OCR (A) specifications: 5.2.2c,f,g

Chapter 14
Kirchhoff's laws

Worksheet

Worked examples

Practical: Determining the e.m.f. of a test cell

End-of-chapter test

Marking scheme: Worksheet

Marking scheme: End-of-chapter test

Worksheet

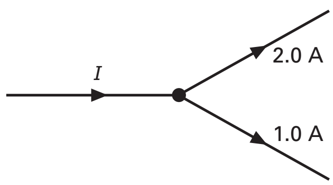
Intermediate level

1 State Kirchhoff's first law. [1]

2 Kirchhoff's first law expresses the conservation of an important physical quantity. Name the quantity that is conserved. [1]

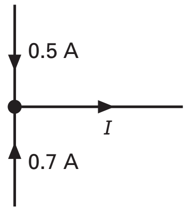
3 Determine the current I in each of the circuits below.

a



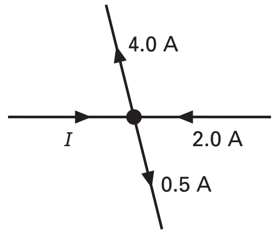
[1]

b



[1]

c



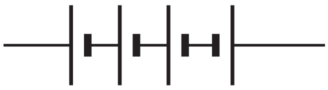
[2]

4 Several identical cells are used to connect up circuits. Each cell has e.m.f. 1.5 V. Determine the total e.m.f. for the following combinations of cells.

a

[1]

b

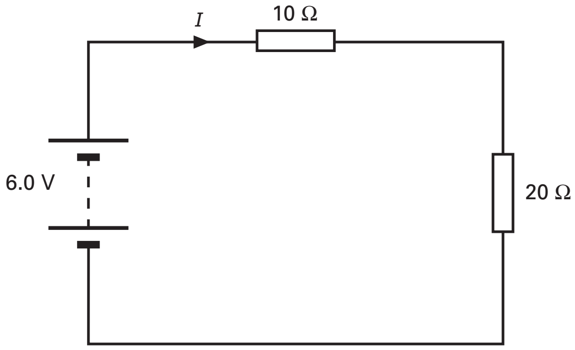


[1]

c

[1]

5 Use Kirchhoff's second law to calculate the current I in the circuit shown below. [3]

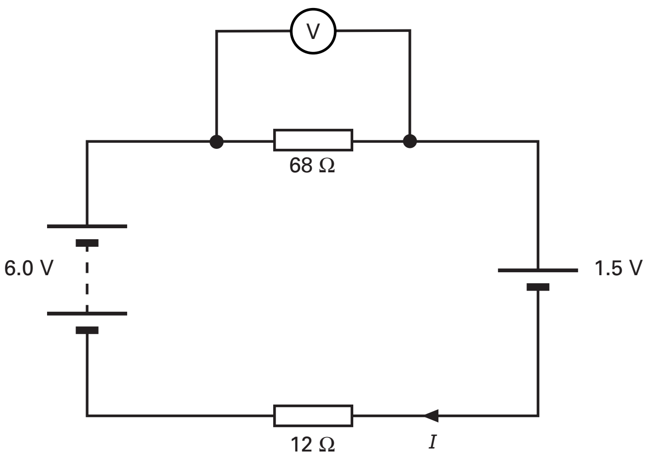


Higher level

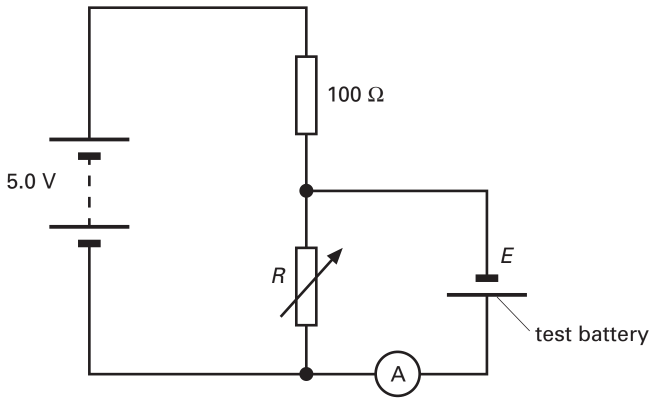
6 The diagram shows an electrical circuit. The battery and cell in the circuit may be assumed to have negligible internal resistance. Calculate:

a the current in the 12 Ω resistor; [3]

b the p.d. across the 68 Ω resistor. [2]



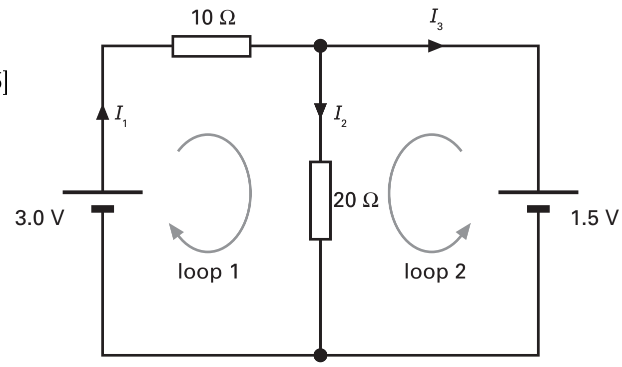
7 The arrangement below can be used to determine the electromotive force of a test battery.



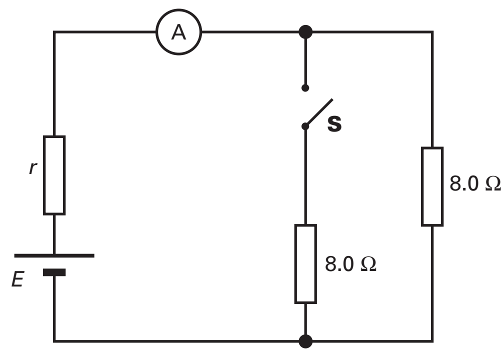
The supply battery may be assumed to have negligible internal resistance. The resistance R of the variable resistor is adjusted until R has a value of 28 Ω and the current shown by the ammeter is zero. Show that the e.m.f. of the test battery is about 1.1 V. [3]

Extension

8 Use Kirchhoff's laws to determine the currents I_1, I_2 and I_3 in the circuit on the right. [6]



9 The current measured by the ammeter in the circuit shown is 0.25 A when the switch **S** is open and 0.45 A when the switch is closed. Use this information to determine the e.m.f. E and the internal resistance r of the cell. [6]

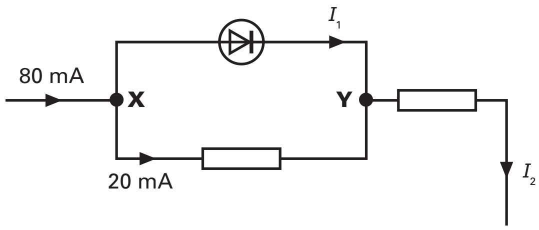


Total: $\frac{\quad}{32}$ Score: %

Worked examples

Example 1

Calculate the currents I_1 and I_2 in the part of the circuit shown.



Applying Kirchhoff's first law to the point **X**, we have:

$80 = 20 + I_1$

$I_1 = 80 - 20 = 60\,\text{mA}$

*The current in a **series** circuit is always the same due to conservation of charge.*

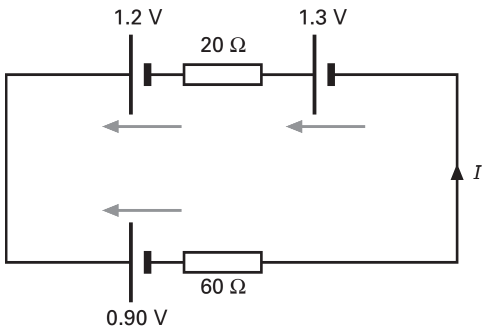
The current I_2 is equal to 80 mA.

Tip

To determine the current I_2, you can always apply Kirchhoff's first law again, but this time with reference to point **Y**.

Example 2

The diagram shows cells of negligible internal resistance connected in a series circuit.



Determine the circuit current I.

Applying Kirchhoff's second law, we have:

Σ e.m.f. = Σ p.d.

For an anticlockwise 'loop', we have

$1.3 + 1.2 - 0.90 = (I \times 20) + (I \times 60)$

*The 0.90 V cell is 'reversed'. Hence its e.m.f. is assigned a **negative** value in this equation.*

$1.60 = 80I$

$I = \frac{1.6}{80} = 0.02\,\text{A}$

Tip

To minimise errors when applying Kirchhoff's second law, always check the polarity of each source of e.m.f. This is indicated by the arrows on the diagram.

Practical

Determining the e.m.f. of a test cell

Safety

Always take sensible precautions when using mains-operated supplies. Teachers and technicians should follow their school and departmental safety policies and should ensure that the employer's risk assessment has been carried out before undertaking any practical work.

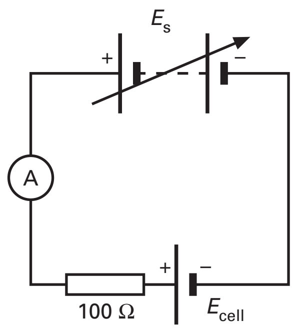
Apparatus

- chemical cell
- digital d.c. supply
- 100 Ω resistor
- digital ammeter
- connecting leads

Introduction

In chapter 13 of *Physics 1*, you met the idea that the e.m.f. of a cell may be determined by connecting a high-resistance voltmeter across its terminals. An alternative method makes use of Kirchhoff's second law.

The arrangement shown here may be used to determine the e.m.f. of a cell by applying Kirchhoff's second law. The direction of the current in the circuit depends on the relative magnitudes of the e.m.f.s. A digital ammeter will show the direction of the current.



According to Kirchhoff's second law:

sum of e.m.f.s in a closed loop = sum of p.d.s in that loop

Therefore:

e.m.f. of supply − e.m.f. of cell = IR

$E_s - E_{cell} = IR$

When the e.m.f. of the supply is equal to the e.m.f. of the cell, the current I in the circuit is equal to zero.

Procedure

1 Set up the circuit as shown in the diagram above.

2 Set the e.m.f. E_s of the supply to zero.

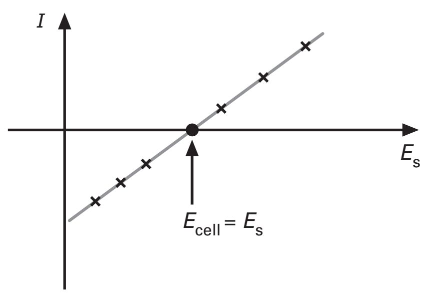
3 Measure the current I in the circuit − make sure that you also take note of the 'sign'.

4 Measure the circuit current I as E_s is increased in steps of 0.5 V.

5 Suitably record your results and plot a graph of I against E_s.

6 Draw straight a line of best fit through the points (see sketch).

7 Use the graph to determine the e.m.f. of the test cell. What is the uncertainty in your value for the e.m.f.?



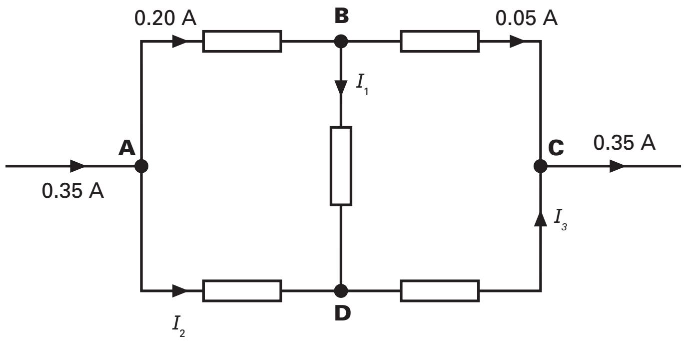
End-of-chapter test

Answer all questions.

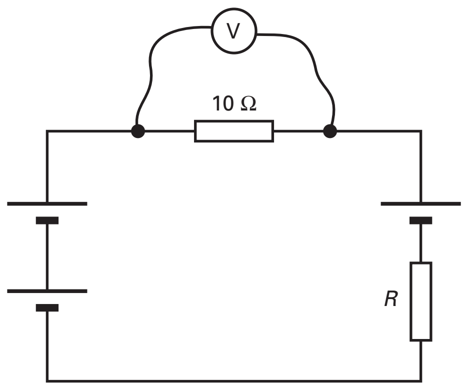
1 **a** State Kirchhoff's second law. [1]

b Kirchhoff's second law expresses the conservation of an important physical quantity. Name the quantity that is conserved. [1]

2 Determine the currents I_1, I_2 and I_3 in the circuit below. [3]



3 In the electrical circuit shown, each cell has e.m.f. 1.5 V and has negligible internal resistance. The voltmeter reading is 1.0 V.

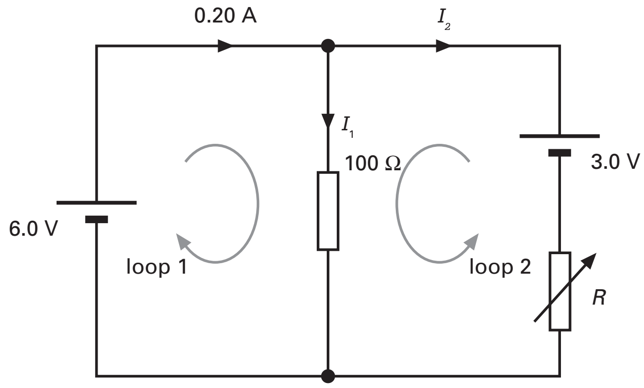


a State the direction of the current in the circuit. [1]

b Calculate the value of the circuit current I. [1]

c Calculate the resistance R of the resistor. [3]

4 This question is about applying Kirchhoff's laws to predict results for the circuit shown below.



The sources of e.m.f. have negligible internal resistance.

a Use 'loop 1' to determine the current I_1 in the 100 Ω resistor. [2]

b State the current I_2. [1]

c Use 'loop 2' to determine the resistance R of the variable resistor. [3]

Total: $\frac{\quad}{16}$ Score: %

Marking scheme

Worksheet

1 The sum of the currents into a point = sum of currents out of the same point. [1]

2 Charge is conserved. [1]

3 **a** $I = 2.0 + 1.0 = 3.0\,\text{A}$ [1];

b $0.7 + 0.5 = I$ therefore $I = 1.2\,\text{A}$ [1];

c $2.0 + I = 4.0 + 0.5$ [1]; $I = 4.5 - 2.0 = 2.5\,\text{A}$ [1]

4 **a** $E = 1.5 + 1.5 = 3.0\,\text{V}$ [1];

b $E = 1.5 + 1.5 + 1.5 - 1.5 = 3.0\,\text{V}$ [1];

c $E = 1.5 - 1.5 = 0\,\text{V}$ [1]

5 $\sum$ e.m.f. = $\sum$ p.d. [1]

$6.0 = (I \times 10) + (I \times 20)$ (clockwise 'loop') [1]

$30I = 6.0$ so $I = \dfrac{6.0}{30} = 0.20\,\text{A}$ [1]

6 **a** $\sum$ e.m.f. = $\sum$ p.d.

$6.0 - 1.5 = (I \times 68) + (I \times 12)$ (clockwise 'loop') [1]

$80I = 4.5$ [1]; so $I = \dfrac{4.5}{80} = 5.63 \times 10^{-2}\,\text{A}$; $I \approx 5.6 \times 10^{-2}\,\text{A}$ [1]

b $V = IR = 5.63 \times 10^{-2} \times 68$ (the current is the **same** in a series circuit) [1]

$V \approx 3.8\,\text{V}$ [1]

7 If the ammeter reading is zero, then the e.m.f. E of the test cell is equal to the p.d. across the variable resistor ($\sum$ e.m.f. = $\sum$ p.d.). [1]

$E = \dfrac{R_b}{R_a + R_b} \times V_{in}$ [1]

$E = \dfrac{28}{100 + 28} \times 5.0 = 1.09\,\text{V} \approx 1.1\,\text{V}$ [1]

8 Loop 1: $\sum$ e.m.f. = $\sum$ p.d.

$3.0 = 10I_1 + 20I_2$ (*equation 1*) [1]

Loop 2: $\sum$ e.m.f. = $\sum$ p.d.

$1.5 = 20I_2$ (*equation 2*) [1]

$I_2 = \dfrac{1.5}{20} = 0.075\,\text{A}$ [1]

Substituting the value for I_2 into *equation 1*, we have:

$3.0 = 10I_1 + (20 \times 0.075)$ [1]

$I_1 = \dfrac{1.5}{10} = 0.15\,\text{A}$ [1]

Finally, using Kirchhoff's first law, we have:

$0.15 = 0.075 + I_3$

$I_3 = 0.075\,\text{A}$ [1]

9 With the switch open:

$E = 0.25\ (8.0 + r)$ or $E = 2.0 + 0.25r$ (*equation 1*) [1]

With the switch closed:

total resistance of the parallel combination $= \frac{8.0}{2} = 4.0\,\Omega$

$E = 0.45\ (4.0 + r)$ or $E = 1.8 + 0.45r$ (*equation 2*) [1]

We have two equations and two unknowns. Substituting for E gives:

$2.0 + 0.25r = 1.8 + 0.45r$ [1]

$0.20r = 0.2$ so $r = 1.0\,\Omega$ [1]

Substituting this value into one of the equations for e.m.f. (*equation 1*) gives:

$E = 2.0 + (0.25 \times 1.0)$ [1]

$E = 2.25\ \text{V}$ [1]

(You can check by substituting into *equation 2*.)

Marking scheme

End-of-chapter test

1 **a** The sum of the e.m.f.s around a circuit loop = sum of the p.d.s around that loop. [1]

b Energy is conserved [1]

2 Point **B** $\Rightarrow I_1 + 0.05 = 0.20$ therefore $I_1 = 0.15\,\text{A}$ [1]

Point **A** $\Rightarrow 0.35 = 0.20 + I_2$ therefore $I_2 = 0.15\,\text{A}$ [1]

Point **C** $\Rightarrow I_3 + 0.05 = 0.35$ therefore $I_3 = 0.30\,\text{A}$ [1]

3 **a** Clockwise [1];

b $I = \frac{V}{R} = \frac{1.0}{10} = 0.10\,\text{A}$ [1];

c $\sum$ e.m.f. = $\sum$ p.d. [1]

$1.5 + 1.5 - 1.5 = 1.0 + (0.1 \times R)$ (clockwise 'loop') [1]

$R = \frac{1.5 - 1.0}{0.1} = 5.0\,\Omega$ [1]

4 **a** $\sum$ e.m.f. = $\sum$ p.d.

$6.0 = 100I_1$ (clockwise 'loop') [1]

$I_1 = 0.06\,\text{A}$ [1]

b $I_2 = 0.20 - 0.06 = 0.14\,\text{A}$ [1]

c $\sum$ e.m.f. = $\sum$ p.d.

$3.0 = 6.0 - (0.14 \times R)$ (anticlockwise 'loop') [1]

$R = \frac{3.0 - 6.0}{-0.14}$ [1]; $R = 21.4\,\Omega \approx 21\,\Omega$ [1]

