Week 10

AP Physics 2

Homework bundle for this week

本周作业合集

exercises.lol

Contents 目录

AP Physics 2 Name: ____________________ Score: ______

1. 6 C of charge flows past a point in 3 s. What is the current, in amperes?

   ______________ A

2. For current to flow in a circuit, the loop must be:

   ☐ open

   ☐ complete (closed)

   ☐ made only of copper

   ☐ very long

3. A resistor carries 0.5 A from a 6 V supply. What is its resistance, in Ω?

   ______________ Ω

4. A bulb carries 0.5 A at 12 V. What power does it dissipate, in watts?

   ______________ W

5. Two 6 Ω resistors are in **series**. What is the total resistance, in Ω?

   ______________ Ω

6. A 9 V battery drives current through $R_1 = 2\ \Omega$ and $R_2 = 1\ \Omega$ in series. Using the loop rule, what is the current, in A?

   ______________ A

7. Electric current is defined as:

   ☐ charge times time

   ☐ charge per unit time

   ☐ voltage per unit charge

   ☐ resistance times charge

8. The voltage a battery provides — its energy per unit charge — is called its ______.

   ____

9. Which expresses Ohm's law?

   ☐ $V = IR$

   ☐ $V = I/R$

   ☐ $V = I + R$

- ☐ $R = IV$

10. Kirchhoff's loop rule is a statement of the conservation of:

- ☐ charge
- ☐ energy
- ☐ momentum
- ☐ mass

AP Physics 2

1. **2 A**

   $I = Q/t = 6/3 = 2$ A.

2. **complete (closed)**

   A complete, closed loop is needed; any break stops the current.

3. **12 Ω**

   $R = V/I = 6/0.5 = 12$ Ω.

4. **6 W**

   $P = IV = 0.5 \times 12 = 6$ W.

5. **12 Ω**

   Series resistances add: $6 + 6 = 12$ Ω.

6. **3 A**

   $9 - 2I - I = 0 \Rightarrow 9 = 3I \Rightarrow I = 3$ A.

7. **charge per unit time**

   $I = Q/t$ — charge flowing per second.

8. **EMF**

   The electromotive force (EMF) is the battery's energy per unit charge.

9. $V = IR$

   $V = IR$ — voltage equals current times resistance.

10. **energy**

    Voltages sum to zero because energy per charge is conserved around a loop.

11.1 Electric Current

Name: ______________ Class: __________ Date: ____________ **Total: 11 marks**

KEY WORDS conventional current 常规电流 • electric current 电流 • amperes 安培

Objective

Build the skills to answer exam questions on **electric current**.

You must be able to:

- define **electric current 电流** as the rate of flow of charge, $I = \dfrac{\Delta q}{\Delta t}$
- describe current as the drift of charge carriers through a conductor
- distinguish **conventional current 常规电流** from electron flow

1 Worked examples

Study these first. Each one shows the method for a question type used later.

■ **Current**

$I = \dfrac{\Delta q}{\Delta t}$, measured in amperes ($1\ \text{A} = 1\ \text{C s}^{-1}$).

■ **Drift of carriers**

In a metal, current is the slow drift of free electrons pushed by the field.

■ **Conventional current**

Conventional current is the direction **positive** charge would flow — opposite to the actual electron flow.

■ **Example**

6.0 C passing in 2.0 s: $I = 3.0$ A.

2 Practice

2.1 A charge of 12 C flows past a point in 4.0 s. Find the current. [2]

2.2 State the direction of conventional current relative to the electron flow. [1]

2.3 A current of 0.50 A flows for 10 s. Find the charge that passes. [2]

3 Exam-style questions

3.1 Electric current is the rate of flow of [1]

- **A** energy
- **B** charge
- **C** mass
- **D** voltage

3.2 Conventional current is defined as the direction of flow of [1]

- **A** electrons
- **B** positive charge
- **C** neutrons
- **D** photons

3.3 A wire carries a current of 2.0 A.

(a) Find the charge that passes in 30 s. [2]

(b) Find the number of electrons this represents ($e = 1.6 \times 10^{-19}$ C). [2]

Solutions

2.1 $I = \dfrac{\Delta q}{\Delta t} = \dfrac{12}{4.0} = 3.0$ A.

2.2 opposite to the electron flow.

2.3 $\Delta q = I\,\Delta t = 0.50 \times 10 = 5.0$ C.

3.1 **B**.

3.2 **B**.

3.3 (a) $\Delta q = I\,\Delta t = 2.0 \times 30 = 60$ C. (b) $N = \dfrac{60}{1.6 \times 10^{-19}} = 3.75 \times 10^{20}$ electrons.

11.2 Simple Circuits

Name: ______________ Class: __________ Date: ____________ **Total: 9 marks**

KEY WORDS circuit 电路 • battery 电池 • series 串联 • resistance 电阻

Objective

Build the skills to answer exam questions on **simple circuits**.

You must be able to:

- identify the parts of a **circuit 电路** — source, wires, resistor, switch — and their symbols
- describe how a **battery 电池** maintains a potential difference that drives the current
- trace a complete conducting loop and explain why a break stops the current

1 Worked examples

Study these first. Each one shows the method for a question type used later.

■ Circuit parts

A simple circuit has a **source** (cell or battery), **wires**, a **resistor** or bulb, and often a **switch** — each with its own symbol.

■ What the battery does

The battery maintains a **potential difference** across the circuit, which drives the current around the loop.

■ A complete loop

Current flows only around an **unbroken** conducting loop. An open switch (a break) stops the current everywhere.

2 Practice

2.1 Name the component that drives the current around a circuit. [1]

2.2 State what happens to the current when the switch is opened. [1]

2.3 Describe a simple series circuit containing a battery, a switch, and a resistor. [2]

3 Exam-style questions

3.1 A battery in a circuit provides [1]

- **A** resistance
- **B** a potential difference
- **C** a store of current
- **D** a magnetic field

3.2 Current flows in a circuit only when the loop is [1]

- **A** broken
- **B** complete
- **C** very long
- **D** at high temperature

3.3 A torch contains a cell, a switch, and a bulb.

(a) State what the cell does in the circuit. [1]

(b) Explain why the bulb goes out when the switch is opened. [2]

Solutions

2.1 the battery (or cell).

2.2 the current stops (the loop is broken).

2.3 the battery, switch, and resistor are connected in one loop by wires, so the same current flows through each in turn.

3.1 B.

3.2 B.

3.3 (a) it maintains a potential difference that drives the current. (b) opening the switch breaks the loop, so no current can flow and the bulb goes out.

Begin your response to **QUESTION 3** on this page.

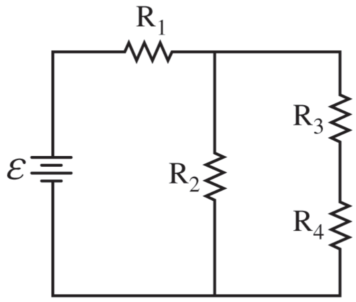

Figure 1

3. (12 points, suggested time 25 minutes)

A circuit consists of an ideal battery of emf $\mathcal{E}$ and four identical resistors R_1, R_2, R_3, and R_4, each of resistance R, as shown in Figure 1.

(a) For parts (a)(i) and (a)(ii), express your answers in terms of numerical values, $\mathcal{E}$, and R <u>only</u>.

i. **Derive** an expression for the current I_1 in Resistor R_1.

ii. **Derive** an expression for the current I_3 in Resistor R_3.

GO ON TO THE NEXT PAGE.

Continue your response to **QUESTION 3** on this page.

(b) The partially completed bar chart in Figure 2 shows a bar that represents the absolute value $|\Delta V|$ of the potential difference across the ideal battery.

- In Figure 2, **draw** a bar to represent $|\Delta V|$ across <u>each</u> resistor, relative to the emf $\mathcal{E}$ of the ideal battery.
- The height of <u>each</u> bar should be proportional to the value of $|\Delta V|$ represented by that bar. If $|\Delta V|$ is zero, write a "0" in that column.

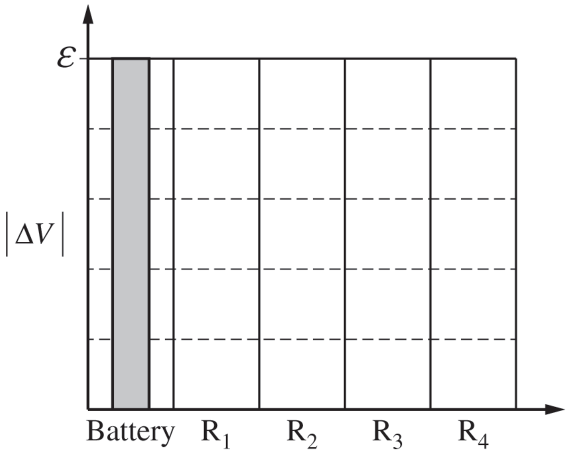

Figure 2

A student claims that the rate at which energy is dissipated (power) by the circuit can be expressed as $P = \dfrac{3\mathcal{E}^2}{5R}$.

(c) **State** whether the expression for P is correct or incorrect. **Justify** your answer by referring to the derivations from part (a) or the bar chart from part (b).

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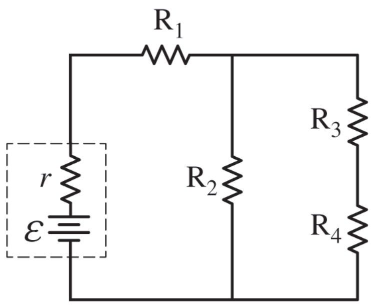


Figure 3

When the ideal battery is connected in the original circuit, the rate at which energy is dissipated by Resistor R_1 is $P_{original}$. The ideal battery is now replaced with a nonideal battery of emf $\mathcal{E}$ and internal resistance r to form the new circuit shown in Figure 3. The rate at which energy is dissipated by Resistor R_1 in the new circuit is P_{new}.

(d) **Indicate** whether P_{new} is greater than, less than, or equal to $P_{original}$.

____ $P_{new} > P_{original}$ ____ $P_{new} < P_{original}$ ____ $P_{new} = P_{original}$

Briefly **justify** your answer.

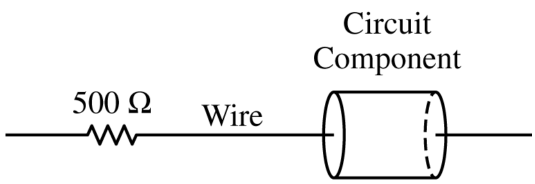
GO ON TO THE NEXT PAGE.

2. (12 points, suggested time 25 minutes)

Students are given an unknown circuit component that is connected in series to a resistor with known resistance $500\ \Omega$.

(a) The students are asked to experimentally determine whether the component is a resistor or an uncharged capacitor.

i. Complete the following diagram to show how to use standard circuit equipment to determine whether the component is a resistor or an uncharged capacitor.



ii. Describe an experimental procedure to determine whether the component is a resistor or an uncharged capacitor. Refer to the circuit equipment in the diagram drawn in part (a)(i).

iii. What results would the students expect if the component is an uncharged capacitor? Support your answer in terms of potential difference and charge.

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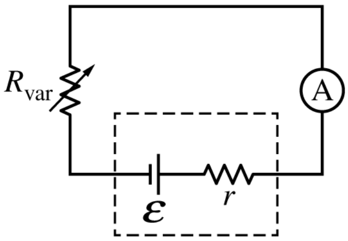

The students conduct a different experiment to determine the emf $\mathcal{E}$ of a battery that is not ideal and has internal resistance $r = 30\,\Omega$. The battery is connected to a variable resistor in a circuit, as shown. The students measure the current I through the circuit for different values of resistance R_{var} of the variable resistor that is connected to the battery. The following table contains the data collected.

I (A)	R_{var} (Ω)		
0.087	200		
0.060	300		
0.042	450		
0.027	700		
0.016	1200		

(b)

i. Write an equation describing the circuit in terms of $\mathcal{E}$, I, r, and R_{var}.

ii. Which quantities could be graphed to yield a straight line that could be used to calculate a numerical value for the emf $\mathcal{E}$ of the battery?

Horizontal Axis:________________ Vertical Axis:________________

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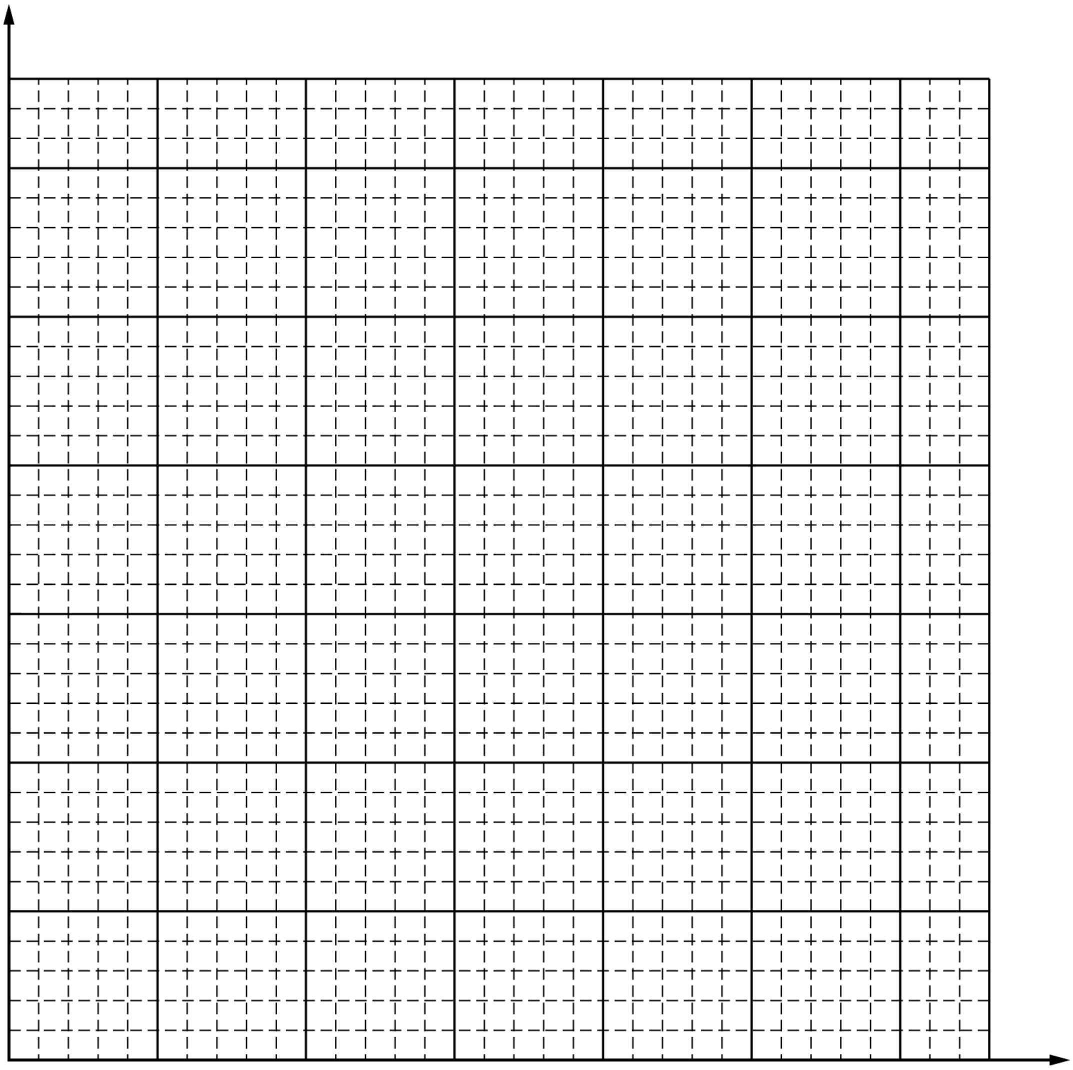
Continue your response to **QUESTION 2** on this page.

iii. Plot the data points for the quantities indicated in part (b)(ii) on the following graph. Clearly scale and label all axes, including units. Draw a straight line that best represents the data.
You may use the blank columns in the table for any quantities you graph other than the given data.



iv. Using the graph from part (b)(iii), determine the emf $\mathcal{E}$ of the battery.

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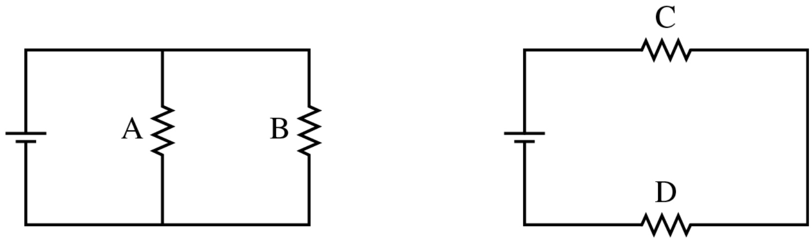

2. (12 points, suggested time 25 minutes)

Students perform an experiment with a battery and four resistors, A, B, C, and D. The resistance of resistors A and C is $R_A = R_C = R$. The resistance of resistors B and D is $R_B = R_D = 2R$. The students create the two circuits shown above and measure the potential differences ΔV_A, ΔV_B, ΔV_C, and ΔV_D across resistors A, B, C, and D, respectively.

(a) From greatest to least, rank the magnitudes of the potential differences across the resistors. Use "1" for the greatest magnitude, "2" for the next greatest magnitude, and so on. If any potential differences have the same magnitude, use the same number for their ranking.

____ΔV_A ____ΔV_B ____ΔV_C ____ ΔV_D

Justify your answer.

In another experiment, the students have a capacitor with unknown capacitance C_U. They want to determine C_U by using a battery of potential difference 4.5 V and several other capacitors of known capacitance. They create circuits with the battery, the unknown capacitor, and one of the capacitors of known capacitance. The students wait until the capacitors are fully charged and then record the potential difference ΔV_{known} across the known capacitor and the potential difference ΔV_U across the unknown capacitor. Their data are shown in the table on the following page.

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Continue your response to **QUESTION 2** on this page.

Known Capacitance of Capacitors (μF)	ΔV_{known} (V)	ΔV_U (V)		
200	0.91	3.53		
300	0.65	3.74		
400	0.51	3.95		
500	0.42	4.06		
600	0.36	4.17		

(b)

i. Calculate the amount of charge on the capacitor of known capacitance of 200 μF in the students' experiment.

ii. Briefly explain why the data in the table provide evidence that the capacitors are connected in series.

iii. Briefly explain why connecting the capacitors in parallel would not provide enough information to determine the capacitance of the unknown capacitor if the only measuring device available is a voltmeter.

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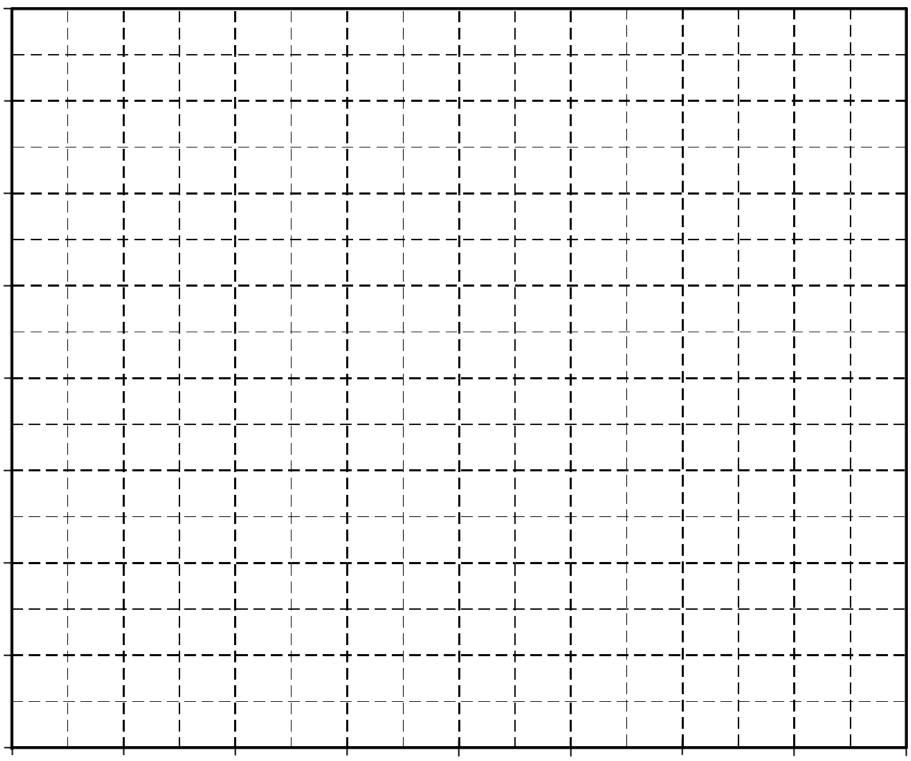
Continue your response to **QUESTION 2** on this page.

(c) The students want to produce a linear graph of the data so that the capacitance C_U of the unknown capacitor can be determined from the slope of the best-fit line for the data.

i. Indicate two quantities that could be plotted to produce the desired graph. Use the empty columns of the data table in part (b) to record any values that you need to calculate.

Vertical axis ____________________ Horizontal axis ____________________

ii. Label the axes below and provide an appropriate scale with units. Plot the data points for the quantities indicated in part (c)(i) on the axes and draw a best-fit line.



iii. Using your best-fit line, determine the capacitance of capacitor C_U.

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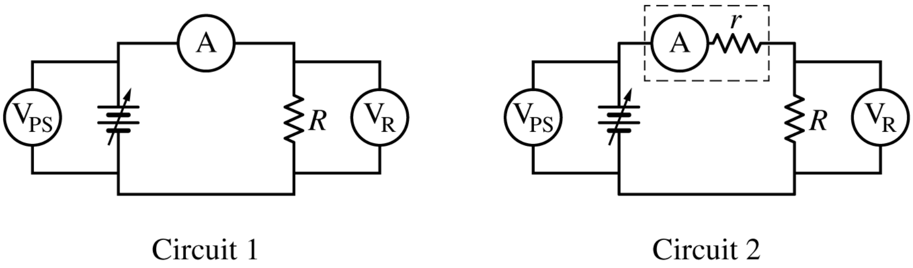
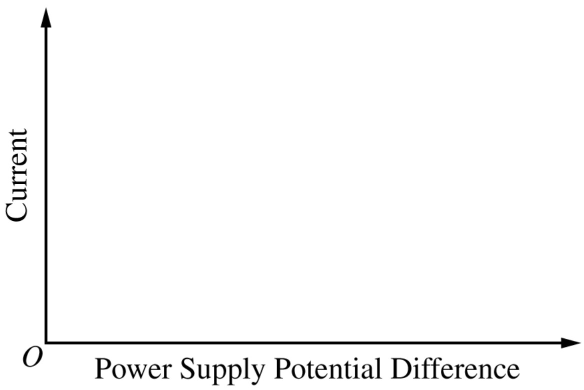


2. (12 points, suggested time 25 minutes)

The two circuits shown above contain an ideal variable power supply, an ohmic resistor of resistance R, an ammeter A, and two voltmeters V_{PS} and V_R. In circuit 1 the ammeter has negligible resistance, and in circuit 2 the ammeter has significant internal ohmic resistance r. The potential difference of the power supply is varied, and measurements of current and potential difference are recorded.

(a) The axes below can be used to graph the current measured by the ammeter as a function of the potential difference measured across the power supply. On the axes, do the following.

- Sketch a possible graph for circuit 1 and label it 1.
- Sketch a possible graph for circuit 2 and label it 2.



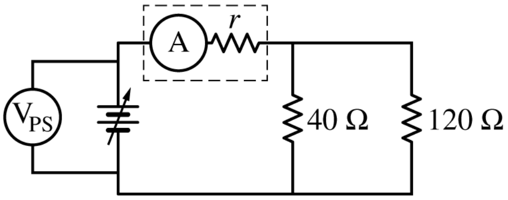
(b) Let ΔV_{PS} be the potential difference measured by voltmeter V_{PS} across the power supply, and let I be the current measured by the ammeter A. For each circuit, write an equation that satisfies conservation of energy, in terms of ΔV_{PS}, I, R, and r, as appropriate.

<u>Circuit 1</u> <u>Circuit 2</u>

(c) Explain how your equations in part (b) account for any differences between graphs 1 and 2 in part (a).

(d) In circuit 2, $R = 40\ \Omega$. When voltmeter V_{PS} reads 3.0 V, voltmeter V_R reads 2.5 V. Calculate the internal resistance r of the ammeter.

(e) Voltmeter V_R in circuit 2 is replaced by a resistor with resistance $120\ \Omega$ to create circuit 3 shown below. Voltmeter V_{PS} still reads 3.0 V.



Circuit 3

i. Calculate the equivalent resistance R_{eq} of the circuit.

ii. Calculate the current in each of the resistors that are in parallel.

2. (12 points, suggested time 25 minutes)

A group of students is given several long, thick, cylindrical conducting rods of the same unknown material with various lengths and diameters and asked to experimentally determine the resistivity of the material using a graph. The available equipment includes a voltmeter, an ammeter, connecting wires, a variable-output DC power supply, and a metric ruler.

(a)

i. Describe a procedure the students could use to collect the data needed to create the graph, including the measurements to be taken and a labeled diagram of the circuit to be used. Include enough detail that another student could follow the procedure and obtain similar data.

Draw a labeled diagram here.

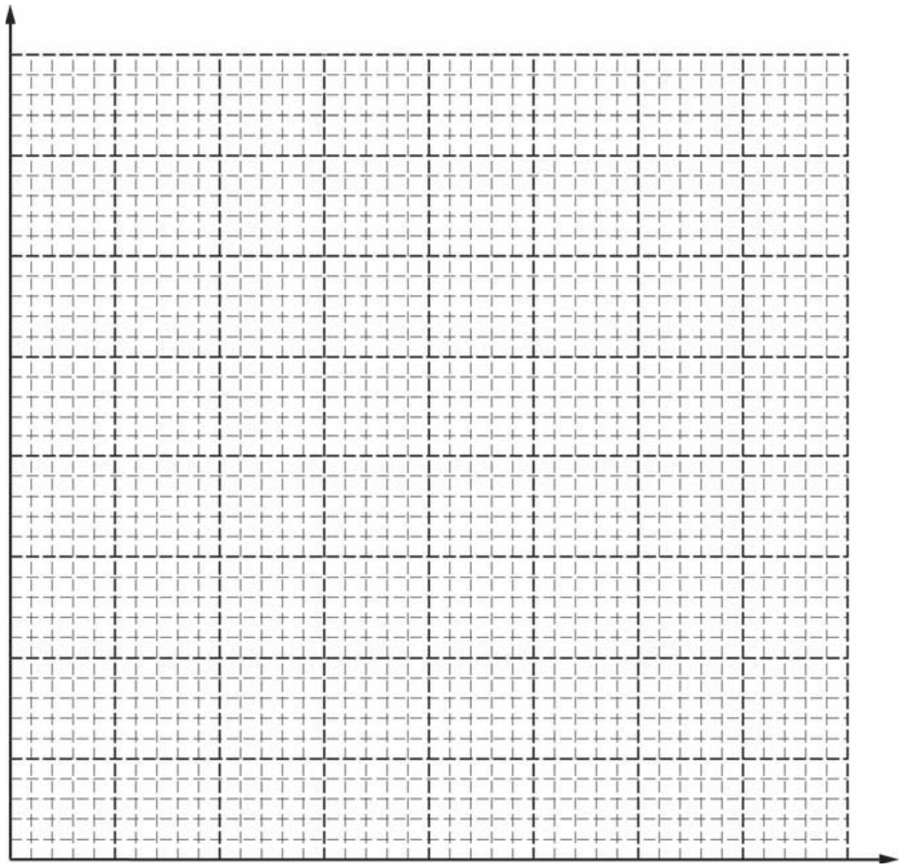
Write your procedure here.

ii. Describe how the data could be graphed in a way that is useful for determining the resistivity of the material. Describe how the graph could be analyzed to calculate the resistivity.

The students are now given a rectangular rod of the material, as shown below, whose dimensions are not known. The students are asked to experimentally determine the resistance of the rod. They obtain the data in the table below for the potential difference ΔV across the rod and the current I in it.

ΔV (V)	6.0	5.0	3.5	2.5	2.0	1.5
I (A)	0.078	0.070	0.044	0.036	0.027	0.018

(b) On the axes below, plot the data so that the resistance of the rectangular rod can be determined from a best-fit line. Label and scale the axes. Use the best-fit line to determine the resistance of the rod, clearly showing your calculations.



(c) After completing their calculations, the students begin to consider the factors that might have produced uncertainties in their results.

i. The students realize that they did not take into account the internal resistance of the power supply. Briefly describe how this would affect their value of the resistance of the rectangular rod. Explain your reasoning.

ii. The students realize that they did not take into account a possible change in the temperature of the cylindrical rods. Should the students be concerned about this? Explain why or why not.

11.3 Resistance, Resistivity, and Ohm's Law

Name: ______________ Class: __________ Date: ____________ **Total: 10 marks**

KEY WORDS resistance 电阻 • resistivity 电阻率 • ohm's law 欧姆定律

Objective

Build the skills to answer exam questions on **resistance, resistivity, and Ohm's law**.

You must be able to:

- apply **Ohm's law** 欧姆定律 $V = IR$ to a resistor
- relate **resistance** 电阻 to the **resistivity** 电阻率, length, and area, $R = \dfrac{\rho \ell}{A}$
- distinguish **ohmic** from non-ohmic devices using their current-voltage graphs

1 Worked examples

Study these first. Each one shows the method for a question type used later.

■ Ohm's law

$V = IR$ links the potential difference, current, and resistance.

■ Resistivity

$R = \dfrac{\rho \ell}{A}$: a **longer** or **thinner** wire has more resistance.

■ Ohmic vs non-ohmic

An **ohmic** conductor has a straight-line I-V graph through the origin (constant R). A filament lamp is **non-ohmic** — its graph curves because R rises with temperature.

2 Practice

2.1 A 6.0 V supply drives 2.0 A through a resistor. Find its resistance. [2]

2.2 State how the resistance of a wire changes if it is made longer. [1]

2.3 Describe the current-voltage graph of an ohmic conductor. [1]

3 Exam-style questions

3.1 Ohm's law is [1]

- **A** $V = IR$
- **B** $P = IV$
- **C** $R = \rho\ell/A$
- **D** $Q = It$

3.2 The resistance of a wire increases if it is made [1]

- **A** shorter
- **B** thicker
- **C** longer
- **D** cooler

3.3 A resistor obeys Ohm's law. A voltage of 9.0 V produces a current of 0.30 A.

(a) Find its resistance. [2]

(b) Find the current when the voltage is raised to 15 V. [2]

Solutions

2.1 $R = \dfrac{V}{I} = \dfrac{6.0}{2.0} = 3.0\ \Omega$.

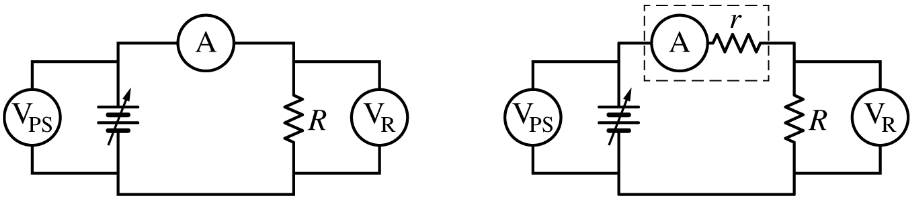
2.2 it increases (resistance is proportional to length).

2.3 a straight line through the origin (constant resistance).

3.1 **A**.

3.2 **C**.

3.3 (a) $R = \dfrac{9.0}{0.30} = 30\ \Omega$. (b) $I = \dfrac{V}{R} = \dfrac{15}{30} = 0.50$ A.



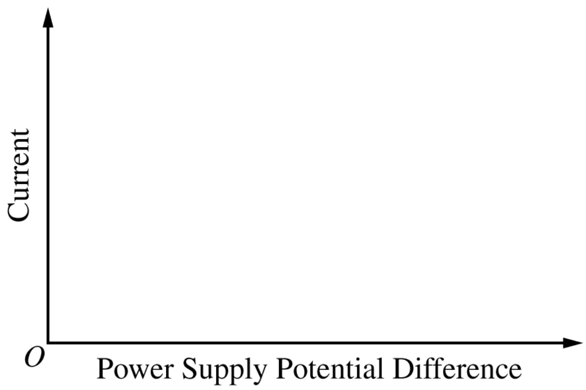
Circuit 1 Circuit 2

2. (12 points, suggested time 25 minutes)

The two circuits shown above contain an ideal variable power supply, an ohmic resistor of resistance R, an ammeter A, and two voltmeters $\mathrm{V_{PS}}$ and $\mathrm{V_R}$. In circuit 1 the ammeter has negligible resistance, and in circuit 2 the ammeter has significant internal ohmic resistance r. The potential difference of the power supply is varied, and measurements of current and potential difference are recorded.

(a) The axes below can be used to graph the current measured by the ammeter as a function of the potential difference measured across the power supply. On the axes, do the following.

- Sketch a possible graph for circuit 1 and label it 1.
- Sketch a possible graph for circuit 2 and label it 2.



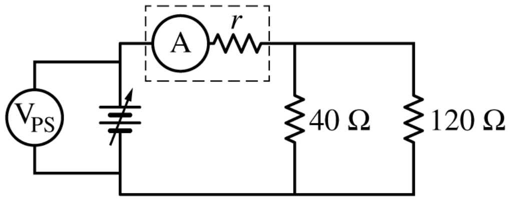
(b) Let ΔV_{PS} be the potential difference measured by voltmeter $\mathrm{V_{PS}}$ across the power supply, and let I be the current measured by the ammeter A. For each circuit, write an equation that satisfies conservation of energy, in terms of ΔV_{PS}, I, R, and r, as appropriate.

<u>Circuit 1</u> <u>Circuit 2</u>

(c) Explain how your equations in part (b) account for any differences between graphs 1 and 2 in part (a).

(d) In circuit 2, $R = 40\ \Omega$. When voltmeter V_{PS} reads 3.0 V, voltmeter V_R reads 2.5 V. Calculate the internal resistance r of the ammeter.

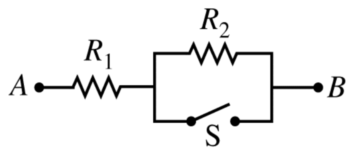
(e) Voltmeter V_R in circuit 2 is replaced by a resistor with resistance $120\ \Omega$ to create circuit 3 shown below. Voltmeter V_{PS} still reads 3.0 V.



Circuit 3

i. Calculate the equivalent resistance R_{eq} of the circuit.

ii. Calculate the current in each of the resistors that are in parallel.



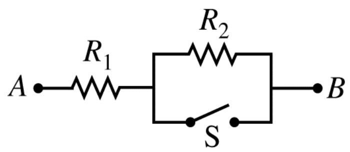
2. (12 points, suggested time 25 minutes)

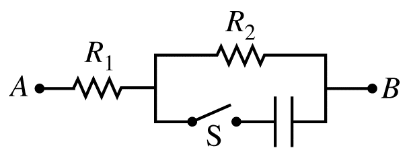
Students are given resistor 1 with resistance R_1 connected in series with the parallel combination of a switch S and resistor 2 with resistance R_2, as shown above. The circuit elements cannot be disconnected from each other, and other circuit components can only be connected at points *A* and *B*. The students also are given an ammeter and one 9 V battery. The teacher instructs the students to take measurements that can be used to determine R_1 and R_2.

(a) Complete the diagram below to show how the ammeter and the battery should be connected to experimentally determine the resistance of each resistor. Describe the experiment by listing the measurements to be taken and explaining how the measurements would be used to calculate resistances R_1 and R_2.

Complete the Diagram

Describe the Experiment





A second group of students is given a combination of circuit elements that is similar to the previous one but has an initially uncharged capacitor in series with the open switch, as shown above. The combination is placed in a circuit with a power supply so that the potential difference between *A* and *B* is maintained at 9 V. The students close the switch and immediately begin to record the current through point *B*. The initial current is 0.9 A, and after a long time the current is 0.3 A.

(b)

i. Compare the currents through resistor 1, resistor 2, and the switch immediately after the switch is closed to the currents a long time after the switch is closed. Specifically state if any current is zero.

ii. Calculate the values of R_1 and R_2.

iii. Determine the potential difference across the capacitor a long time after the switch is closed.

A third group of students now uses the combination of circuit elements with the capacitor. They connect it to a 9 V battery that they treat as ideal but which is actually not ideal and has internal resistance.

(c) How does the third group's value of R_1 calculated from the data they collected compare to the second group's value? Explain your reasoning with reference to physics principles and/or mathematical models.

2. (12 points, suggested time 25 minutes)

A group of students is given several long, thick, cylindrical conducting rods of the same unknown material with various lengths and diameters and asked to experimentally determine the resistivity of the material using a graph. The available equipment includes a voltmeter, an ammeter, connecting wires, a variable-output DC power supply, and a metric ruler.

(a)

i. Describe a procedure the students could use to collect the data needed to create the graph, including the measurements to be taken and a labeled diagram of the circuit to be used. Include enough detail that another student could follow the procedure and obtain similar data.

Draw a labeled diagram here.

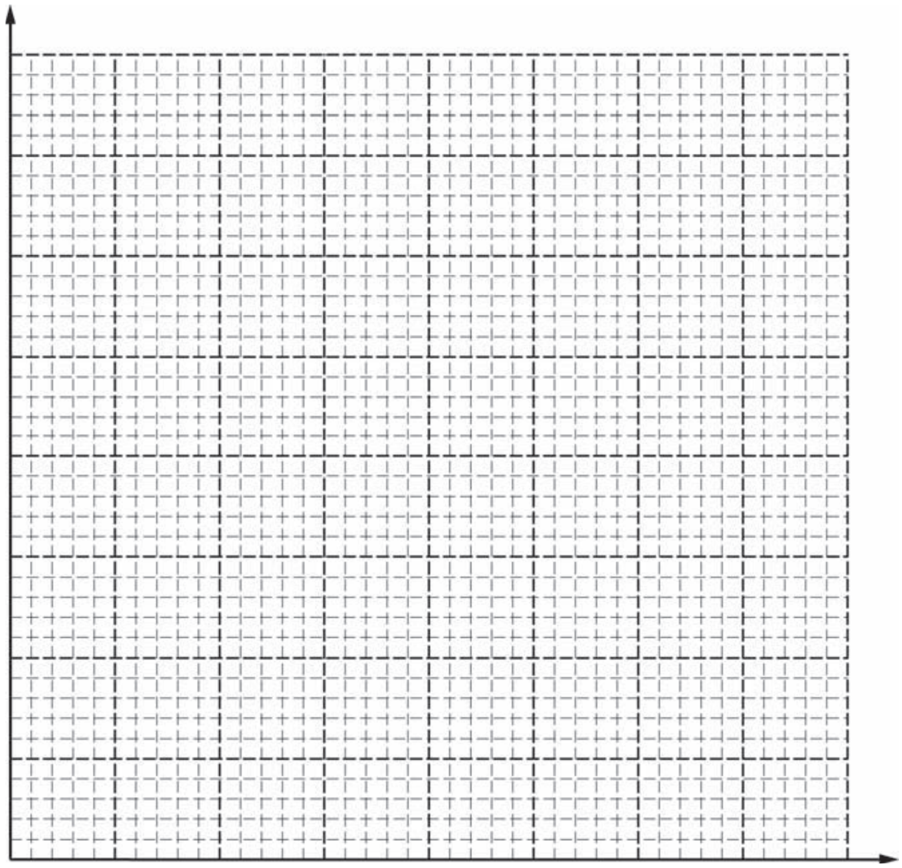
Write your procedure here.

ii. Describe how the data could be graphed in a way that is useful for determining the resistivity of the material. Describe how the graph could be analyzed to calculate the resistivity.

The students are now given a rectangular rod of the material, as shown below, whose dimensions are not known. The students are asked to experimentally determine the resistance of the rod. They obtain the data in the table below for the potential difference ΔV across the rod and the current I in it.

ΔV (V)	6.0	5.0	3.5	2.5	2.0	1.5
I (A)	0.078	0.070	0.044	0.036	0.027	0.018

(b) On the axes below, plot the data so that the resistance of the rectangular rod can be determined from a best-fit line. Label and scale the axes. Use the best-fit line to determine the resistance of the rod, clearly showing your calculations.



(c) After completing their calculations, the students begin to consider the factors that might have produced uncertainties in their results.

i. The students realize that they did not take into account the internal resistance of the power supply. Briefly describe how this would affect their value of the resistance of the rectangular rod. Explain your reasoning.

ii. The students realize that they did not take into account a possible change in the temperature of the cylindrical rods. Should the students be concerned about this? Explain why or why not.

11.4 Electric Power

Name: ______________ Class: __________ Date: ____________ **Total: 12 marks**

KEY WORDS electric power 电功率 • resistance 电阻

Objective

Build the skills to answer exam questions on **electric power**.

You must be able to:

- calculate **electric power 电功率** delivered to a device, $P = IV$
- rewrite power for a resistor as $P = I^2R = \dfrac{V^2}{R}$
- relate power to the **energy** transferred over time, $E = Pt$

1 Worked examples

Study these first. Each one shows the method for a question type used later.

■ **Power**

$P = IV$, in watts. For a resistor, using $V = IR$ gives two more forms:

$$P = I^2R = \frac{V^2}{R}.$$

■ **Energy**

$E = Pt$ — power multiplied by time.

■ **Example**

A device drawing 2.0 A at 12 V: $P = 24$ W.

2 Practice

2.1 A device draws 3.0 A at 12 V. Find the power. [2]

2.2 A 6.0 Ω resistor carries 2.0 A. Find the power dissipated. [2]

2.3 A 60 W bulb runs for 120 s. Find the energy transferred. [2]

3 Exam-style questions

3.1 Electric power is [1]

- **A** IV
- **B** I/V
- **C** V/I
- **D** IR

3.2 The power dissipated in a resistor can be written as [1]

- **A** V^2R
- **B** V^2/R
- **C** I/R^2
- **D** IR^2

3.3 A 240 V heater has a resistance of 60 Ω.

(a) Find the current it draws. [2]

(b) Find the power it dissipates. [2]

Solutions

2.1 $P = IV = 3.0 \times 12 = 36$ W.

2.2 $P = I^2R = (2.0)^2 \times 6.0 = 24$ W.

2.3 $E = Pt = 60 \times 120 = 7200$ J.

3.1 **A**.

3.2 **B**.

3.3 (a) $I = \dfrac{V}{R} = \dfrac{240}{60} = 4.0$ A. (b) $P = IV = 4.0 \times 240 = 960$ W.

Begin your response to **QUESTION 3** on this page.

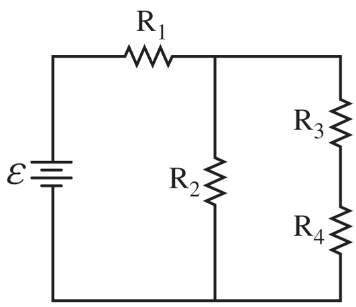


Figure 1

3. (12 points, suggested time 25 minutes)

A circuit consists of an ideal battery of emf $\mathcal{E}$ and four identical resistors R_1, R_2, R_3, and R_4, each of resistance R, as shown in Figure 1.

(a) For parts (a)(i) and (a)(ii), express your answers in terms of numerical values, $\mathcal{E}$, and R only.

i. **Derive** an expression for the current I_1 in Resistor R_1.

ii. **Derive** an expression for the current I_3 in Resistor R_3.

GO ON TO THE NEXT PAGE.

Continue your response to **QUESTION 3** on this page.

(b) The partially completed bar chart in Figure 2 shows a bar that represents the absolute value $|\Delta V|$ of the potential difference across the ideal battery.

- In Figure 2, **draw** a bar to represent $|\Delta V|$ across each resistor, relative to the emf $\mathcal{E}$ of the ideal battery.
- The height of each bar should be proportional to the value of $|\Delta V|$ represented by that bar. If $|\Delta V|$ is zero, write a "0" in that column.

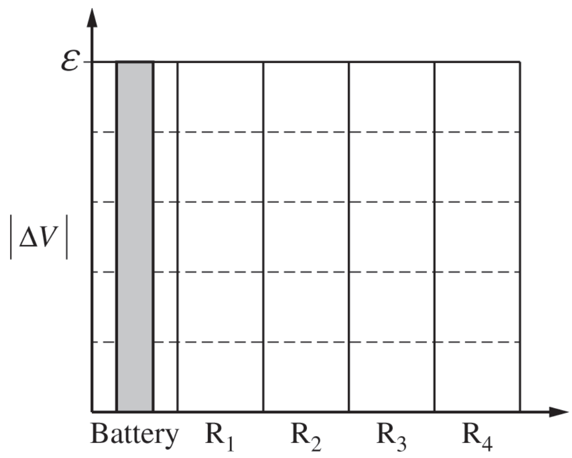


Figure 2

A student claims that the rate at which energy is dissipated (power) by the circuit can be expressed as $P = \dfrac{3\mathcal{E}^2}{5R}$.

(c) **State** whether the expression for P is correct or incorrect. **Justify** your answer by referring to the derivations from part (a) or the bar chart from part (b).

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Continue your response to **QUESTION 3** on this page.

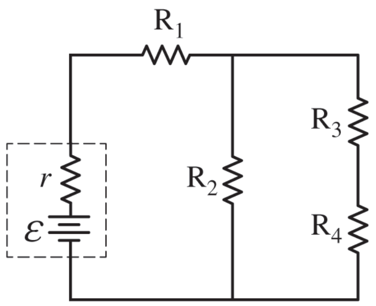

Figure 3

When the ideal battery is connected in the original circuit, the rate at which energy is dissipated by Resistor R_1 is $P_{original}$. The ideal battery is now replaced with a nonideal battery of emf $\mathcal{E}$ and internal resistance r to form the new circuit shown in Figure 3. The rate at which energy is dissipated by Resistor R_1 in the new circuit is P_{new}.

(d) **Indicate** whether P_{new} is greater than, less than, or equal to $P_{original}$.

_____ $P_{new} > P_{original}$ _____ $P_{new} < P_{original}$ _____ $P_{new} = P_{original}$

Briefly **justify** your answer.

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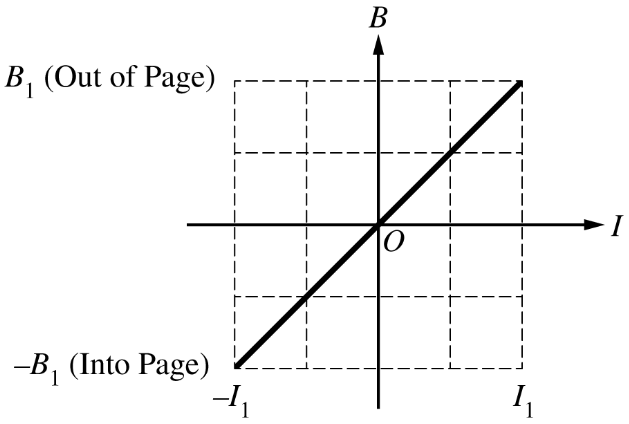
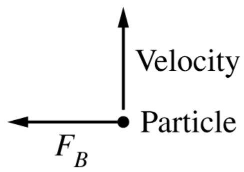


Graph 1

3. (12 points, suggested time 25 minutes)

An electromagnet produces a magnetic field that is uniform in a certain region and zero outside that region. The graph above represents the field as a function of the current in the electromagnet, with positive field directed out of the page and negative field directed into the page.



(a) The current in the electromagnet is set at $0.5I_1$. When a charged particle in the region moves toward the top of the page, the force exerted on it by the field is F_B toward the left, as shown above. What changes to the current in the electromagnet could make the magnitude of the force exerted on the particle equal to $2F_B$ and the direction of the force to the right? Support your answer using physics principles.

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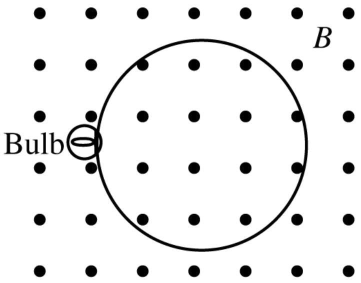
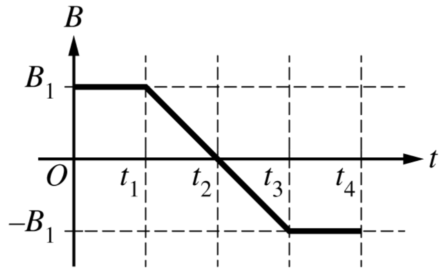
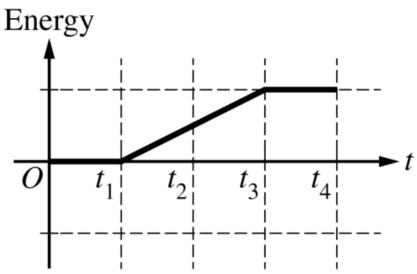




Graph 2

A circuit is made by connecting an ohmic lightbulb of resistance R and a circular loop of area A made of a wire with negligible resistance. The circuit is placed with the plane of the loop perpendicular to the field of the electromagnet, as shown above on the left. The magnetic field changes as a function of time, as shown in Graph 2. The bulb dissipates energy during the interval $t_1 < t < t_3$. Graph 3 below shows the cumulative energy dissipated by the bulb (the total energy dissipated since $t = 0$) as a function of time.



Graph 3

(b) The original bulb is replaced by a new ohmic lightbulb with a greater resistance, but everything else stays the same. How would the cumulative energy graph for the new bulb be different, if at all, from Graph 3 above? Support your answer using physics principles.

GO ON TO THE NEXT PAGE.

(c) The new lightbulb is removed and replaced by the original lightbulb. The magnetic field now changes from $2B_1$ to $-2B_1$ during the same interval $t_1 < t < t_3$. A new cumulative energy graph is created for this situation. How would the new graph be different, if at all, from Graph 3 ? Support your answer using physics principles.

(d) A student derives the following expression for the cumulative energy dissipated by the original bulb during the interval $t_1 < t < t_3$ and with the original change in magnetic field shown in Graph 2.

$$\text{Energy} = \frac{A^2 B_1 R}{4(t_3 - t_1)}$$

Whether or not the equation is correct, does the functional dependence of cumulative energy on the elapsed time $(t_3 - t_1)$ make physical sense? Support your answer using physics principles.

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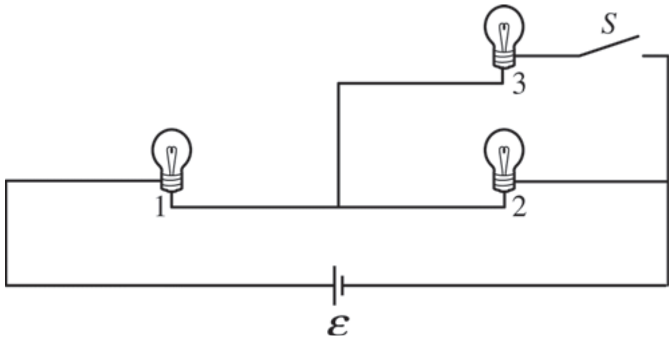

2. (12 points, suggested time 25 minutes)

A battery of emf $\mathcal{E}$ and negligible internal resistance, three identical incandescent lightbulbs, and a switch S that is initially open are connected in the circuit shown above. The bulbs each have resistance R. Students make predictions about what happens to the brightness of the bulbs after the switch is closed.

(a) A student makes the following prediction about bulb 1: "Bulb 1 will decrease in brightness when the switch is closed."

i. Do you agree or disagree with the student's prediction about bulb 1 ? Qualitatively explain your reasoning.

ii. Before the switch is closed, the power expended by bulb 1 is P_1. Derive an expression for the power P_{new} expended by bulb 1 after the switch is closed in terms of P_1.

iii. How does the result of your derivation in part (a)ii relate to your explanation in part (a)i?

(b) A student makes the following prediction about bulb 2: "Bulb 2 will decrease in brightness after the switch is closed."

i. Do you agree or disagree with the student's prediction about bulb 2 ? Explain your reasoning in words.

ii. Justify your explanation with a calculation.

(c) While the switch is open, bulb 3 is replaced with an uncharged capacitor. The switch is then closed.

i. How does the brightness of bulb 1 compare to the brightness of bulb 2 immediately after the switch is closed? Justify your answer.

ii. How does the brightness of bulb 1 compare to the brightness of bulb 2 a long time after the switch is closed? Justify your answer.

11.5 Compound DC Circuits

Name: ______________ Class: __________ Date: ____________ **Total: 11 marks**

KEY WORDS parallel 并联 • series 串联 • internal resistance 内阻 • resistance 电阻

Objective

Build the skills to answer exam questions on **compound DC circuits**.

You must be able to:

- combine resistors in **series** 串联 ($R_s = R_1 + R_2 + \ldots$) and in **parallel** 并联 ($\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} + \ldots$)
- account for the **internal resistance** 内阻 of a real battery and its terminal voltage
- analyse a circuit with mixed series and parallel sections

1 Worked examples

Study these first. Each one shows the method for a question type used later.

Series and parallel

- **Series:** same current, $R_s = R_1 + R_2 + \ldots$ (resistance adds up).
- **Parallel:** same voltage, $\dfrac{1}{R_p} = \dfrac{1}{R_1} + \dfrac{1}{R_2} + \ldots$ (total is **less** than the smallest).

Internal resistance

A real cell has internal resistance r, so the terminal voltage is $V = \varepsilon - Ir$.

Example

Two 4.0 Ω resistors in parallel: $\dfrac{1}{R_p} = \dfrac{1}{4} + \dfrac{1}{4} \Rightarrow R_p = 2.0\ \Omega$.

2 Practice

2.1 Two 6.0 Ω resistors are connected in series. Find the total resistance. [1]

2.2 The same two 6.0 Ω resistors are connected in parallel. Find the total resistance. [2]

2.3 A battery of emf 12 V and internal resistance 0.50 Ω drives a current of 2.0 A. Find the terminal voltage. [2]

3 Exam-style questions

3.1 Resistors in series have a total resistance equal to [1]

- **A** less than the smallest
- **B** the sum of the individual resistances
- **C** their average
- **D** their product

3.2 Adding another resistor in parallel makes the total resistance [1]

- **A** larger
- **B** smaller
- **C** unchanged
- **D** infinite

3.3 A 3.0 Ω and a 6.0 Ω resistor are in parallel across a 12 V supply.

(a) Find the combined resistance. [2]

(b) Find the total current drawn from the supply. [2]

Solutions

2.1 $R_s = 6.0 + 6.0 = 12\ \Omega$.

2.2 $\dfrac{1}{R_p} = \dfrac{1}{6.0} + \dfrac{1}{6.0} = \dfrac{2}{6.0} \Rightarrow R_p = 3.0\ \Omega$.

2.3 $V = \varepsilon - Ir = 12 - 2.0(0.50) = 11\ \text{V}$.

3.1 **B**.

3.2 **B**.

3.3 (a) $\dfrac{1}{R_p} = \dfrac{1}{3.0} + \dfrac{1}{6.0} = \dfrac{3}{6.0} \Rightarrow R_p = 2.0\ \Omega$. (b) $I = \dfrac{V}{R_p} = \dfrac{12}{2.0} = 6.0\ \text{A}$.

Begin your response to **QUESTION 3** on this page.

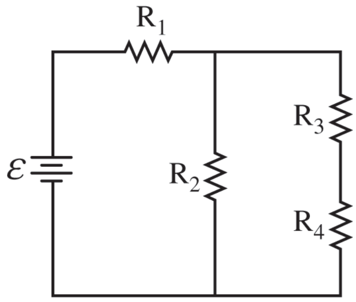

Figure 1

3. (12 points, suggested time 25 minutes)

A circuit consists of an ideal battery of emf $\mathcal{E}$ and four identical resistors R_1, R_2, R_3, and R_4, each of resistance R, as shown in Figure 1.

(a) For parts (a)(i) and (a)(ii), express your answers in terms of numerical values, $\mathcal{E}$, and R only.

i. **Derive** an expression for the current I_1 in Resistor R_1.

ii. **Derive** an expression for the current I_3 in Resistor R_3.

GO ON TO THE NEXT PAGE.

Continue your response to **QUESTION 3** on this page.

(b) The partially completed bar chart in Figure 2 shows a bar that represents the absolute value $|\Delta V|$ of the potential difference across the ideal battery.

- In Figure 2, **draw** a bar to represent $|\Delta V|$ across <u>each</u> resistor, relative to the emf $\mathcal{E}$ of the ideal battery.
- The height of <u>each</u> bar should be proportional to the value of $|\Delta V|$ represented by that bar. If $|\Delta V|$ is zero, write a "0" in that column.

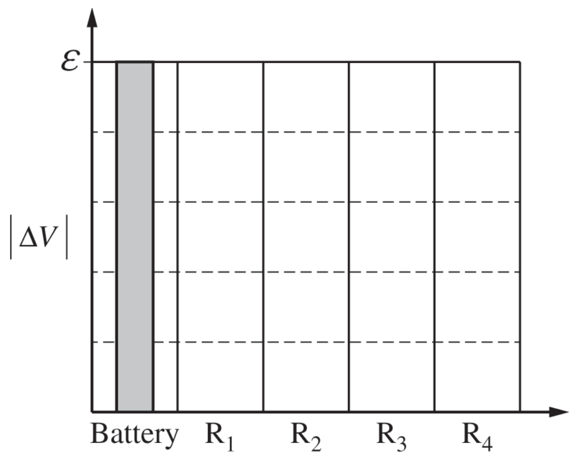

Figure 2

A student claims that the rate at which energy is dissipated (power) by the circuit can be expressed as $P = \dfrac{3\mathcal{E}^2}{5R}$.

(c) **State** whether the expression for P is correct or incorrect. **Justify** your answer by referring to the derivations from part (a) or the bar chart from part (b).

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Continue your response to **QUESTION 3** on this page.

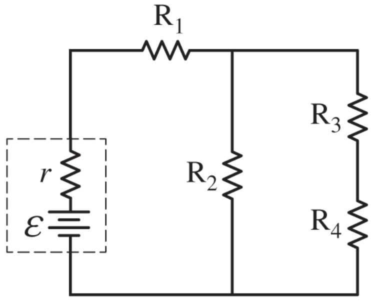


Figure 3

When the ideal battery is connected in the original circuit, the rate at which energy is dissipated by Resistor R_1 is $P_{original}$. The ideal battery is now replaced with a nonideal battery of emf $\mathcal{E}$ and internal resistance r to form the new circuit shown in Figure 3. The rate at which energy is dissipated by Resistor R_1 in the new circuit is P_{new}.

(d) **Indicate** whether P_{new} is greater than, less than, or equal to $P_{original}$.

_____ $P_{new} > P_{original}$ _____ $P_{new} < P_{original}$ _____ $P_{new} = P_{original}$

Briefly **justify** your answer.

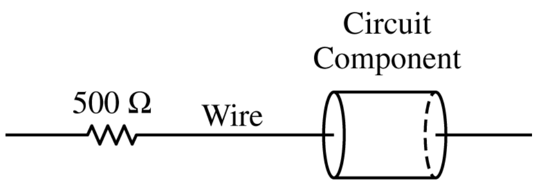
GO ON TO THE NEXT PAGE.

2. (12 points, suggested time 25 minutes)

Students are given an unknown circuit component that is connected in series to a resistor with known resistance $500\,\Omega$.

(a) The students are asked to experimentally determine whether the component is a resistor or an uncharged capacitor.

i. Complete the following diagram to show how to use standard circuit equipment to determine whether the component is a resistor or an uncharged capacitor.



ii. Describe an experimental procedure to determine whether the component is a resistor or an uncharged capacitor. Refer to the circuit equipment in the diagram drawn in part (a)(i).

iii. What results would the students expect if the component is an uncharged capacitor? Support your answer in terms of potential difference and charge.

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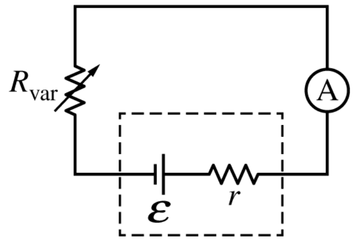
Continue your response to **QUESTION 2** on this page.



The students conduct a different experiment to determine the emf $\mathcal{E}$ of a battery that is not ideal and has internal resistance $r = 30\,\Omega$. The battery is connected to a variable resistor in a circuit, as shown. The students measure the current I through the circuit for different values of resistance R_{var} of the variable resistor that is connected to the battery. The following table contains the data collected.

I (A)	R_{var} (Ω)		
0.087	200		
0.060	300		
0.042	450		
0.027	700		
0.016	1200		

(b)

i. Write an equation describing the circuit in terms of $\mathcal{E}$, I, r, and R_{var}.

ii. Which quantities could be graphed to yield a straight line that could be used to calculate a numerical value for the emf $\mathcal{E}$ of the battery?

Horizontal Axis:________________ Vertical Axis:________________

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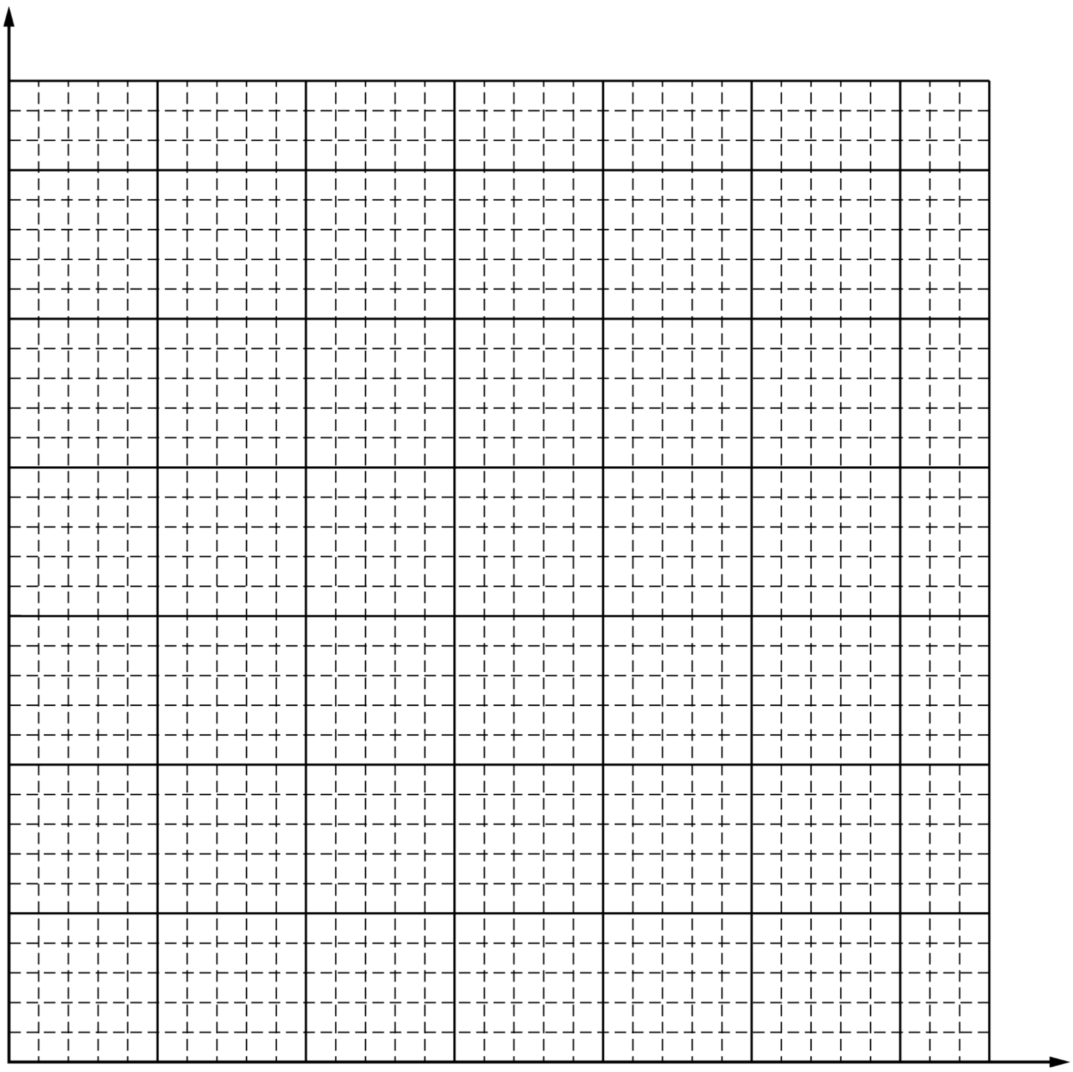
Continue your response to **QUESTION 2** on this page.

iii. Plot the data points for the quantities indicated in part (b)(ii) on the following graph. Clearly scale and label all axes, including units. Draw a straight line that best represents the data.
You may use the blank columns in the table for any quantities you graph other than the given data.



iv. Using the graph from part (b)(iii), determine the emf $\mathcal{E}$ of the battery.

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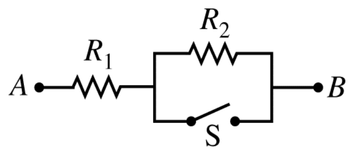


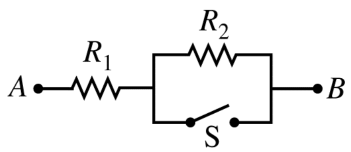
2. (12 points, suggested time 25 minutes)

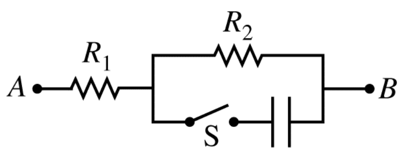
Students are given resistor 1 with resistance R_1 connected in series with the parallel combination of a switch S and resistor 2 with resistance R_2, as shown above. The circuit elements cannot be disconnected from each other, and other circuit components can only be connected at points *A* and *B*. The students also are given an ammeter and one 9 V battery. The teacher instructs the students to take measurements that can be used to determine R_1 and R_2.

(a) Complete the diagram below to show how the ammeter and the battery should be connected to experimentally determine the resistance of each resistor. Describe the experiment by listing the measurements to be taken and explaining how the measurements would be used to calculate resistances R_1 and R_2.

<u>Complete the Diagram</u>

<u>Describe the Experiment</u>





A second group of students is given a combination of circuit elements that is similar to the previous one but has an initially uncharged capacitor in series with the open switch, as shown above. The combination is placed in a circuit with a power supply so that the potential difference between *A* and *B* is maintained at 9 V. The students close the switch and immediately begin to record the current through point *B*. The initial current is 0.9 A, and after a long time the current is 0.3 A.

(b)

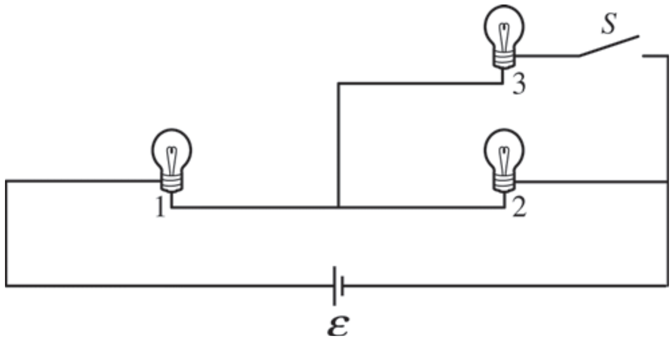
i. Compare the currents through resistor 1, resistor 2, and the switch immediately after the switch is closed to the currents a long time after the switch is closed. Specifically state if any current is zero.

ii. Calculate the values of R_1 and R_2.

iii. Determine the potential difference across the capacitor a long time after the switch is closed.

A third group of students now uses the combination of circuit elements with the capacitor. They connect it to a 9 V battery that they treat as ideal but which is actually not ideal and has internal resistance.

(c) How does the third group's value of R_1 calculated from the data they collected compare to the second group's value? Explain your reasoning with reference to physics principles and/or mathematical models.



2. (12 points, suggested time 25 minutes)

A battery of emf $\mathcal{E}$ and negligible internal resistance, three identical incandescent lightbulbs, and a switch S that is initially open are connected in the circuit shown above. The bulbs each have resistance R. Students make predictions about what happens to the brightness of the bulbs after the switch is closed.

(a) A student makes the following prediction about bulb 1: "Bulb 1 will decrease in brightness when the switch is closed."

i. Do you agree or disagree with the student's prediction about bulb 1 ? Qualitatively explain your reasoning.

ii. Before the switch is closed, the power expended by bulb 1 is P_1. Derive an expression for the power P_{new} expended by bulb 1 after the switch is closed in terms of P_1.

iii. How does the result of your derivation in part (a)ii relate to your explanation in part (a)i?

(b) A student makes the following prediction about bulb 2: "Bulb 2 will decrease in brightness after the switch is closed."

i. Do you agree or disagree with the student's prediction about bulb 2 ? Explain your reasoning in words.

ii. Justify your explanation with a calculation.

(c) While the switch is open, bulb 3 is replaced with an uncharged capacitor. The switch is then closed.

i. How does the brightness of bulb 1 compare to the brightness of bulb 2 immediately after the switch is closed? Justify your answer.

ii. How does the brightness of bulb 1 compare to the brightness of bulb 2 a long time after the switch is closed? Justify your answer.

11.6 Kirchhoff's Loop Rule

Name: ____________ Class: ________ Date: __________ **Total: 9 marks**

KEY WORDS conservation of energy 能量守恒 • kirchhoff's loop rule 基尔霍夫电压定律 • series 串联

Objective

Build the skills to answer exam questions on **Kirchhoff's loop rule**.

You must be able to:

- state **Kirchhoff's loop rule** 基尔霍夫电压定律: the sum of potential differences around any closed loop is zero
- explain the loop rule as a statement of **conservation of energy** 能量守恒
- apply the loop rule to write equations for a circuit

1 Worked examples

Study these first. Each one shows the method for a question type used later.

■ The loop rule

Around any closed loop, $\sum V = 0$: the potential rises across the battery equal the drops across the resistors.

■ Why it holds

A charge returning to its start has the **same** potential energy, so the total change around the loop is zero — this is conservation of energy.

■ Example

A single loop with a 12 V battery and resistors R_1, R_2 in series: $12 = IR_1 + IR_2$.

2 Practice

2.1 State Kirchhoff's loop rule. [1]

2.2 State the conservation law that the loop rule expresses. [1]

2.3 A single loop has a 9.0 V battery and resistors 2.0 Ω and 1.0 Ω in series. Write the loop equation and find the current. [2]

3 Exam-style questions

3.1 Kirchhoff's loop rule states that around a closed loop the sum of the potential differences is [1]

- **A** a maximum
- **B** zero
- **C** equal to the emf only
- **D** always negative

3.2 The loop rule is a statement of conservation of [1]

- **A** charge
- **B** energy
- **C** momentum
- **D** mass

3.3 A single loop contains a 6.0 V battery and resistors of 4.0 Ω and 2.0 Ω in series.

(a) Write the loop equation. [2]

(b) Find the current. [1]

Solutions

2.1 the sum of the potential differences around any closed loop is zero.

2.2 conservation of energy.

2.3 $9.0 = I(2.0 + 1.0) \Rightarrow I = 3.0$ A.

3.1 **B**.

3.2 **B**.

3.3 (a) $6.0 = I(4.0) + I(2.0)$. (b) $I = \dfrac{6.0}{6.0} = 1.0$ A.

Begin your response to **QUESTION 3** on this page.

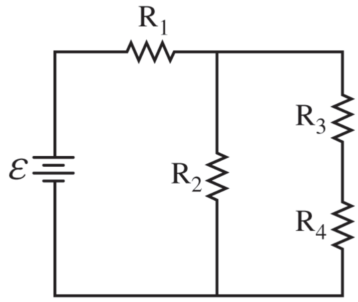


Figure 1

3. (12 points, suggested time 25 minutes)

A circuit consists of an ideal battery of emf $\mathcal{E}$ and four identical resistors R_1, R_2, R_3, and R_4, each of resistance R, as shown in Figure 1.

(a) For parts (a)(i) and (a)(ii), express your answers in terms of numerical values, $\mathcal{E}$, and R only.

i. **Derive** an expression for the current I_1 in Resistor R_1.

ii. **Derive** an expression for the current I_3 in Resistor R_3.

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Continue your response to **QUESTION 3** on this page.

(b) The partially completed bar chart in Figure 2 shows a bar that represents the absolute value $|\Delta V|$ of the potential difference across the ideal battery.

- In Figure 2, **draw** a bar to represent $|\Delta V|$ across each resistor, relative to the emf $\mathcal{E}$ of the ideal battery.
- The height of each bar should be proportional to the value of $|\Delta V|$ represented by that bar. If $|\Delta V|$ is zero, write a "0" in that column.

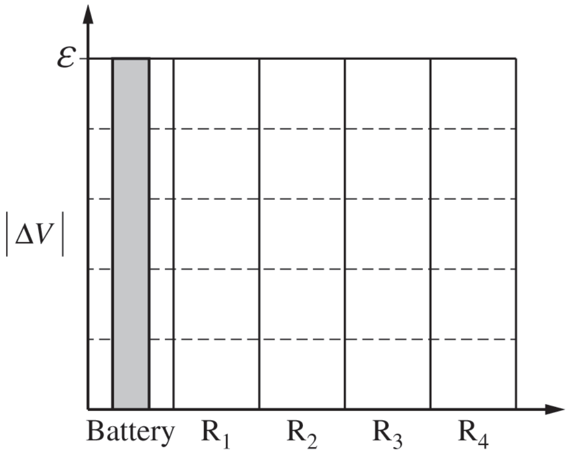

Figure 2

A student claims that the rate at which energy is dissipated (power) by the circuit can be expressed as $P = \dfrac{3\mathcal{E}^2}{5R}$.

(c) **State** whether the expression for P is correct or incorrect. **Justify** your answer by referring to the derivations from part (a) or the bar chart from part (b).

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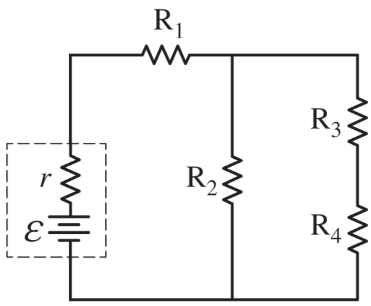


Figure 3

When the ideal battery is connected in the original circuit, the rate at which energy is dissipated by Resistor R_1 is $P_{original}$. The ideal battery is now replaced with a nonideal battery of emf $\mathcal{E}$ and internal resistance r to form the new circuit shown in Figure 3. The rate at which energy is dissipated by Resistor R_1 in the new circuit is P_{new}.

(d) **Indicate** whether P_{new} is greater than, less than, or equal to $P_{original}$.

_____ $P_{new} > P_{original}$ _____ $P_{new} < P_{original}$ _____ $P_{new} = P_{original}$

Briefly **justify** your answer.

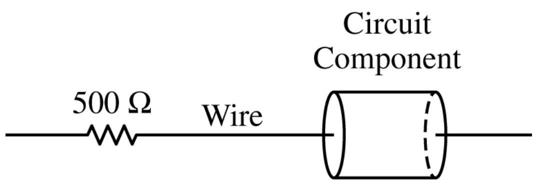
GO ON TO THE NEXT PAGE.

2. (12 points, suggested time 25 minutes)

Students are given an unknown circuit component that is connected in series to a resistor with known resistance $500\ \Omega$.

(a) The students are asked to experimentally determine whether the component is a resistor or an uncharged capacitor.

i. Complete the following diagram to show how to use standard circuit equipment to determine whether the component is a resistor or an uncharged capacitor.



ii. Describe an experimental procedure to determine whether the component is a resistor or an uncharged capacitor. Refer to the circuit equipment in the diagram drawn in part (a)(i).

iii. What results would the students expect if the component is an uncharged capacitor? Support your answer in terms of potential difference and charge.

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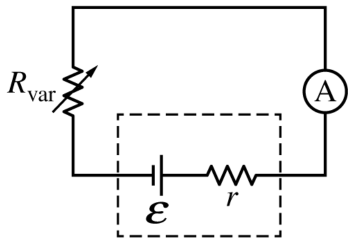
Continue your response to **QUESTION 2** on this page.



The students conduct a different experiment to determine the emf $\mathcal{E}$ of a battery that is not ideal and has internal resistance $r = 30\,\Omega$. The battery is connected to a variable resistor in a circuit, as shown. The students measure the current I through the circuit for different values of resistance R_{var} of the variable resistor that is connected to the battery. The following table contains the data collected.

I (A)	R_{var} (Ω)		
0.087	200		
0.060	300		
0.042	450		
0.027	700		
0.016	1200		

(b)

i. Write an equation describing the circuit in terms of $\mathcal{E}$, I, r, and R_{var}.

ii. Which quantities could be graphed to yield a straight line that could be used to calculate a numerical value for the emf $\mathcal{E}$ of the battery?

Horizontal Axis:________________ Vertical Axis:________________

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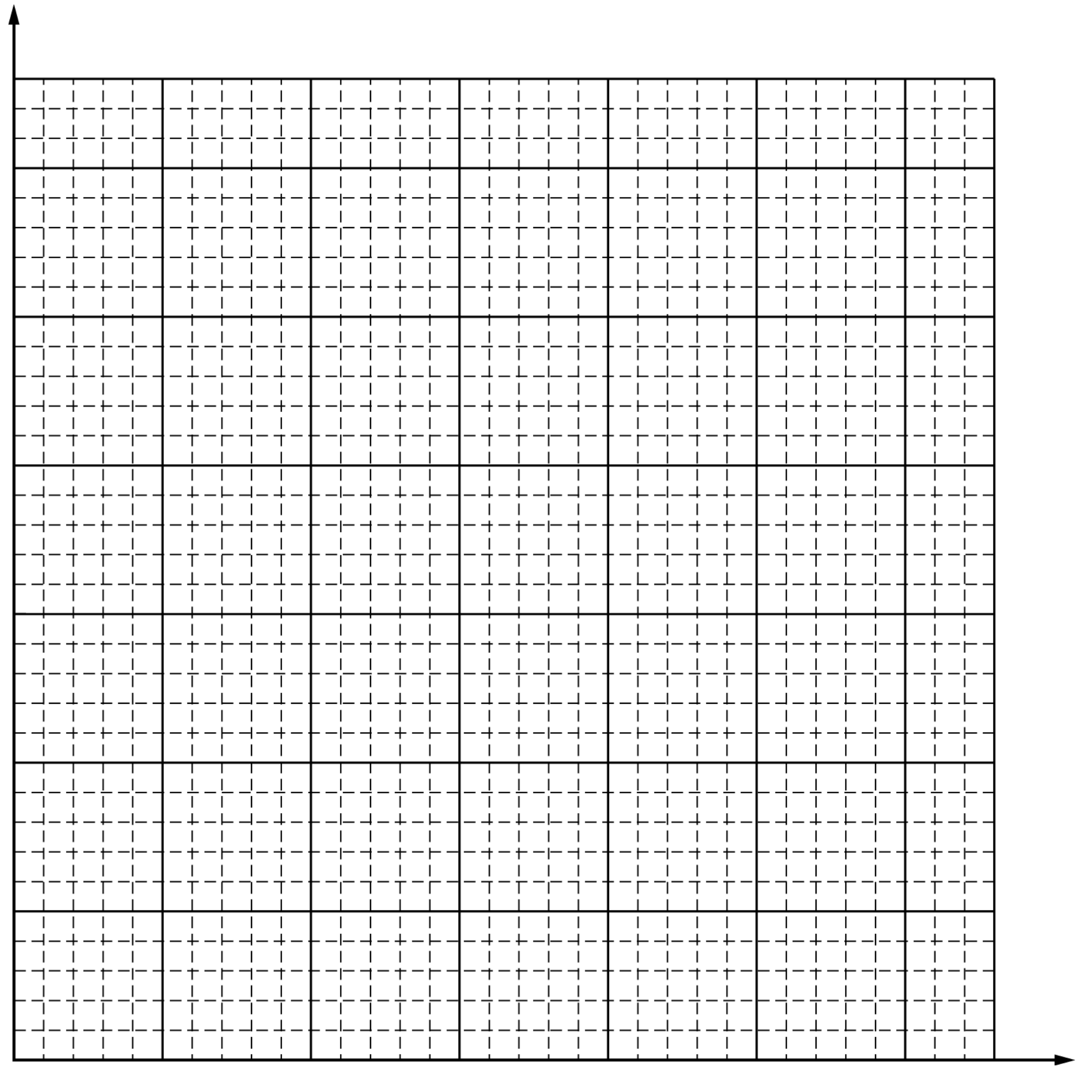
Continue your response to **QUESTION 2** on this page.

iii. Plot the data points for the quantities indicated in part (b)(ii) on the following graph. Clearly scale and label all axes, including units. Draw a straight line that best represents the data.
You may use the blank columns in the table for any quantities you graph other than the given data.



iv. Using the graph from part (b)(iii), determine the emf $\mathcal{E}$ of the battery.

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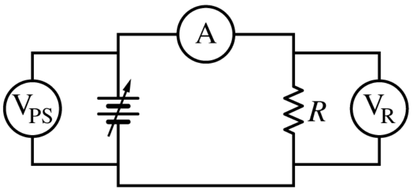
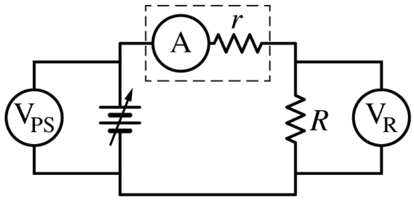


Circuit 1



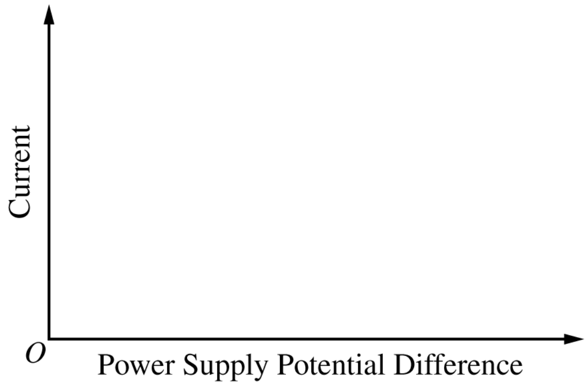
Circuit 2

2. (12 points, suggested time 25 minutes)

The two circuits shown above contain an ideal variable power supply, an ohmic resistor of resistance R, an ammeter A, and two voltmeters V_{PS} and V_R. In circuit 1 the ammeter has negligible resistance, and in circuit 2 the ammeter has significant internal ohmic resistance r. The potential difference of the power supply is varied, and measurements of current and potential difference are recorded.

(a) The axes below can be used to graph the current measured by the ammeter as a function of the potential difference measured across the power supply. On the axes, do the following.

- Sketch a possible graph for circuit 1 and label it 1.
- Sketch a possible graph for circuit 2 and label it 2.



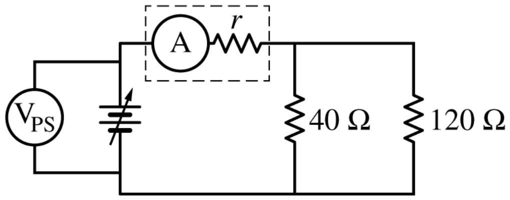
(b) Let ΔV_{PS} be the potential difference measured by voltmeter V_{PS} across the power supply, and let I be the current measured by the ammeter A. For each circuit, write an equation that satisfies conservation of energy, in terms of ΔV_{PS}, I, R, and r, as appropriate.

Circuit 1 | Circuit 2

(c) Explain how your equations in part (b) account for any differences between graphs 1 and 2 in part (a).

(d) In circuit 2, $R = 40\ \Omega$. When voltmeter V_{PS} reads 3.0 V, voltmeter V_R reads 2.5 V. Calculate the internal resistance r of the ammeter.

(e) Voltmeter V_R in circuit 2 is replaced by a resistor with resistance $120\ \Omega$ to create circuit 3 shown below. Voltmeter V_{PS} still reads 3.0 V.



Circuit 3

i. Calculate the equivalent resistance R_{eq} of the circuit.

ii. Calculate the current in each of the resistors that are in parallel.

11.7 Kirchhoff's Junction Rule

Name: ______________ Class: __________ Date: ____________ **Total: 9 marks**

KEY WORDS kirchhoff's junction rule 基尔霍夫电流定律 • conservation of charge 电荷守恒

Objective

Build the skills to answer exam questions on **Kirchhoff's junction rule**.

You must be able to:

- state **Kirchhoff's junction rule 基尔霍夫电流定律**: the current into a junction equals the current out
- explain the junction rule as a statement of **conservation of charge 电荷守恒**
- apply it with the loop rule to find unknown currents

1 Worked examples

Study these first. Each one shows the method for a question type used later.

■ The junction rule

At any junction, $\sum I_{in} = \sum I_{out}$: charge is not created or destroyed, so what flows in must flow out.

■ Why it holds

Charge is conserved, and it cannot pile up at a point, so the currents must balance.

■ Example

If 5.0 A enters a junction and splits into two branches carrying 2.0 A and I, then $I = 3.0$ A.

2 Practice

2.1 State Kirchhoff's junction rule. [1]

2.2 State the conservation law that the junction rule expresses. [1]

2.3 At a junction, 4.0 A enters and one branch carries 1.5 A out. Find the current in the other branch. [2]

3 Exam-style questions

3.1 Kirchhoff's junction rule states that the current into a junction equals the current [1]

- **A** stored there
- **B** out of it
- **C** squared
- **D** halved

3.2 The junction rule is a statement of conservation of [1]

- **A** energy
- **B** charge
- **C** momentum
- **D** power

3.3 At a node, 6.0 A enters and two branches leave; one carries 2.5 A.

(a) Find the current in the other branch. [2]

(b) State the conservation law you used. [1]

Solutions

2.1 the total current into a junction equals the total current out of it.

2.2 conservation of charge.

2.3 $4.0 - 1.5 = 2.5$ A.

3.1 **B**.

3.2 **B**.

3.3 (a) $6.0 - 2.5 = 3.5$ A. (b) conservation of charge.

11.8 RC Circuits

Name: ____________ Class: ________ Date: __________ **Total: 9 marks**

KEY WORDS capacitor 电容器 • time constant 时间常数 • rc circuit RC 电路 • resistance 电阻

Objective

Build the skills to answer exam questions on **RC circuits**.

You must be able to:

- describe how a **capacitor 电容器** charges and discharges through a resistor over time
- relate the **time constant 时间常数** $\tau = RC$ to how quickly the circuit responds
- describe the current and voltage at the start and after a long time

1 Worked examples

Study these first. Each one shows the method for a question type used later.

■ Charging and discharging

A capacitor charges up through a resistor, its voltage rising toward the supply value; it discharges the same way in reverse.

■ Time constant

$\tau = RC$ (seconds) sets the pace: a bigger R or C means slower charging.

■ Start and steady state

At $t = 0$ the uncharged capacitor acts like a **wire** (maximum current); after a long time it is **fully charged** and the current is **zero**.

2 Practice

2.1 Find the time constant of a 2000 Ω resistor and a 50 μF capacitor. [2]

2.2 State the current through the capacitor a long time after charging begins. [1]

2.3 State what happens to the charging rate if the resistance is increased. [1]

3 Exam-style questions

3.1 The time constant of an RC circuit is [1]

- **A** R/C
- **B** RC
- **C** $R+C$
- **D** C/R

3.2 A long time after charging begins, the current in an RC circuit is [1]

- **A** at its maximum
- **B** zero
- **C** constant and large
- **D** negative

3.3 A 10 kΩ resistor charges a 100 μF capacitor from a 9.0 V supply.

(a) Find the time constant. [2]

(b) State the final voltage across the capacitor. [1]

Solutions

2.1 $\tau = RC = 2000 \times 50 \times 10^{-6} = 0.10$ s.

2.2 zero (the capacitor is fully charged).

2.3 it slows down (a larger $\tau = RC$).

3.1 **B**.

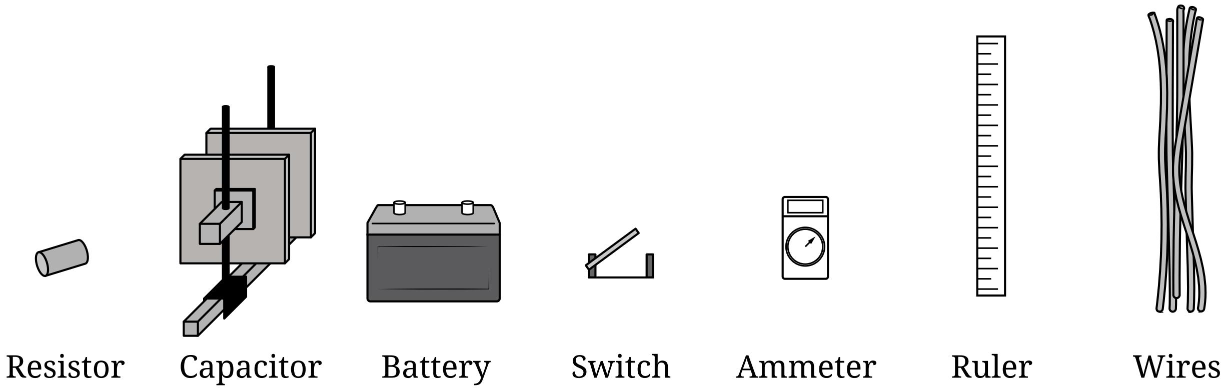
3.2 **B**.

3.3 (a) $\tau = RC = (10 \times 10^3)(100 \times 10^{-6}) = 1.0$ s. (b) 9.0 V (the supply voltage).

Question 3

3. In Experiment 1, a student is given a resistor of unknown resistance and an air-filled parallel-plate capacitor of unknown capacitance. The student is asked to predict the expected time constant τ of a circuit if these two circuit elements were connected in series with a battery. The student has access to a battery of known emf, a switch, an ammeter, a ruler, and wires, as shown in Figure 1. The plates of the capacitor are square, and the separation between the plates is small compared to the dimensions of the plates. The capacitor is initially uncharged. Assume that the dielectric constant of air is 1.

Figure 1



Note: Figure not drawn to scale.

A. Describe a procedure for collecting data that would allow the student to determine the expected time constant τ. In your description, include the measurements to be made. Include any steps necessary to reduce experimental uncertainty.

B. Describe how the collected data could be analyzed to determine τ. Include references to appropriate equations and to relationships between measured and known quantities.

C. In Experiment 2, the student is asked to determine the capacitance *C* of a new parallel-plate capacitor. For each trial, the absolute value $|\Delta V|$ of the potential difference across the capacitor is varied and the charge *q* stored on one plate of the fully charged capacitor is measured. Table 1 contains the data collected.

Table 1

$\lvert\Delta V\rvert$ (V)	q $(\times 10^{-10}$ C$)$
3.0	2.4
5.0	4.2
7.2	5.6
8.0	6.6
10.0	8.0

i. **Indicate** two quantities, either measured quantities from Table 1 or additional calculated quantities, that could be graphed to produce a straight line that could be used to determine *C*.

Vertical axis: ______ Horizontal axis: ______

ii. On the grid provided, create a graph of the quantities indicated in part C (i).

- Use Table 2 to record the measured or calculated quantities that you will plot.
- Clearly **label** the axes, including units as appropriate.
- **Plot** the points you recorded in Table 2.

iii. **Draw** a best-fit line for the data graphed in part C (ii).

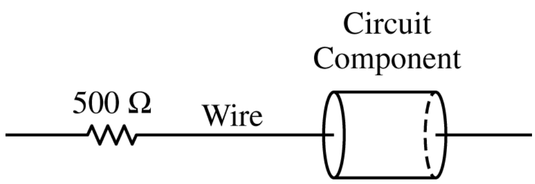
D. Using the best-fit line that you drew in part C (iii), **calculate** an experimental value for capacitance C.

2. (12 points, suggested time 25 minutes)

Students are given an unknown circuit component that is connected in series to a resistor with known resistance $500\ \Omega$.

(a) The students are asked to experimentally determine whether the component is a resistor or an uncharged capacitor.

i. Complete the following diagram to show how to use standard circuit equipment to determine whether the component is a resistor or an uncharged capacitor.



ii. Describe an experimental procedure to determine whether the component is a resistor or an uncharged capacitor. Refer to the circuit equipment in the diagram drawn in part (a)(i).

iii. What results would the students expect if the component is an uncharged capacitor? Support your answer in terms of potential difference and charge.

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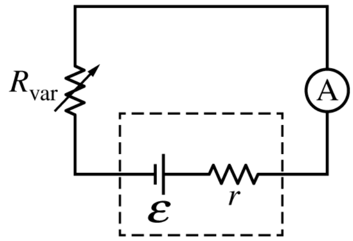
Continue your response to **QUESTION 2** on this page.



The students conduct a different experiment to determine the emf $\mathcal{E}$ of a battery that is not ideal and has internal resistance $r = 30\,\Omega$. The battery is connected to a variable resistor in a circuit, as shown. The students measure the current I through the circuit for different values of resistance R_{var} of the variable resistor that is connected to the battery. The following table contains the data collected.

I (A)	R_{var} (Ω)		
0.087	200		
0.060	300		
0.042	450		
0.027	700		
0.016	1200		

(b)

i. Write an equation describing the circuit in terms of $\mathcal{E}$, I, r, and R_{var}.

ii. Which quantities could be graphed to yield a straight line that could be used to calculate a numerical value for the emf $\mathcal{E}$ of the battery?

Horizontal Axis:________________ Vertical Axis:________________

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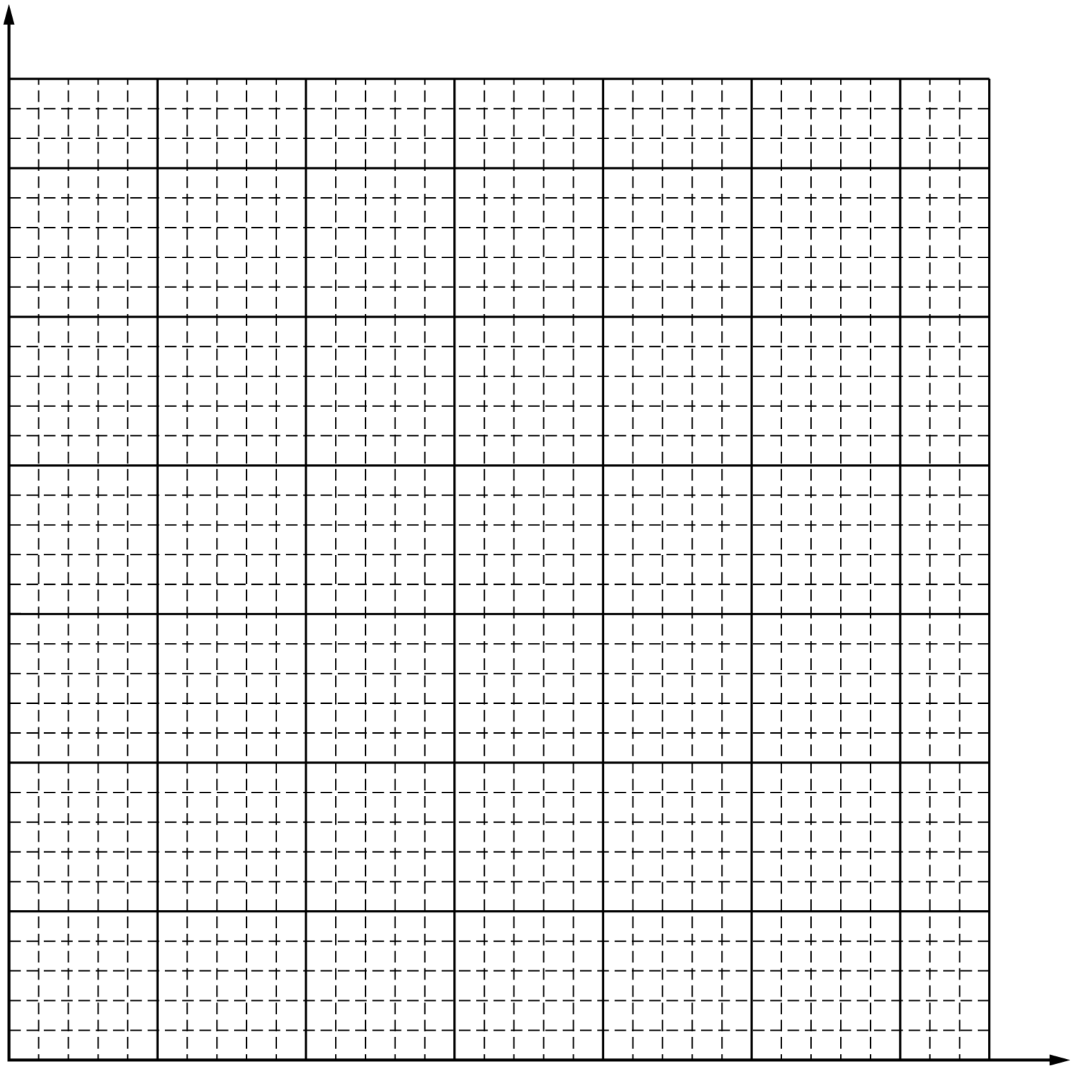
Continue your response to **QUESTION 2** on this page.

iii. Plot the data points for the quantities indicated in part (b)(ii) on the following graph. Clearly scale and label all axes, including units. Draw a straight line that best represents the data.
You may use the blank columns in the table for any quantities you graph other than the given data.



iv. Using the graph from part (b)(iii), determine the emf $\mathcal{E}$ of the battery.

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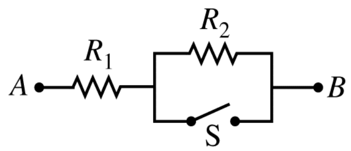


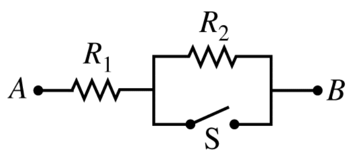
2. (12 points, suggested time 25 minutes)

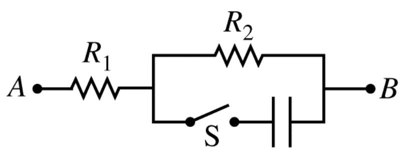
Students are given resistor 1 with resistance R_1 connected in series with the parallel combination of a switch S and resistor 2 with resistance R_2, as shown above. The circuit elements cannot be disconnected from each other, and other circuit components can only be connected at points *A* and *B*. The students also are given an ammeter and one 9 V battery. The teacher instructs the students to take measurements that can be used to determine R_1 and R_2.

(a) Complete the diagram below to show how the ammeter and the battery should be connected to experimentally determine the resistance of each resistor. Describe the experiment by listing the measurements to be taken and explaining how the measurements would be used to calculate resistances R_1 and R_2.

Complete the Diagram

Describe the Experiment





A second group of students is given a combination of circuit elements that is similar to the previous one but has an initially uncharged capacitor in series with the open switch, as shown above. The combination is placed in a circuit with a power supply so that the potential difference between *A* and *B* is maintained at 9 V. The students close the switch and immediately begin to record the current through point *B*. The initial current is 0.9 A, and after a long time the current is 0.3 A.

(b)

i. Compare the currents through resistor 1, resistor 2, and the switch immediately after the switch is closed to the currents a long time after the switch is closed. Specifically state if any current is zero.

ii. Calculate the values of R_1 and R_2.

iii. Determine the potential difference across the capacitor a long time after the switch is closed.

A third group of students now uses the combination of circuit elements with the capacitor. They connect it to a 9 V battery that they treat as ideal but which is actually not ideal and has internal resistance.

(c) How does the third group's value of R_1 calculated from the data they collected compare to the second group's value? Explain your reasoning with reference to physics principles and/or mathematical models.

4. (10 points, suggested time 20 minutes)

Some students are investigating the behavior of a circuit with four components in series: a resistor of resistance R, a capacitor of capacitance C, a battery with potential difference $\mathcal{E}$, and a switch. Initially, the capacitor is uncharged and the switch is open.

(a)

i. Determine the current in the resistor and the potential difference across the capacitor immediately after the switch is closed.

ii. Determine the current in the resistor and the potential difference across the capacitor a long time after the switch is closed.

(b) The switch is opened, the capacitor is discharged, and a second, identical capacitor is added to the circuit in series with the other components. The switch is then closed again.

i. A long time after the switch is closed, the energy stored in the single capacitor in the original circuit is U_1 , and the total energy stored in the two capacitors in the new circuit is U_2 . Calculate the ratio U_1/U_2 .

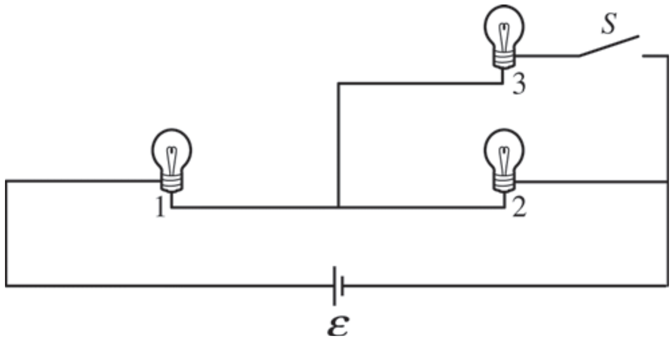
ii. The two capacitors in series are to be replaced with a single capacitor that will have the same energy U_2 . Indicate a plate area and a distance between the plates for the new capacitor, compared with one of the original capacitors, that will accomplish this. Support your reasoning using appropriate physics principles and/or mathematical models.

The students are then asked to design two circuits each containing a switch, a battery with a small internal resistance, a lightbulb, and a capacitor. In arrangement 1, the bulb should gradually light up after the switch is closed, becoming brightest after the switch has been closed a long time. In arrangement 2, the bulb should be brightest when the switch is first closed, getting dimmer with time, and going out completely when the switch has been closed for a long time.

(c) Using standard symbols, draw two circuit diagrams, one showing a possible circuit for arrangement 1 and the other showing a possible circuit for arrangement 2. Justify your circuit diagrams with a paragraph-length explanation referring to the properties of lightbulbs and capacitors in circuits and the conservation of energy and/or the conservation of charge.

STOP

END OF EXAM



2. (12 points, suggested time 25 minutes)

A battery of emf $\mathcal{E}$ and negligible internal resistance, three identical incandescent lightbulbs, and a switch S that is initially open are connected in the circuit shown above. The bulbs each have resistance R. Students make predictions about what happens to the brightness of the bulbs after the switch is closed.

(a) A student makes the following prediction about bulb 1: “Bulb 1 will decrease in brightness when the switch is closed.”

i. Do you agree or disagree with the student’s prediction about bulb 1 ? Qualitatively explain your reasoning.

ii. Before the switch is closed, the power expended by bulb 1 is P_1. Derive an expression for the power P_{new} expended by bulb 1 after the switch is closed in terms of P_1.

iii. How does the result of your derivation in part (a)ii relate to your explanation in part (a)i?

(b) A student makes the following prediction about bulb 2: “Bulb 2 will decrease in brightness after the switch is closed.”

i. Do you agree or disagree with the student’s prediction about bulb 2 ? Explain your reasoning in words.

ii. Justify your explanation with a calculation.

(c) While the switch is open, bulb 3 is replaced with an uncharged capacitor. The switch is then closed.

i. How does the brightness of bulb 1 compare to the brightness of bulb 2 immediately after the switch is closed? Justify your answer.

ii. How does the brightness of bulb 1 compare to the brightness of bulb 2 a long time after the switch is closed? Justify your answer.