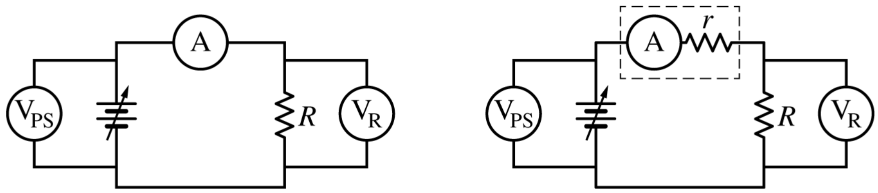


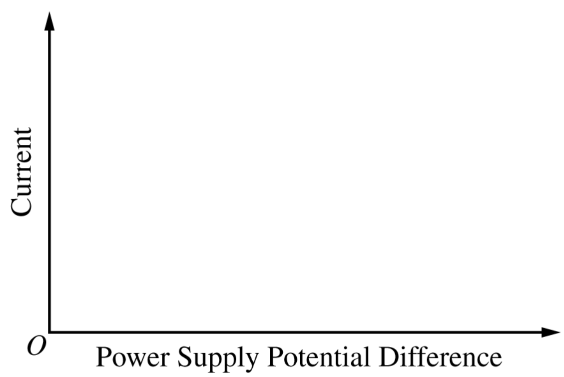
Circuit 1 Circuit 2

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.



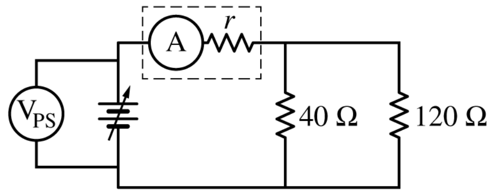
(b) Let ΔV_{PS} be the potential difference measured by voltmeter V_{PS} across the power supply, and let I be the current measured by the ammeter A. For each circuit, write an equation that satisfies conservation of energy, in terms of ΔV_{PS}, I, R, and r, as appropriate.

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.



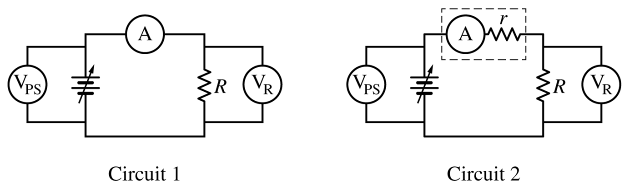
Circuit 3

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

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

Question 2

12 points

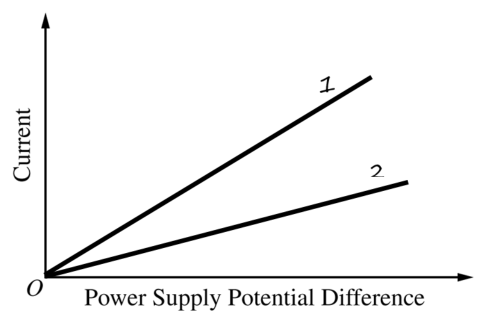


The two circuits shown above contain an ideal variable power supply, an ohmic resistor of resistance R, an ammeter A, and two voltmeters V_{PS} and V_R. In circuit 1 the ammeter has negligible resistance, and in circuit 2 the ammeter has significant internal ohmic resistance r. The potential difference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

(a) LO 4.E.5.1, SP 6.4
2 points

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.



For graph 1 a straight line with a positive slope through origin		1 point
For graph 2 a straight line with a positive slope through origin with a smaller slope than line 1		1 point

(b) LO 5.B.9.6, SP 2.2; LO 5.C.3.4, SP 6.4
2 points

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>

For a correct equation for circuit 1		1 point
$\Delta V_{PS} - IR = 0$		
For a correct equation for circuit 2		1 point
$\Delta V_{PS} - I(R + r) = 0$		

Question 2 (continued)

(c) LO 5.B.9.8, SP 1.5
2 points

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

For indicating that the slope is inversely proportional to the resistance		1 point
For explaining that the equations in part (b) show that a larger total resistance corresponds to a smaller slope or smaller current		1 point
Example: Claim: The equations in part (b) account for the differences between graphs 1 and 2 in part (a). Evidence: The graphs show a linear relationship between current and potential difference. The equations are linear functions, which when graphed would have a slope that is the inverse of the total resistance. Reasoning: The difference between the equations is the value of the total resistance, so the equations account for the difference in slopes. The larger the total resistance, the smaller the slope.		

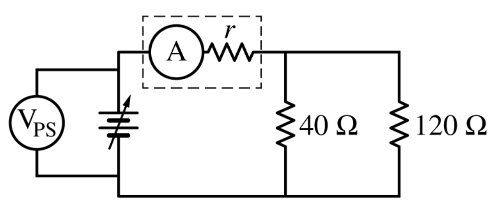
(d) LO 5.B.9.6, SP 2.2; LO 5.C.3.4, SP 6.4, 7.2
2 points

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.

Ohm's law solution:		
For correctly calculating the current in the circuit		1 point
$I = \Delta V_R / R = 2.5\ \text{V}/40\ \Omega = 0.0625\ \text{A}$		
For using Ohm's law with the calculated current and correct potential difference		1 point
$r = \Delta V_r / I = (3\ \text{V} - 2.5\ \text{V})/0.0625\ \text{A}$		
$r = 8\ \Omega$		

(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

Question 2 (continued)

(e) (continued)

i. LO 4.E.5.1, SP 2.2
2 points

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

For calculating the equivalent resistance of the parallel branches		1 point
$\dfrac{1}{40\ \Omega} + \dfrac{1}{120\ \Omega} = \dfrac{4}{120\ \Omega}$		
$R_{\parallel} = 30\ \Omega$		
For adding the value of r from part (d) to $R_{\parallel}$		1 point
$R_{eq} = 30\ \Omega + 8\ \Omega = 38\ \Omega$		

ii. LO 5.B.9.6, SP 2.2
2 points

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

For substituting the correct potential difference and the resistance from part (e)(i) into Ohm's law to determine the current through the battery		1 point
$I_{tot} = 3\ \text{V}/38\ \Omega = 0.079\ \text{A}$		
For calculating two currents that are in the correct ratio ($I_{40\ \Omega} = 3I_{120\ \Omega}$)		1 point
$\Delta V_{\text{parallel}} = (3\ \text{V}) - (8\ \Omega)(0.079\ \text{A}) = 2.36\ \text{V}$ $I_{40\ \Omega} = \dfrac{2.36\ \text{V}}{40\ \Omega} = 0.059\ \text{A}$ $I_{120\ \Omega} = \dfrac{2.36\ \text{V}}{120\ \Omega} = 0.020\ \text{A}$		

Learning Objectives

LO 4.E.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. [See Science Practices 2.2, 6.4]

LO 5.B.9.6: The student is able to mathematically express the changes in electric potential energy of a loop in a multiloop electrical circuit and justify this expression using the principle of the conservation of energy. [See Science Practices 2.1, 2.2]

LO 5.B.9.8: The student is able to translate between graphical and symbolic representations of experimental data describing relationships among power, current, and potential difference across a resistor. [See Science Practices 1.5]

LO 5.C.3.4: The student is able to predict or describe current values in series and parallel arrangements of resistors and other branching circuits using Kirchhoff's junction rule and explain the relationship of the rule to the law of charge conservation. [See Science Practices 6.4, 7.2]