistors and the voltage drops across them?
   A. $I_A = I_B$ and $V_A = 4V_B$
   B. $I_A = I_B$ and $4V_A = V_B$
   C. $I_A = 4I_B$ and $V_A = 4V_B$
   D. $4I_A = I_B$ and $4V_A = V_B$

2. All of the following wires are made of the same material but are different sizes. Identify the wire with the lowest resistance.
   A. $\frac{R}{L} = \frac{I}{J}$
   B. $R = 2\frac{I}{L}$
   C. $\frac{R}{L} = \frac{I}{J}$
   D. $\frac{R}{L} = \frac{I}{J}$

3. The total equivalent resistance between points X and Y in the circuit shown right is:
   A. 3 Ω
   B. 5 Ω
   C. 10 Ω
   D. 14 Ω

4. Two capacitors are connected in parallel as shown above. A voltage $V$ is applied to the pair. What is the ratio of charge stored on $C_1$ to the charge stored on $C_2$, when $C_1 = 4C_2$?
   A. 1/4
   B. 1/2
   C. 2/1
   D. 4/1

5. The diagram to the right represents a circuit with a 4Ω resistor connected to a 12V battery with a 2Ω internal resistance. What is the terminal voltage of the battery?
   A. 3 V
   B. 4 V
   C. 8 V
   D. 12 V

6. Three light bulbs are connected in parallel to a source of emf. What will happen if the middle bulb burns out? (Assume if open that current flows)
   A. All the light bulbs will go out
   B. The light intensity of the other two bulbs will decrease
   C. The light intensity of the other two bulbs will increase
   D. The light intensity of the other two bulbs remains the same

7. If $V_1$ represents the potential difference across the first resistor, $V_2$ across the second resistor, $V_3$ across the third resistor and $V$ the terminal voltage in the battery. What is the relationship between the $V_1$, $V_2$, $V_3$, and $V$?
   A. $V > V_3 > V_2 > V_1$
   B. $V_1 = V_2 = V_3 = V$
   C. $V_1 + V_2 + V_3 = V$
   D. $V_1 = V_2 = V_3 < V$

Remember - $V$ is the same.
8. What is the ratio of current $I_1$ in resistor $R_1$ to the current in $I_2$ in resistor $R_2$?

- $\frac{I_1}{I_2} = \frac{1}{3}$
- $\frac{I_1}{I_2} = \frac{1}{2}$
- $\frac{I_1}{I_2} = \frac{2}{3}$
- $\frac{I_1}{I_2} = \frac{2}{1}$

Multi-correct Section: For each question or incomplete statement, two of the answers are correct. For each question you must select both answers.

9. Which two arrangements of capacitors and resistors shown below will store charge if connected to a battery and then is disconnected? Choose two answers.

- A
- B
- C
- D

10. A single resistor is connected across the terminals of a battery. Which of the following will leave the power output unaffected? Choose two answers.

- A. Doubling both the resistance and the voltage.
- B. Reducing both the resistance and the voltage by a factor of 4.
- C. Reducing the resistance by a factor of 4 and the voltage by a factor of 2.
- D. Doubling the voltage and increasing the resistance by a factor of 4.
D2-CIRCUITS

D2-R701: CARBON RESISTORS—RESISTANCE
Carbon resistors are made from the same pieces of “wood.” The length and the diameter of each resistor are shown.

Calculate the resistance of the four resistors.

\[ R = \frac{V}{I} \]

A - 50 \, \text{ohms}
B - 25 \, \text{ohms}
C - 10 \, \text{ohms}
D - 5 \, \text{ohms}

Explain your reasoning.

D2-W105: BATTERIES AND LIGHT BULBS—BULB BRIGHTNESS
All the bulbs in the circuits shown are identical, as are the light bulbs. A student comparing the brightness of the bulbs is shown.

"Balls A and C are the brightest since they have the same batteries, but bulbs B and D since they have a resistance, and the inner bright one is A, since there is only one battery. The more batteries, the brighter the bulb, and it does not matter how they are connected."

What if anything is wrong with this statement? If something is wrong, explain the error and how to correct it.

Incorrect: Arrangement of batteries determines brightness not #.

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D2-CIRCUITS

D2-R702: SIMPLE LIGHT BULB CIRCUITS—BULB BRIGHTNESS
All of the bulbs in the circuits below are identical, as are all of the batteries.

(a) For the three items below, rank the brightness of the bulb labeled X.

(b) Explain your reasoning.

(c) Light bulbs get hot.

(d) \[ \frac{1}{\text{resistance in series}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \]

Explain your reasoning.

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D2-CIRCUITS

D2-R703: SIMPLE BATTERY CIRCUITS—BATTERY VOLTAGE
All of the batteries in the circuits below are identical, as are all of the circuits.

(a) For each of the items below, rank the brightness of the bulb labeled X.

(b) Explain your reasoning.

(b) Short circuit

(c) Explain your reasoning.

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D2-CIRCUITS

D2-R704: SIMPLE BATTERY CIRCUITS B—BATTERY VOLTAGE
All of the batteries in the circuits below are identical, as are all of the batteries.

(a) For each of the items below, rank the brightness of the bulb labeled X.

(b) Explain your reasoning.

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D2-CIRCUITS

D2-R705: SIMPLE BATTERY CIRCUITS C—BATTERY VOLTAGE
All of the circuits in the circuits below are identical, as are all of the circuits.

(a) For each of the items below, rank the brightness of the bulb labeled X.

(b) Explain your reasoning.

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**D2 Circuits**

**D2-RT14: Simple Light Bulb Circuits I—Potential Difference Between Two Points**
All of the bulbs in the circuits below are identical, as are all of the batteries. For the two items below, rank the magnitude of the potential difference between points A and X.

(a) [Diagram showing three circuits with labeled parts and potential differences]

(b) [Diagram showing two circuits with labeled parts and potential differences]

Explain your reasoning:

1. \( V_A > V_B > V_C \)

2. \( V_A < V_B < V_C \)

3. \( V_A = V_B = V_C \)

4. \( V_A > V_B < V_C \)

5. \( V_A < V_B > V_C \)

6. \( V_A = V_B = V_C \)

**D2-RT15: Simple Light Bulb Circuits II—Current in Battery**
All of the bulbs in the circuits below are identical, as are all of the batteries. For the two items below, rank the current in the battery.

(a) [Diagram showing two circuits with labeled parts and current directions]

(b) [Diagram showing two circuits with labeled parts and current directions]

Explain your reasoning:

1. \( I_A > I_B > I_C \)

2. \( I_A < I_B < I_C \)

3. \( I_A = I_B = I_C \)

4. \( I_A > I_B < I_C \)

5. \( I_A < I_B > I_C \)

6. \( I_A = I_B = I_C \)

**D2-RT16: Circuit with Two Batteries—Bulb Brightness**
Two identical light bulbs, a switch, and a battery are connected as shown. When the switch is closed, will the brightness of the bulb (a) increase, (b) decrease, or (c) remain the same?

Explain your reasoning:

1. Stay Same: Batteries in Parallel

2. Stay Same: Batteries in Series

3. Provide Some Voltage

**D2 Circuits**

**D2-RT17: Simple Light Bulb Circuits III—Current in Battery**
All of the bulbs in the circuits below are identical, as are all of the batteries. For the two items below, rank the current in the battery.

(a) [Diagram showing two circuits with labeled parts and current directions]

(b) [Diagram showing two circuits with labeled parts and current directions]

Explain your reasoning:

1. \( I_A > I_B > I_C \)

2. \( I_A < I_B < I_C \)

3. \( I_A = I_B = I_C \)

4. \( I_A > I_B < I_C \)

5. \( I_A < I_B > I_C \)

6. \( I_A = I_B = I_C \)

**D2-RT18: Two Resistor Circuits—Current, Resistance, and Voltage Drop Chart**
For items (a) and (b) below complete the table, showing the value of the current in and voltages across all elements.

(a) The resistance values for this circuit are given in the table, as is the battery voltage.

(b) The resistance values for this circuit are given in the table, as is the current in the battery.

**D2-CT19: Two Light Bulbs in a Circuit—Bulb Brightness**
Two identical light bulbs are connected in a battery as shown. When the switch is closed, will the brightness of the bulb (a) increase, (b) decrease, or (c) remain the same?

Explain your reasoning:

1. Brighter

2. Darker

3. Same Brightness

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02 CIRCUITS

02-CIRCUIT WITH TWO SWITCHES—AMMETER READINGS
The circuit contains a battery, two switches, a pair of resistors, and an ammeter. Four possible switch configurations (open or closed) for the circuit are shown in the table.

<table>
<thead>
<tr>
<th>Configuration</th>
<th>Switch S1</th>
<th>Switch S2</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Open</td>
<td>Open</td>
</tr>
<tr>
<td>B</td>
<td>Open</td>
<td>Closed</td>
</tr>
<tr>
<td>C</td>
<td>Closed</td>
<td>Open</td>
</tr>
<tr>
<td>D</td>
<td>Closed</td>
<td>Closed</td>
</tr>
</tbody>
</table>

Rank the ammeter reading for the four configurations.

A  B  C  D

Explain your reasoning.

02-CIRCUIT WITH TWO SWITCHES—VOLTMETER READINGS
The circuit contains a battery, two switches, two identical resistors, and a voltmeter. Four possible switch configurations (open or closed) for the circuit are shown in the table.

<table>
<thead>
<tr>
<th>Configuration</th>
<th>Switch S1</th>
<th>Switch S2</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Open</td>
<td>Open</td>
</tr>
<tr>
<td>B</td>
<td>Open</td>
<td>Closed</td>
</tr>
<tr>
<td>C</td>
<td>Closed</td>
<td>Open</td>
</tr>
<tr>
<td>D</td>
<td>Closed</td>
<td>Closed</td>
</tr>
</tbody>
</table>

Rank the voltmeter reading for the four configurations.

A  B  C  D

Explain your reasoning.

02-CIRCUIT WITH THREE SWITCHES—AMMETER READINGS
The circuit contains a battery, three switches, two identical resistors, and an ammeter. Eight possible switch configurations (open or closed) for the circuit are shown in the table.

<table>
<thead>
<tr>
<th>Configuration</th>
<th>Switch S1</th>
<th>Switch S2</th>
<th>Switch S3</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Open</td>
<td>Open</td>
<td>Open</td>
</tr>
<tr>
<td>B</td>
<td>Open</td>
<td>Open</td>
<td>Closed</td>
</tr>
<tr>
<td>C</td>
<td>Closed</td>
<td>Open</td>
<td>Open</td>
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<tr>
<td>D</td>
<td>Closed</td>
<td>Open</td>
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<tr>
<td>E</td>
<td>Open</td>
<td>Closed</td>
<td>Open</td>
</tr>
<tr>
<td>F</td>
<td>Open</td>
<td>Closed</td>
<td>Closed</td>
</tr>
<tr>
<td>G</td>
<td>Closed</td>
<td>Open</td>
<td>Open</td>
</tr>
<tr>
<td>H</td>
<td>Closed</td>
<td>Closed</td>
<td>Closed</td>
</tr>
</tbody>
</table>

Rank the ammeter reading for the four configurations.

A  B  C  D  E  F  G  H

Explain your reasoning.

02-CIRCUIT WITH THREE RESISTORS—CURRENT, RESISTANCE, AND VOLTAGE DROP
Four of the five resistor values for this circuit are given in the table, as is the battery voltage and the current in resistor R1.

Complete the table, showing the value of V, and the currents in and voltages across all elements.

<table>
<thead>
<tr>
<th>Battery</th>
<th>R1</th>
<th>R2</th>
<th>R3</th>
<th>V</th>
<th>I1</th>
<th>I2</th>
<th>I3</th>
<th>I1 + I2 + I3</th>
</tr>
</thead>
<tbody>
<tr>
<td>72.0 V</td>
<td>48</td>
<td>6.4</td>
<td>3.4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Explain your reasoning.

02-CIRCUIT WITH THREE RESISTORS—CURRENT
A battery is connected to a circuit containing two resistors and a switch as shown. A student states:

"When the switch is open, the current is zero. A good answer, because current is zero means there is no current through the battery or resistor R1." What, if anything, is wrong with this statement? If something is wrong, identify it and explain how to correct it. If this statement is correct, explain why.

02-CIRCUIT WITH TWO RESISTORS—CURRENT
A battery is connected to a circuit containing two resistors as shown. A student states:

"Using Ohm's law, the current is the voltage divided by the resistance, so when you have a larger resistor, you have a smaller current.
A larger resistor will have a smaller current. What, if anything, is wrong with this statement? If something is wrong, identify it and explain how to correct it. If this statement is correct, explain why.

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DE-CIRCUITS

DE-C746: Four Resistor Circuits III—Current
For these two circuits, consider the current in the resistor R1 closest to the battery.

\[ I_1 \]

Will the current in R1 be (i) larger in the circuit on the left, (ii) smaller in the circuit on the left, or (iii) equal in both circuits?
Explain your reasoning.

\[ R_1 \]

\[ R_2 \]

\[ R_3 \]

\[ R_4 \]

DE-C746: Four Resistor Circuits III—Potential Difference
For these two circuits, consider the potential difference across the resistor R1 closest to the battery.

\[ V_{R1} \]

Will the potential difference across R1 be (i) larger in the circuit on the left, (ii) smaller in the circuit on the left, or (iii) equal in both circuits?
Explain your reasoning.

\[ V_{R1} \]

\[ V_{R1} \]

\[ V_{R1} \]

\[ V_{R1} \]

TIPERS

DE-W847: Four Resistors Circuit Chart I—Circuit
A circuit contains three resistors and a battery. The chart gives the current in each element, the potential difference across each element, and the resistance values of the resistors.

\[ I_1 \]

\[ I_2 \]

\[ I_3 \]

\[ I_4 \]

\[ V_{R1} \]

\[ V_{R2} \]

\[ V_{R3} \]

\[ V_{R4} \]

Draw an electric circuit that is consistent with the values of this chart. Label the resistors.

\[ R_1 \]

\[ R_2 \]

\[ R_3 \]

\[ R_4 \]

DE-W848: Three Resistors Circuit Chart III—Circuit
A circuit contains three resistors and a battery. The chart gives the current in each element, the potential difference across each element, and the resistance values of the resistors.

\[ I_1 \]

\[ I_2 \]

\[ I_3 \]

\[ V_{R1} \]

\[ V_{R2} \]

\[ V_{R3} \]

Draw an electric circuit that is consistent with the values of this chart. Label the resistors.

\[ R_1 \]

\[ R_2 \]

\[ R_3 \]

\[ R_4 \]

DE-W849: Three Resistors Circuit Chart IV—Circuit
A circuit contains three resistors and a battery. The chart gives the current in each element, the potential difference across each element, and the resistance values of the resistors.

\[ I_1 \]

\[ I_2 \]

\[ I_3 \]

\[ V_{R1} \]

\[ V_{R2} \]

\[ V_{R3} \]

Draw an electric circuit that is consistent with the values of this chart. Label the resistors.

\[ R_1 \]

\[ R_2 \]

\[ R_3 \]

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