**EXPERIMENT E 51 - OHM'S LAW**

Introduction:
Ohm's law relates the current flowing through an electrical device or conductor to the potential difference (voltage) across it. In order to test the law, we need ways of establishing or measuring current and voltage which do not use apparatus whose operation is itself dependent on the validity of Ohm's law. In the following series of experiments the current passing through a wire is measured by observing its magnetic effect. The greater the current passing, the greater should be the magnetic effect observed. Potential differences are established by combining in series sources of electromotive force (e.m.f.) that are nominally identical.

Experimental objective:
To test Ohm's Law and the relationship V = IR ,where V = voltage, I = current and R = resistance, using a number of basic electrical circuits containing up to four cells and up to four resistors connected in series, in combination with a magnetometer wired into different configurations. A magnetometer acts like a compass and its pointer is deflected by a magnetic field, which will be produced by a current passing in a circuit. The greater the current flowing, the greater should be the corresponding magnetometer deflection. The experiment involves testing components both individually and in combination to see if a given deflection on the magnetometer is proportional to applied electromotive force (e.m.f.) or inversely proportional to applied resistance. Because the components are nominally similar there should be a proportional increase in deflection on the magnetometer for each additional cell added in series for a given resistance. Similarly, there should be a current reduction for each additional resistance applied in series to a given e.m.f., resulting in a corresponding inversely proportional decrease in the magnetometer deflection.

The experiment consists of 4 separate parts:-
Part 1 – Assessment of the Apparatus
Testing the variability of nominally identical electrical components: 3 Resistors and 4 cells

Part 2 – Oersted's Experiment
Testing if magnetometer deflection due to magnetic effects is proportional to current flowing
*Magnetometer Deflection* $\alpha\, I$

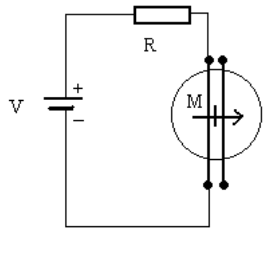
Part3 – Dependence of current (I) through a fixed resistance (R) on voltage (V)
Test for proportionality of current flow to applied voltage
$I \,\alpha\, V$

Part 4 – Dependence of current on resistance
Testing the inverse proportionality of current flow to applied resistance.
$I \,\alpha\, 1/R$

Part 1 – Assessment of the Apparatus:
Testing for variability between nominally similar components

Experimental Set-up and method:
The series circuit shown below is wired up to the magnetometer (labelled M). Each of the four cells (labelled A, B, C and D) is connected individually, and the corresponding magnetometer defection in degrees (°) from rest position is recorded for each e.m.f. A single resistance (labelled R) is held constant throughout.

The test process is then repeated for each resistor individually (labelled X, Y and Z) while holding a single e.m.f. constant throughout.



Test circuit for single cells and resistors in series

Data and data analysis:

The following data for the magnetometer deflection from rest point was obtained for each of the cells:

| | | |
|---|---|---|
| Cell A: | 9.0° | (Resistor X held constant throughout) |
| Cell B: | 8.0° | |
| Cell C: | 8.5° | |
| Cell D: | 9.0° | |

Mean deflection per cell: 8.625° degrees

Standard deviation: 0.47871355°

(Standard deviation/Mean) $\times 100$ = 5.55 % variability

The following data for magnetometer deflection was obtained for each resistor in turn:

| | | |
|---|---|---|
| Resistor X: | 10° | (Cell B held constant throughout) |
| Resistor Y: | 9.8° | |
| Resistor Z: | 9.8° | |

Mean deflection for each resistor: 9.86666667°

Standard deviation: 0.115470053

(Standard deviation/Mean) $\times 100$: 1.17 % variability

Summary – Part 1:

Mean magnetometer deflection for each battery = 8.625° degrees with a variability of $\pm$ 5.55 %

Mean deflection for each resistor = 9.87° with a variability of $\pm$ 1.17 %

## Part 2 – Oersted's Experiment:

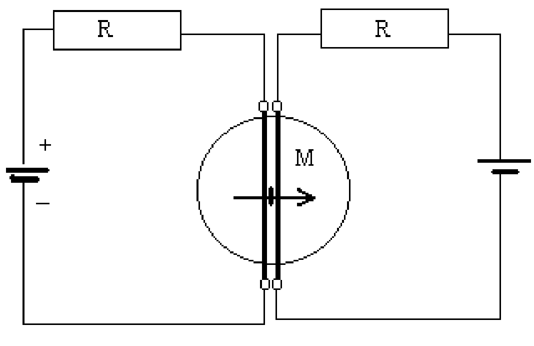
Test for magnetometer deflection being proportional to current flow

Experimental set-up and method:

a) A double circuit shown below is wired up to the magnetometer. Each circuit (M and N) contains one resistor and one cell. The circuits are nominally identical. The circuits are closed individually in series with the magnetometer and the corresponding deflections due to each is recorded separately. These two individual deflections should be approximately equal and in the same direction.

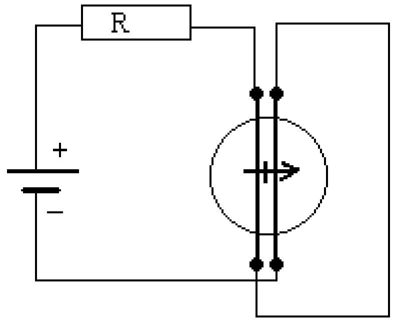
b) Then both circuits are closed together with both currents flowing in the same direction, and the corresponding magnetometer deflection due to their combined effect is recorded. It would be expected that the deflection due to the current flow in the double circuit is approximately double the deflection produced by either individual circuit alone.

c) The current in Circuit M only is then reversed. As the currents now oppose each other, the resultant magnetometer deflection should be approximately zero.




CIRCUIT M CIRCUIT N

d) The resistor and cell in Circuit N are then replaced by a conductor so that the same current flows through the magnetometer twice:




CIRCUIT M CIRCUIT N

Data and data analysis:

| | |
|---|---|
| Deflection due to Circuit M alone: | Deflection due to Circuit N alone: |
| Cell B with Resistor X: 11.4° | Cell A with Resistor Y: 11.2° |
| Mean single deflection: 11.2° | |
| Deflection due to combination of Circuit M and Circuit N together with current in same direction: 23° | |

Deflection due to reversal of current in Circuit M alone: -12°
Deflection due to Circuit 2 alone: + 12.5°
Net deflection with the current in Circuit M opposing the current flow in Circuit N: -0.2°

Deflection due to the same current from Circuit M flowing twice through the magnetometer: 21.5°

Summary:

Mean Single deflection: 11.1°
Standard deviation: 0.14142°
(Standard deviation/Mean) $\times$100 = 1.27 % variability

Mean deflection due to double current: 22.25°
Standard deviation: 1.06066°
(Standard deviation/Mean) $\times$100 = 4.767 % variability

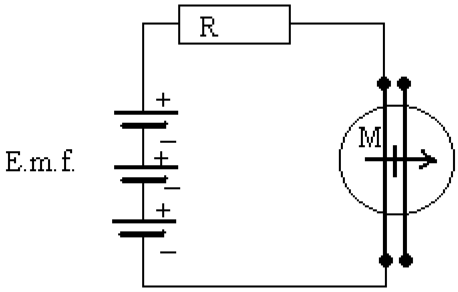
Therefore, based on the above data the deflection due to double the current was 22.25° approximately double the deflection due to a single current, 11.1°. The net deflection due to the two currents opposing each other was –0.2°, which is close to the expected value of 0° net deflection. This can be compared with the standard deviation of the cells of 0.4787° or the standard deviation of the resistors of 0.11547° obtained in Part 1.

## Part 3 - Test for proportionality of current flow to applied voltage

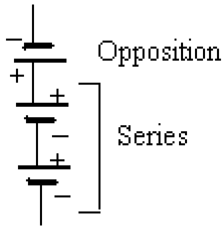
Investigation to what degree the current for 2 cells in series is twice that of a single cell. The process is repeated for 3 cells and for 4 cells. Test to see the resultant deflection due to reversal of some of the individual e.m.f.'s.

Experimental set-up and method:

1. One cell is tested individually with a single resistance (kept constant throughout). Additional cells are added one by one, with e.m.f. acting in the same direction and the resulting magnetometer deflection recorded each time. Forward e.m.f.'s are counted as +1, and reversed e.m.f.'s are counted as –1 as all the cells (labelled A, B, C and D) are nominally similar.




2. The e.m.f.'s are then reversed one by one. Reversed e.m.f.'s are counted as –1 algebraically.




Data and data analysis:

| No. of Cells: (N) | Deflection from 0: (D) | Deflection ÷ No. of Cells: (D/N) |
|---|---|---|
| A | 11.8° | 11.8/1 = 11.8° |
| A + B | 21.6° | 21.6/2 = 10.8° |
| A + B + C | 30.2° | 30.2/3 = 10.8° |
| A + B + C + D | 36.0° | 36/4 = 9.0° |
| Mean (D/N): 10.41675 | Standard deviation: 1.1817732° | (S.D./Mean) × 100 = 11.34494 % |

| No. of cells: (N) | Deflection from 0: (D) | Deflection ÷ No. of Cells: (D/N) |
|---|---|---|
| A + B – C | 11.6° | 11.6° |
| A + B + C – D | 21.4° | 10.7° |
| Mean (D/N): 11.15° | Standard deviation: 0.6363961° | (S.D./Mean) × 100 = 5.707588 % |

Summary:

Comparison between deflection for one cell of 11.8° is almost equal to the deflection of 11.6° due to three cells one of which is reversed. Similarly, the deflection due to two cells of 21.6° is close to the deflection of 21.4° due to four cells one of which is reversed.

For I ∝ V:

For the equivalent of one cell:
Mean (Deflection/No. of cells) was 10.41° and 11.6° per cell
(S.D./Mean) × 100 = (0.841457 ÷ 11.005) × 100 = 0.07646 % variability in deflection due to 1 cell.

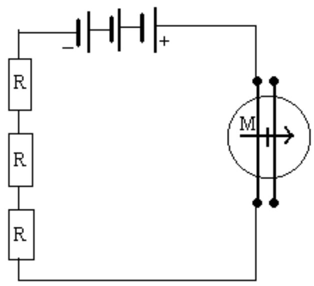
For the equivalent of 2 cells:
Mean Deflection due to 2 cells was 21.6° and 21.4°
(S.D./Mean) × 100 = (0.14142 ÷ 21.5) × 100 = 0.006578 % variability in deflection due to 2 cells.

Mean deflection due to 2 cells was approximately double the deflection due to 1 cell only with approximately one tenth the variability. These results can be compared with the results from Part 1:
Mean deflection due to 1 cell: 8.625° with a variability of 5.55 %. Or comparing with results from Oersted's Experiment in Part 2:
Deflection due to combination of double circuit (Cells A and B) with all current flowing in one direction: 23.0°

Part 4 - Testing the inverse proportionality of current flow to applied resistance

To test the inverse proportionality between current flow and the number of nominally equal resistors resulting in a series of magnetometer deflections. As deflections are proportional to current flowing, then deflections should decrease with each additional resistor added in series for a given e.m.f.

Experimental set-up and method:




The deflection due to first one resistor, then 2 resistors, and then 3 resistors in series acting on a current due to a constant e.m.f. is recorded.

Data and data analysis:

| Number of cells: | Deflection: (D) | Number of Resistors: (R) | Deflection × No. of Resistors: (D×R) |
|---|---|---|---|
| 3 | 24.0° | 1 | 24 |
| | 13.6° | 2 | 27.2 |
| | 9.2° | 3 | 27.6 |
| Mean (D×R) = 26.266667 | | S.D. = 1.9731539 | (S.D./mean)×100 = 7.512 % variability |
| For I ∝ 1/R: (Deflection × No. of Resistors) = Constant = 26.267 ± 1.973 | | | |

| Number of cells: | Deflection: (D) | Number of Resistors: (R) | Deflection × No. of Resistors: (D×R) |
|---|---|---|---|
| 2 | 18.2° | 1 | 18.2 |
| | 9.5° | 2 | 19 |
| | 6.5° | 3 | 19.5 |
| Mean (D×R): 18.9 | | S.D. = 0.655743852 | (S.D./Mean)×100 = 3.469 % variability |
| Therefore, (Deflection × No. of Resistors) = 18.90 ± 0.66 | | | |

Summary:

The results for (Deflection × Number of Resistors) are very close within each configuration:

Mean (D×R): 26.267 with a variability of 7.512 % for three cells

Mean (D×R): 18.9 with a variability of 3.469 % for two cells

Conclusion:

For V = IR = constant

As magnetometer deflection is proportional to current flow, then the quantity (Deflection × Number of resistors) = constant for a given voltage:

| For 3 cells: | For 2 cells: |
|---|---|
| 24 × 1 = 24° | 18.2 × 1 = 18.2° |
| 13.6 × 2 = 27.2° | 9.5 × 2 = 19.0° |
| 9.2 × 3 = 27.6° | 6.5 × 3 = 19.5° |

The results for each applied e.m.f. were quite close within the values for that e.m.f.

Mean = 26.27° with a variability of 7.51 % for the experiment using 3 cells.

Mean = 18.9° with a variability of 3.469 % for the experiment using 2 cells.

Conclusion:
In general the results from Parts 1 to 4 show that for nominally similar cells and resistors, the greater the number of resistors used for a given e.m.f., the less the resultant magnetometer deflection due to the decrease in current flow:

Mean deflection for 1 resistor: 24.0° (From Part 4)

Mean deflection for 2 resistors: 13.6°

Mean deflection for 3 resistors: 9.2°

Similarly, the greater the number of e.m.f.'s used in combination with a fixed resistance, the greater the resultant magnetometer deflection due to increased current flow:

Deflection for 1 cell: 11.8° (From Part 3)

Deflection for 2 cells: 21.6°

Deflection for 3 cells: 30.2°

Deflection for 4 cells: 36.0°

When one half of the current flow opposed the other half, net magnetometer deflection for the opposing currents was close to 0 at –0.2° (from Oersted's Experiment in Part 2).

When both halves of the current flowed in the same direction, combined deflection was: 23.0°.
This is comparable to the deflection produced by the same current flowing twice through the magnetometer: 21.5°