Unit 14 · Electrical Circuits

ANSWER KEY · FOR TEACHERS

Full marks 35

Give the marks for the points in the marking scheme; an answer in other words that says the same is right.

1 Key words

1. junction
2. charge
3. energy
4. null point
5. potential gradient
6. shunt
7. critical temperature
8. Meissner effect

K · 4

Each carries 0.5 mark.

2 Label the diagram

1. driver cell
2. E, r
3. K_2
4. rheostat

K · 2

Each carries 0.5 mark.

3 Multiple choice

i. **b.** 2.5 A out — A · 1

In: $4 + 1.5 = 5.5$ A. Out so far: 3 A. The fourth wire carries the other $5.5 - 3 = 2.5$ A out, so that the current in equals the current out.

ii. **c.** 26 Ω — A · 1

$\frac{14}{X} = \frac{35}{65}$, so $X = 14 \times 65 \div 35 = 26\ \Omega$. The larger resistance faces the longer part of the wire.

iii. **c.** using a longer wire — U · 1

A potentiometer is more sensitive when its potential gradient is smaller: a longer wire, or a smaller current in it, spreads the same p.d. over more length.

iv. **b.** 4980 Ω — A · 1

$R = \frac{V}{I_g} - G = \frac{10}{0.002} - 20 = 4980\ \Omega$.

v. **c.** four times as much — U · 1

$H = I^2Rt$: the heat goes as the square of the current, so $2^2 = 4$ times as much.

4 Short answers

a. MARKING SCHEME — U · 2

- ✓ The + terminals of both cells go to the same end of the wire.
- ✓ The p.d. across the whole wire is greater than the e.m.f. measured.

b. MARKING SCHEME — U · 2

- ✓ X depends on the ratio l/(100 − l).
- ✓ Near the middle a small reading error changes the ratio least (near an end it is a large fraction of the short length).

c. MARKING SCHEME — U · 2

- ✓ A perfect conductor keeps the field that was inside it.
- ✓ A superconductor expels the field from its interior (the Meissner effect).

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5 Long answer

ANSWER U · 4

Let I_1, I_3, I_4 and I_2 be the currents in P, Q, R and X, and I_g the current in the galvanometer G from B to D.

Loop ABDA: $-I_1P - I_gG + I_2X = 0$. Loop BCDB: $-I_3Q + I_4R + I_gG = 0$.

Junction B: $I_1 = I_g + I_3$. Junction D: $I_4 = I_g + I_2$.

At balance $I_g = 0$, so $I_1P = I_2X$, $I_3Q = I_4R$, $I_1 = I_3$ and $I_2 = I_4$. Then $I_1Q = I_2R$, and dividing $I_1P = I_2X$ by it gives $\frac{P}{Q} = \frac{X}{R}$.

MARKING SCHEME

- ✓ The loop equations for ABDA and BCDB.
- ✓ The junction equations at B and D.
- ✓ With $I_g = 0$: $I_1 = I_3$, $I_2 = I_4$, $I_1P = I_2X$ and $I_3Q = I_4R$.
- ✓ Dividing gives P/Q = X/R.

6 Numerical problems

a. **ANSWER** A · 4

Let I_1 leave the 9 V cell and I_2 the 6 V cell at their + ends, so $I_1 + I_2$ flows through the 6 Ω resistor.

Loop with the 9 V cell: $9 = 1 \times I_1 + 6(I_1 + I_2)$, so $7I_1 + 6I_2 = 9$.

Loop with the 6 V cell: $6 = 2 \times I_2 + 6(I_1 + I_2)$, so $6I_1 + 8I_2 = 6$.

Solving: $I_1 =$ **1.8 A** and $I_2 =$ **−0.6 A**, and the resistor carries $1.8 - 0.6 =$ **1.2 A** (7.2 V across it).

I_2 is negative: 0.6 A flows **into** the + terminal of the 6 V cell, so the 6 V cell is being charged by the 9 V cell.

MARKING SCHEME

- ✓ Two correct loop equations with $I_1 + I_2$ through the resistor.
- ✓ $I_1 = 1.8$ A.
- ✓ $I_2 = -0.6$ A, and 1.2 A through the resistor.
- ✓ The 6 V cell is being charged (the current flows into its + terminal).

b. **ANSWER** A · 4

i. $E = kl_1 = 0.0175 \times 84.0 =$ **1.47 V**.

ii. $r = \left(\frac{l_1}{l_2} - 1\right)R = \left(\frac{84.0}{70.0} - 1\right) \times 15 = 0.2 \times 15 =$ **3.0 Ω**.

iii. The terminal p.d. $V = kl_2 = 0.0175 \times 70.0 = 1.225$ V, so $I = V/R = 1.225 \div 15 =$ **0.082 A** (check: $E/(R + r) = 1.47 \div 18 = 0.082$ A).

MARKING SCHEME

- ✓ E = 1.47 V.
- ✓ $r = (l_1/l_2 - 1)R$.
- ✓ r = 3.0 Ω.
- ✓ I = 0.082 A.

c. **ANSWER** A · 3

$S = \frac{I_g}{I - I_g}G = \frac{0.005}{2 - 0.005} \times 40 =$ **0.100 Ω**, joined in parallel with the galvanometer.

The ammeter's resistance is $\frac{GS}{G + S} = \frac{40 \times 0.100}{40.1} \approx$ **0.10 Ω**: very small, as an ammeter's should be.

MARKING SCHEME

- ✓ $S = I_gG/(I - I_g)$.
- ✓ S = 0.100 Ω in parallel.
- ✓ The ammeter's resistance ≈ 0.10 Ω.

7 Think

ANSWER

The balance point does not move. Only the ratio of the resistances of the two parts of the wire matters, and for a uniform wire that ratio is the ratio of their lengths, $l/(100 - l)$, whatever the diameter. If the left half were thinner, each centimeter of it would have more resistance than a centimeter of the right

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half: resistance would no longer be proportional to length, and $l/(100 - l)$ would give a wrong value of X. That is why the wire must be uniform.

MARKING SCHEME

- ✓ No change: for a uniform wire, $P/Q = l/(100 - l)$ whatever its diameter.
- ✓ A thinner left half has more resistance per centimeter.
- ✓ So resistance is no longer proportional to length and the formula gives a wrong X.

8 Activity: Kirchhoff's laws on the bench (Activity 14.1)

(not marked)

WHAT STUDENTS SHOULD FIND

The current into the junction, I, equals $I_1 + I_2$, and the p.d. across R_1 plus that across R_2 (or R_3, which is the same) equals the battery's p.d., within the meters' accuracy (a few percent). The first result is Kirchhoff's first law, the second his second law round each loop.

Marks by level	Knowledge	Understanding	Application	Higher ability	Total
Marks	6	12	14	3	**35**

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