Chapter 11

Practical circuits

LEARNING INTENTIONS

In this chapter you will learn how to:

- explain the effects of internal resistance on terminal p.d. and power output of a source of e.m.f.
- explain the use of potential divider circuits
- solve problems involving the potentiometer as a means of comparing voltages.

BEFORE YOU START

How confident are you on the concepts of terminal potential difference and e.m.f.? Without looking at a textbook, either write down the meaning of each or discuss it with a partner. This will help you in the first part of this chapter, which further develops the idea of e.m.f. and illustrates why the terminal p.d. and the e.m.f. are different.

THE FIRST ELECTRICAL CELL: AN HISTORICAL MYSTERY

The Italian Alessandro Volta (Figure 11.1a) is generally credited with inventing the first battery. He devised it after his friend and rival Luigi Galvani had shown that a (dead) frog’s leg could be made to twitch if an electrically charged plate was connected to it. Volta’s battery consisted of alternate discs of copper and zinc, separated by felt soaked in brine–see Figure 11.1b.

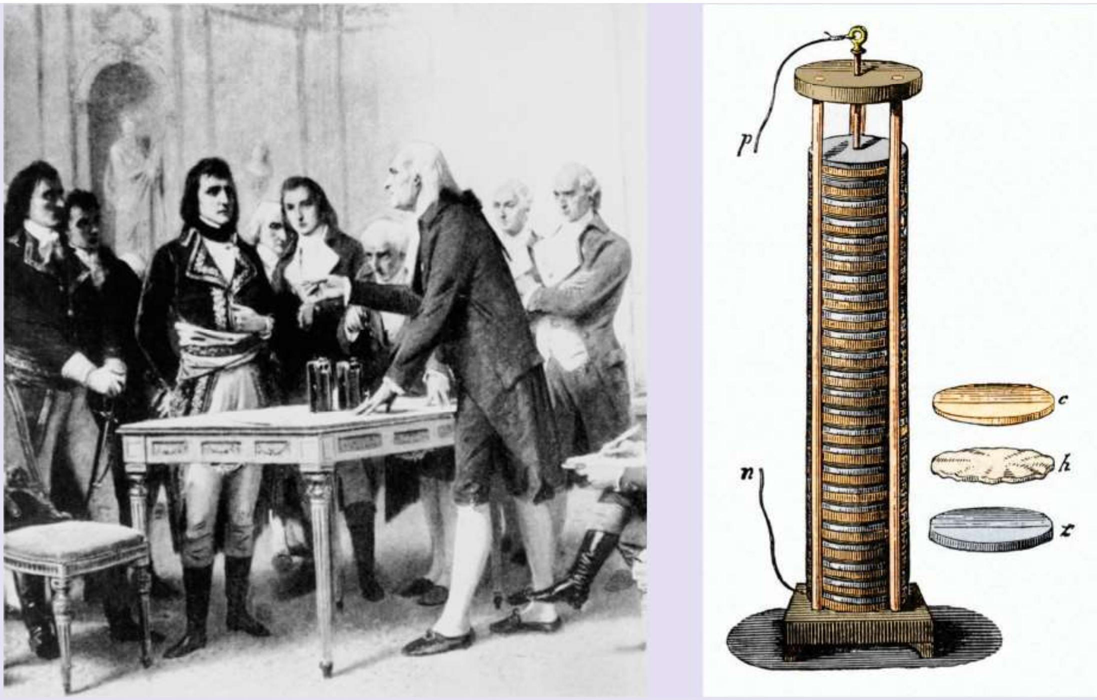


Figure 11.1: a Alessandro Volta demonstrating his newly invented pile (battery) to the French Emperor Napoleon. **b** Volta's pile, showing (top to bottom) discs of copper, wet felt and zinc.

However, there is evidence that earlier technologists may have beaten him by over 1000 years. In 1936, a small pot was discovered during an archaeological dig near Baghdad. The pot was sealed with pitch, and inside the pot there was a copper cylinder surrounding an iron rod. When filled with an acid, perhaps vinegar, a potential difference of around 1.5 volts could be produced between the copper and the iron.

It has been suggested that this battery might have been used to electroplate metal objects with gold. So, did Volta really invent the battery, or did he just rekindle an art that had been lost for more than a millennium?

11.1 Internal resistance

You will have learnt that, when you use a power supply or other source of e.m.f., you cannot assume that it is providing you with the exact voltage across its terminals as suggested by the value of its e.m.f. There are several reasons for this. For example, the supply may not be made to a high degree of precision, or the batteries may have become flat, and so on. However, there is a more important factor, which is that all sources of e.m.f. have an **internal resistance**. For a power supply, this may be due to the wires and components inside, whereas for a cell the internal resistance is due to the chemicals within it. Experiments show that the voltage across the terminals of the power supply depends on the circuit of which it is part. In particular, the voltage across the power supply terminals decreases if it is required to supply more current.

Figure 11.2 shows a circuit you can use to investigate this effect, and a sketch graph showing how the voltage across the terminals of a power supply might decrease as the supplied current increases.

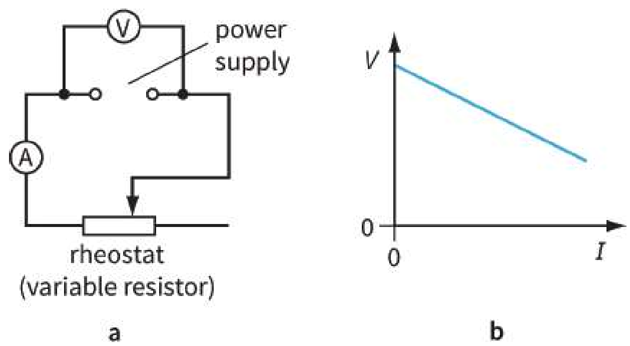


Figure 11.2: **a** A circuit for determining the e.m.f. and internal resistance of a supply; **b** typical form of results.

The charges moving round a circuit have to pass through the external components **and** through the internal resistance of the power supply. These charges gain electrical energy from the power supply. This energy is lost as thermal energy as the charges pass through the external components and through the internal resistance of the power supply. Power supplies and batteries get warm when they are being used. (Try using a cell to light a small torch bulb; feel the cell before connecting to the bulb, and then feel it again after the bulb has been lit for about 15 seconds.)

The reason for this heating effect is that some of the electrical potential energy of the charges is transformed to internal energy as they do work against the internal resistance of the cell.

It can often help to solve problems if we show the internal resistance r of a source of e.m.f. explicitly in circuit diagrams (Figure 11.3). Here, we are representing a cell as if it were a 'perfect' cell of e.m.f. E, together with a separate resistor of resistance r. The dashed line enclosing E and r represents the fact that these two are, in fact, a single component.

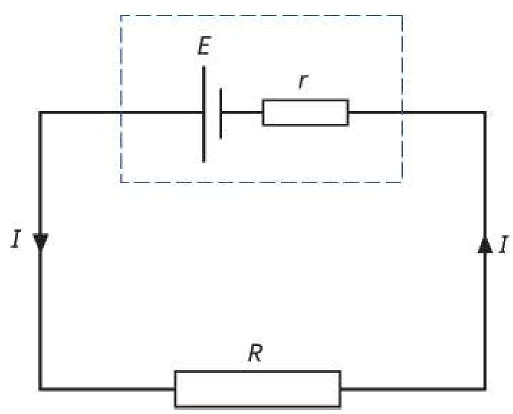


Figure 11.3: It can be helpful to show the internal resistance r of a cell (or a supply) in a circuit diagram.

Now we can determine the current when this cell is connected to an external resistor of resistance R. You can see that R and r are in series with each other. The current I is the same for both of these resistors. The combined resistance of the circuit is thus $R + r$, and we can write:

$$E = I(R + r) \quad \text{or} \quad E = IR + Ir$$

We cannot measure the e.m.f. E of the cell directly, because we can only connect a voltmeter across its terminals. This **terminal p.d.** V across the cell is always the same as the p.d. across the external resistor.

Therefore, we have:

$$V = IR$$

This will be less than the e.m.f. E by an amount Ir. The quantity Ir is the potential difference across the internal resistor. If we combine these two equations, we get:

$$V = E - Ir$$

where E is the emf of the source, I is the current in the source and r is the internal resistance of the source.

or

terminal p.d. = e.m.f. − p.d across the internal resistance

The potential difference across the internal resistance indicates the energy transferred to the internal resistance of the supply. If you short-circuit a battery with a piece of wire, a large current will flow, and the battery will get warm as energy is transferred within it. This is also why you may damage a power supply by trying to make it supply a larger current than it is designed to give.

KEY EQUATION

Potential difference across a power source:

$$V = E - Ir$$

WORKED EXAMPLE

1 There is a current of 0.40 A when a battery of e.m.f. 6.0 V is connected to a resistor of 13.5 Ω. Calculate the internal resistance of the cell.

Step 1 Substitute values from the question in the equation for e.m.f.:

$$E = 6.0\text{ V}, \quad I = 0.40\text{ A}, \quad R = 13.5\Omega$$

$$E = IR + Ir$$

$$\begin{aligned} 6.0 &= 0.40 \times 13.5 + 0.40 \times r \\ &= 5.4 + 0.40r \end{aligned}$$

Step 2 Rearrange the equation to make r the subject and solve:

$$\begin{aligned} 6.0 - 5.4 &= 0.40r \\ 0.60 &= 0.40r \\ r &= \frac{0.60}{0.40} = 1.5\Omega \end{aligned}$$

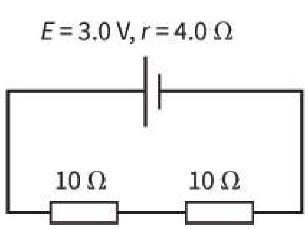
Questions

1 A battery of e.m.f. 5.0 V and internal resistance 2.0 Ω is connected to an 8.0 Ω resistor. Draw a circuit diagram and calculate the current in the circuit.

2 **a** Calculate the current in each circuit in Figure 11.4.

b Calculate also the potential difference across the internal resistance for each cell, and the terminal p.d.

i



ii

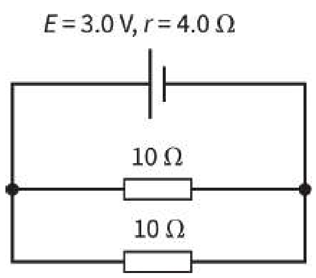


Figure 11.4: For Question 2.

3 Four identical cells, each of e.m.f. 1.5 V and internal resistance 0.10 Ω, are connected in series. A lamp of resistance 2.0 Ω is connected across the four cells. Calculate the current in the lamp.

PRACTICAL ACTIVITY 12.1

Determining e.m.f. and internal resistance

You can get a good idea of the e.m.f. of an isolated power supply or a battery by connecting a digital voltmeter across it. A digital voltmeter has a very high resistance (~10^7 Ω), so only a tiny current will pass through it. The potential difference across the internal resistance will then only be a tiny fraction of the e.m.f. If you want to determine the internal resistance r as well as the e.m.f. E, you need to use a circuit like that shown in Figure 11.2. When the variable resistor is altered, the current in the circuit changes and measurements can be recorded of the circuit current I and terminal p.d. V. The internal resistance r can be found from a graph of V against I (Figure 11.5).

Compare the equation $V = E - Ir$ with the equation of a straight line $y = mx + c$. By plotting V on the y-axis and I on the x-axis, a straight line should result. The intercept on the y-axis is E, and the gradient is $-r$.

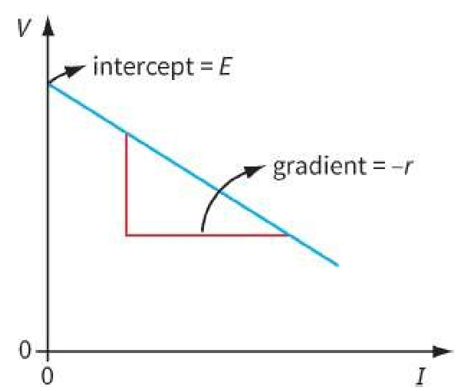


Figure 11.5: E and r can be found from this graph.

Questions

4 When a high-resistance voltmeter is placed across an isolated battery, its reading is 3.0 V. When a 10 Ω resistor is connected across the terminals of the battery, the voltmeter reading drops to 2.8 V. Use this information to determine the internal resistance of the battery.

5 The results of an experiment to determine the e.m.f. E and internal resistance r of a power supply are shown in Table 11.1. Plot a suitable graph and use it to find E and r.

V / V	1.43	1.33	1.18	1.10	0.98
I / A	0.10	0.30	0.60	0.75	1.00

Table 11.1: Results for Question 5.

The effects of internal resistance

You cannot ignore the effects of internal resistance. Consider a battery of e.m.f. 3.0 V and of internal resistance 1.0 Ω. The **maximum current** that can be drawn from this battery is when its terminals are shorted-out. (The external resistance $R \approx 0$.) The maximum current is given by:

$$\begin{aligned}\text{maximum current} &= \frac{E}{r} \\ &= \frac{3.0}{1.0} \\ &= 3.0\ \text{A}\end{aligned}$$

The **terminal p.d.** of the battery depends on the resistance of the external resistor. For an external resistor of resistance 1.0 Ω, the terminal p.d. is 1.5 V – half of the e.m.f. The terminal p.d. approaches the value of the e.m.f. when the external resistance R is very much greater than the internal resistance of the battery. For example, a resistor of resistance 1000 Ω connected to the battery gives a terminal p.d. of 2.997 V. This is almost equal to the e.m.f. of the battery. The more current a battery supplies, the more its terminal p.d. will decrease. An example of this can be seen when a driver tries to start a car with the headlamps on. The starter motor requires a large current from the battery, the battery's terminal p.d. drops and the headlamps dim.

Question

6 A car battery has an e.m.f. of 12 V and an internal resistance of 0.04 Ω. The starter motor draws a current of 100 A.

- **a** Calculate the terminal p.d. of the battery when the starter motor is in operation.
- **b** Each headlamp is rated as '12 V, 36 W'. Calculate the resistance of a headlamp.
- **c** To what value will the power output of each headlamp decrease when the starter motor is in operation? (Assume that the resistance of the headlamp remains constant.)

11.2 Potential dividers

How can we get an output of 3.0 V from a battery of e.m.f. 6.0 V? Sometimes we want to use only part of the e.m.f. of a supply. To do this, we use an arrangement of resistors called a **potential divider** circuit.

Figure 11.6 shows two potential divider circuits, each connected across a battery of e.m.f. 6.0 V and of negligible internal resistance. The high-resistance voltmeter measures the voltage across the resistor of resistance R_2. We refer to this voltage as the output voltage, V_{out}, of the circuit. The first circuit, **a**, consists of two resistors of values R_1 and R_2. The voltage across the resistor of resistance R_2 is half of the 6.0 V of the battery. The second potential divider, **b**, is more useful. It consists of a single variable resistor. By moving the sliding contact, we can achieve any value of V_{out} between 0.0 V (slider at the bottom) and 6.0 V (slider at the top).

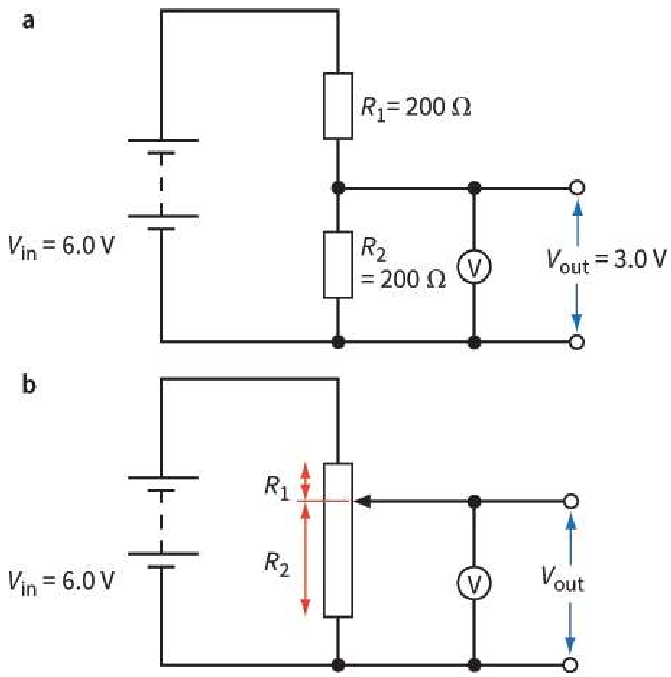


Figure 11.6: Two potential divider circuits.

The output voltage V_{out} depends on the relative values of R_1 and R_2. You can calculate the value of V_{out} using the **potential divider equation**:

$$V_{out} = \left(\frac{R_2}{R_1+R_2}\right) \times V_{in}$$

where R_2 is the resistance of the component over which the output is taken, R_1 is the resistance of the second component in the potential divider and V_{in} is the p.d. across the two components.

KEY EQUATION

Potential divider equation:

$$V_{out} = \left(\frac{R_2}{R_1+R_2}\right) \times V_{in}$$

Question

7 Determine the range of V_{out} for the circuit in Figure 11.7 as the variable resistor R_2 is adjusted over its full range from 0 Ω to 40 Ω. (Assume the supply of e.m.f. 10 V has negligible internal resistance.)

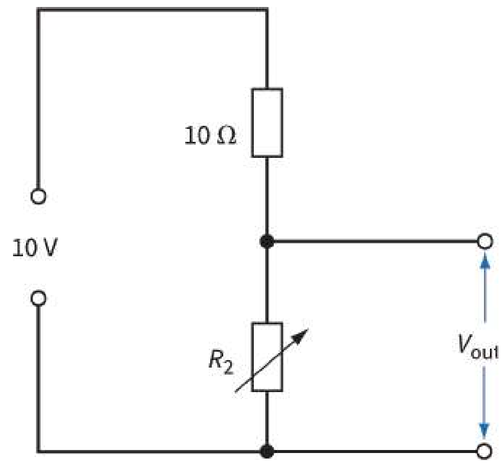


Figure 11.7: For Question 7.

11.3 Sensors

Light-dependent resistors as sensors

How is a light-dependent resistor (LDR) used as a **sensor** or **transducer**? A voltage is needed to drive the output device, such as a voltmeter, yet the LDR only produces a change in resistance. The sensor must use this change in resistance to generate the change in voltage. The solution is to place the LDR in series with a fixed resistor, as shown in Figure 11.8.

The voltage of the supply is shared between the two resistors in proportion to their resistance so, as the light level changes and the LDR's resistance changes, so does the voltage across each of the resistors. The two resistors form a potential divider whose output changes automatically with changing light intensities.

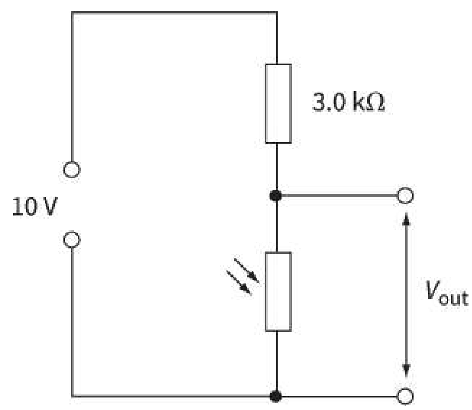


Figure 11.8: An LDR used as a sensor.

WORKED EXAMPLE

2 Using the graph in Figure 11.9, calculate V_{out} in Figure 11.8 when the light intensity is 60 lux.

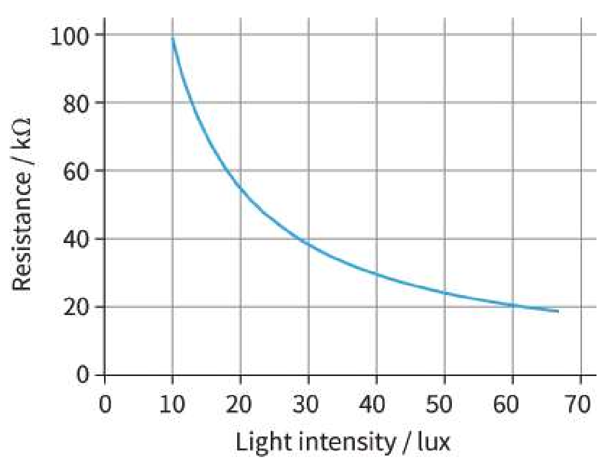


Figure 11.9: for Worked example 2 and question 8.

Step 1 Find the resistance of the LDR at 60 lux.

$R_{LDR} = 20$ kΩ

Step 2 Divide the total voltage of 10 V in the ratio 3 : 20. The total number of parts is 23 so:

$$V_{out} = \frac{20}{23} \times 10 = 8.70\text{V}$$

Hint: *The answer on your calculator might be 8.69565. When you give your answer to three significant figures, do not write 8.69 – you must round correctly.*

Questions

8 What is the voltage across the 3.0 kΩ resistor in Figure 11.9 when the light intensity is 10 lux?

9 The circuit shown in Figure 11.8 produces a decreasing output voltage when the light intensity increases. How can the circuit be altered to produce an increasing output voltage as the light intensity increases?

Thermistors as a sensors

The thermistors that we refer to in this course are known as **negative temperature coefficient** (NTC) thermistors. This means that, when the temperature rises, the resistance of the thermistor falls. This happens because the thermistor is made from a semiconductor material. One property of a semiconductor is that when the temperature rises the number of free electrons increases, and thus the resistance falls.

Figure 11.10 shows a graph of the resistance of a thermistor and the resistance of a metal wire plotted against temperature. You can see that the resistance of a metal wire increases with increase in temperature. A metal wire is not a negative temperature device, but it could be used as a sensing device. A thermistor is more useful than a metal wire because there is a much larger change in resistance with change in temperature. However, the change in resistance of a thermistor is not linear with temperature; indeed, it is likely to be an exponential decrease. This means that any device used to measure temperature electronically must be calibrated to take into account the resistance–temperature graph. The scale on an ordinary laboratory thermometer between 0 °C and 100 °C is divided up into 100 equal parts, each of which represents 1 °C. If the resistance of a thermistor were divided like this, the scale would be incorrect.

The thermistor can be used as a sensing device in the same way as an LDR. Instead of sensing a change in light level, it senses a change in temperature.

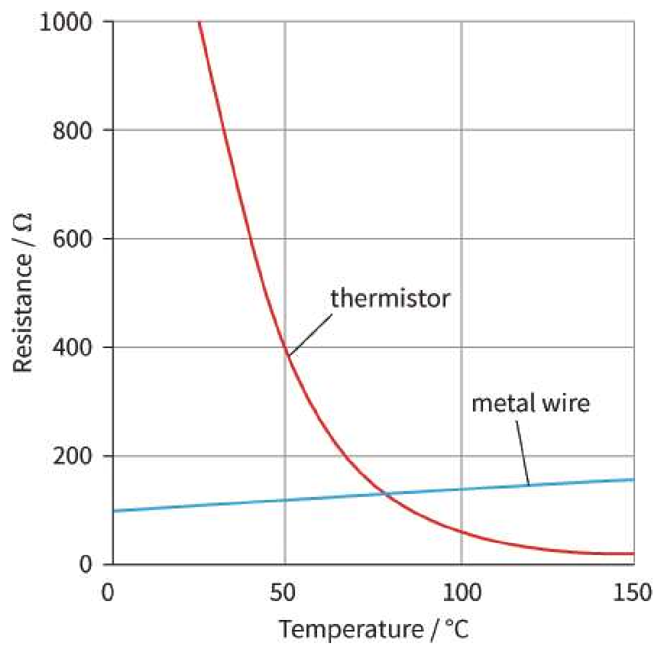


Figure 11.10: Variation of resistance with temperature.

Questions

10 Explain how a thermistor can be used as a transducer.

11 State **two** similarities between an LDR and a thermistor.

12 Design a circuit using the thermistor in Figure 11.10 that uses a cell of 10 V and produces an output voltage of 5 V at 50 °C. Explain whether the voltage output of your circuit increases or decreases as the temperature rises.

11.4 Potentiometer circuits

A **potentiometer** is a device used for comparing potential differences. For example, it can be used to measure the e.m.f. of a cell, provided you already have a source whose e.m.f. is known accurately. As we will see, a potentiometer can be thought of as a type of potential divider circuit.

A potentiometer consists of a piece of resistance wire, usually 1 m in length, stretched horizontally between two points. In Figure 11.11, the ends of the wire are labelled A and B. A **driver cell** is connected across the length of wire. Suppose this cell has an e.m.f. E_o of 2.0 V. We can then say that point A is at a voltage of 2.0 V, B is at 0 V, and the midpoint of the wire is at 1.0 V. In other words, the voltage decreases steadily along the length of the wire.

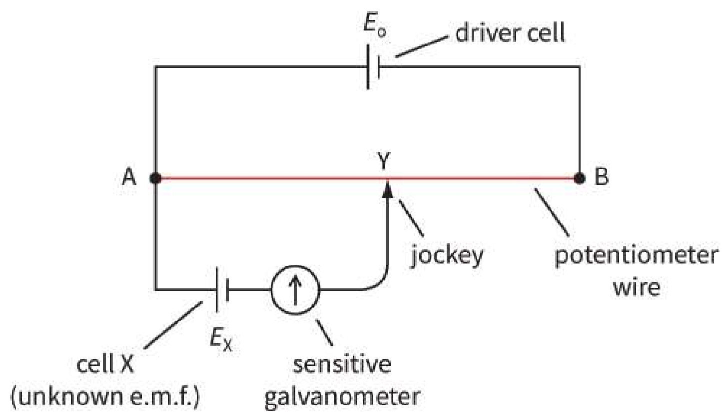


Figure 11.11: A potentiometer connected to measure the e.m.f. of cell X.

Now, suppose we wish to measure the e.m.f. E_X of cell X (this must have a value less than that of the driver cell). The positive terminal of cell X is connected to point A. (Note that both cells have their positive terminals connected to A.) A lead from the negative terminal is connected to a sensitive **galvanometer** (such as a microammeter), and a lead from the other terminal of the galvanometer ends with a metal **jockey**. This is a simple connecting device with a very sharp edge that allows very precise positioning on the wire.

If the jockey is touched onto the wire close to point A, the galvanometer needle will deflect in one direction. If the jockey is touched close to B, the galvanometer needle will deflect in the opposite direction. Clearly, there must be some point Y along the wire that, when touched by the jockey, gives zero deflection – the needle moves neither to the left nor the right.

In finding this position, the jockey must be touched gently and briefly onto the wire; the deflection of the galvanometer shows whether the jockey is too far to the left or right. It is important not to slide the jockey along the potentiometer wire as this may scrape its surface, making it non-uniform so that the voltage does not vary uniformly along its length.

When the jockey is positioned at Y, the galvanometer gives zero deflection, showing that there is no current through it. This can only happen if the potential difference across the length of wire AY is equal to the e.m.f. of cell X. We can say that the potentiometer is balanced. If the balance point was exactly half-way along the wire, we would be able to say that the e.m.f. of X was half that of the driver cell. This technique – finding a point where there is a reading of zero – is known as a **null method**.

To calculate the unknown e.m.f. E_X we measure the length AY. Then we have:

$$E_X = \frac{AY}{AB} \times E_o$$

where E_o is the e.m.f. of the driver cell.

KEY EQUATION

To compare two e.m.f.s E_X and E_o:

$$E_X = \frac{AY}{AB} \times E_o$$

The potentiometer can be thought of as a potential divider because the point of contact Y divides the resistance wire into two parts, equivalent to the two resistors of a potential divider.

Comparing e.m.f.s with a potentiometer

When a potentiometer is balanced, no current flows from the cell being investigated. This means that its terminal p.d. is equal to its e.m.f.; we do not have to worry about the potential difference across the internal resistance. This is a great advantage that a potentiometer has over a voltmeter, which must draw a small current in order to work.

However, there is a problem: the driver cell is supplying current to the potentiometer, and so the p.d. between A and B will be less than the e.m.f. of the driver cell (some volts are lost because of its internal resistance). To overcome this problem, we use the potentiometer to **compare** p.d.s. Suppose we have two cells whose e.m.f.s E_X and E_Y we want to compare. Each is connected in turn to the potentiometer, giving balance points at C and D–see Figure 11.12. (In the diagram, you can see immediately that E_Y must be greater than E_X because D is further to the right than C.)

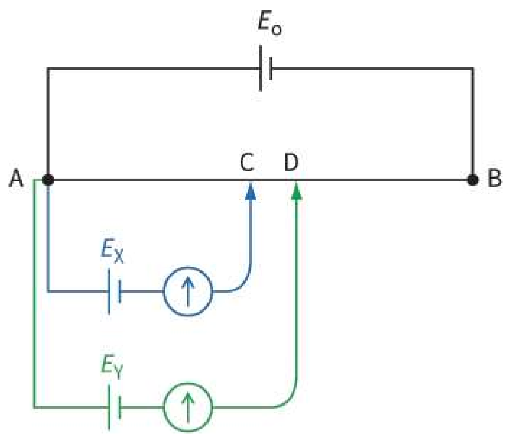


Figure 11.12: Comparing two e.m.f.s using a potentiometer.

The ratio of the e.m.f.s of the two cells will be equal to the ratio of the two lengths AC and AD:

$$\frac{E_X}{E_Y} = \frac{AC}{AD}$$

If one of the cells used has an accurately known e.m.f., the other can be calculated with the same degree of accuracy.

Comparing p.d.s

The same technique can be used to compare potential differences. For example, two resistors could be connected in series with a cell (Figure 11.13). The p.d. across one resistor is first connected to the potentiometer and the balance length found. This is repeated with the other resistor and the new balance point is found. The ratio of the lengths is the ratio of the p.d.s.

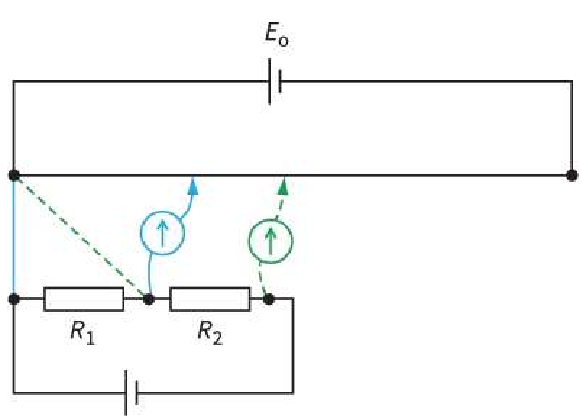


Figure 11.13: Comparing two potential differences using a potentiometer.

Since both resistors have the same current flowing through them, the ratio of the p.d.s is also the ratio of their resistances.

Question

13 To make a potentiometer, a driver cell of e.m.f. 4.0 V is connected across a 1.00 m length of resistance wire.

- **a** What is the potential difference across each 1 cm length of the wire? What length of wire has a p.d. of 1.0 V across it?
- **b** A cell of unknown e.m.f. E is connected to the potentiometer and the balance point is found at a distance of 37.0 cm from the end of the wire to which the galvanometer is connected. Estimate the value of E. Explain why this can only be an estimate.
- **c** A standard cell of e.m.f. 1.230 V gives a balance length of 31.2 cm. Use this value to obtain a more accurate value for E.

REFLECTION

A student sets up a potentiometer circuit to compare the e.m.f.s of two cells. The student is unable to find a balance point.

Discuss with a partner possible reasons for this. Consider using Kirchhoff's Laws as a way of exploring the reasons.

Did you do your work the way other people did theirs? In what ways did you do it differently? In what ways was your work or process similar?

SUMMARY

A source of e.m.f., such as a battery, has an internal resistance. We can think of the source as having an internal resistance, *r*, in series with an e.m.f., *E*.

The terminal p.d. of a source of e.m.f. is less than the e.m.f. because of the potential difference across the internal resistor:

terminal p.d. = e.m.f. − p.d across the internal resistor

$$V = E - Ir$$

A potential divider circuit consists of two or more resistors connected in series to a supply. The output voltage V_{out} across the resistor of resistance R_2 is given by:

$$V_{\text{out}} = \left(\frac{R_2}{R_1+R_2}\right) \times V_{\text{in}}$$

A potentiometer can be used to compare potential differences.

EXAM-STYLE QUESTIONS

1 A resistor of resistance 6.0 Ω and a second resistor of resistance 3.0 Ω are connected in parallel across a battery of e.m.f. 4.5 V and internal resistance 0.50 Ω.

What is the current in the battery? **[1]**

A 0.47 A

B 1.8 A

C 3.0 A

D 11 A

2 This diagram shows a potential divider.

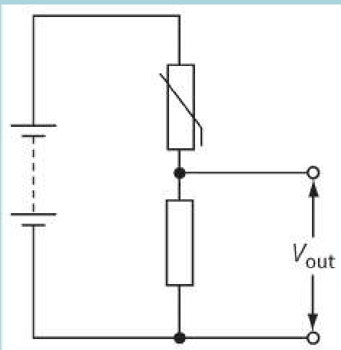


Figure 11.14

What happens when the temperature decreases? **[1]**

A The resistance of the thermistor decreases and V_{out} decreases.

B The resistance of the thermistor decreases and V_{out} increases.

C The resistance of the thermistor increases and V_{out} decreases.

D The resistance of the thermistor increases and V_{out} increases.

3 A single cell of e.m.f. 1.5 V is connected across a 0.30 Ω resistor. The current in the circuit is 2.5 A.

a Calculate the terminal p.d. and explain why it is not equal to the e.m.f. of the cell. **[2]**

b Show that the internal resistance r of the cell is 0.30 Ω. **[3]**

c It is suggested that the power dissipated in the external resistor is a maximum when its resistance R is equal to the internal resistance r of the cell.

i Calculate the power dissipated when $R = r$. **[1]**

ii Show that the power dissipated when $R = 0.50$ Ω and $R = 0.20$ Ω is less than that dissipated when $R = r$, as the statement suggests. **[4]**

[Total: 10]

4 A student is asked to compare the e.m.f.s of a standard cell and a test cell. He sets up the circuit shown using the test cell.

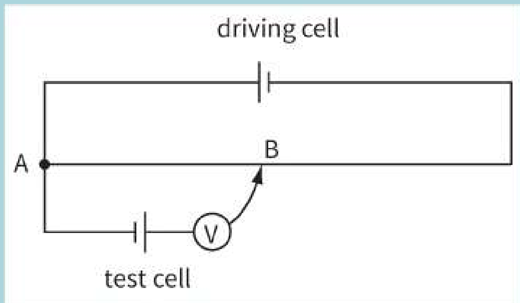


Figure 11.15

a **i** Explain why he is unable to find a balance point and state the change he must make in order to achieve balance. **[2]**

ii State how he would recognise the balance point. **[1]**

b He achieves balance when the distance AB is 22.5 cm. He repeats the experiment with a standard cell of e.m.f. of 1.434 V. The balance point using this cell is at 34.6 cm. Calculate the e.m.f. of the test cell. **[2]**

[Total: 5]

5 **a** Explain what is meant by the **internal resistance** of a cell. **[2]**

b When a cell is connected in series with a resistor of 2.00 Ω there is a current of 0.625 A. If a second resistor of 2.00 Ω is put in series with the first, the current falls to 0.341 A.

Calculate:

i the internal resistance of the cell **[2]**

ii the e.m.f. of the cell. **[1]**

c A car battery needs to supply a current of 200 A to turn over the starter motor. Explain why a battery made of a series of cells of the type described **b** would not be suitable for a car battery. **[2]**

[Total: 7]

6 **a** State what is meant by the term **e.m.f. of a cell**. **[2]**

A student connects a high-resistance voltmeter across the terminals of a battery and observes a reading of 8.94 V. He then connects a 12 Ω resistor across the terminals and finds that the potential difference falls to 8.40 V.

b Explain why the measured voltage falls. **[2]**

c **i** Calculate the current in the circuit. **[2]**

ii Calculate the internal resistance of the cell. **[2]**

iii State any assumptions you made in your calculations. **[1]**

[Total: 9]

7 This diagram shows two circuits that could be used to act as a dimmer switch for a lamp.

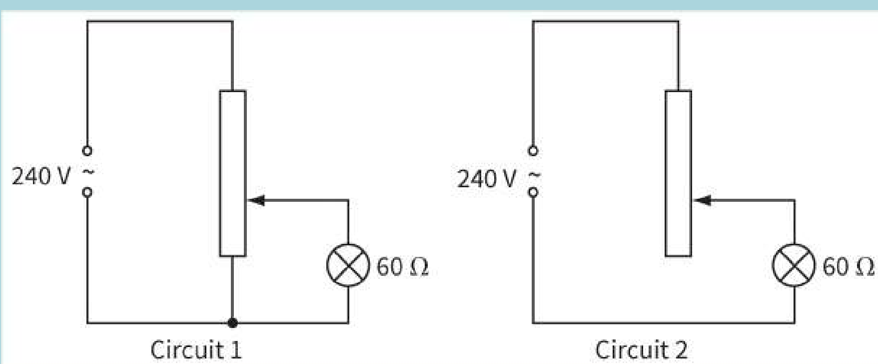


Figure 11.16

a Explain **one** advantage circuit 1 has over circuit 2. **[2]**

b **i** The lamp is rated at 60 W at 240 V. Calculate the resistance of the lamp filament at its normal operating temperature. **[2]**

ii State and explain how the resistance of the filament at room temperature would compare with the value calculated in **i**. **[2]**

[Total: 6]

8 This circuit shows a potential divider. The battery has negligible internal resistance and the voltmeter has infinite resistance.

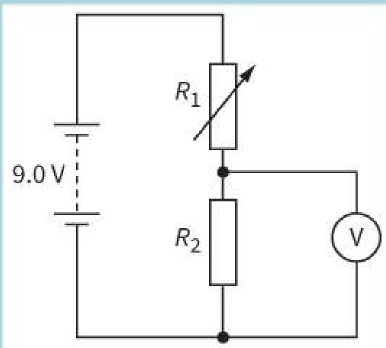


Figure 11.17

a State and explain how the reading on the voltmeter will change when the resistance of the variable resistor is increased. **[2]**

b Resistor R_2 has a resistance of 470 Ω. Calculate the value of the variable resistor when the reading on the voltmeter is 2.0 V. **[2]**

c The voltmeter is now replaced with one of resistance 2 kΩ. Calculate the reading on this voltmeter. **[2]**

[Total: 6]

9 This is a potentiometer circuit.

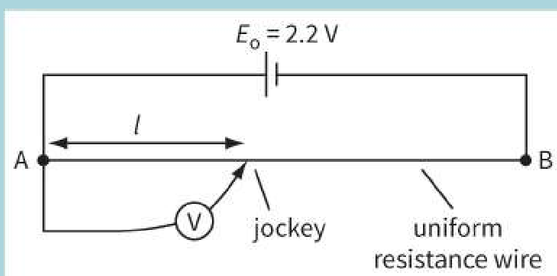


Figure 11.18

a **i** Sketch a graph of reading on the voltmeter against length, l, as the jockey is moved from point A to point B. **[2]**

ii State the readings on the voltmeter when the jockey is connected to A and when it is connected to B. (You may assume that the driver cell has negligible internal resistance.) **[1]**

iii Draw a circuit diagram to show how the potentiometer could be used to compare the e.m.f.s of two batteries. **[3]**

b When a pair of 4 Ω resistors are connected in series with a battery, there is a current of 0.60 A current through the battery. When the same two resistors are connected in parallel and then connected across the battery, there is a current of 1.50 A through it. Calculate the e.m.f. and the internal resistance of the battery. **[4]**

[Total: 10]

10 A potentiometer, which consists of a driving cell connected to a resistance wire of length 100 cm, is used to compare the resistances of two resistors.

a Draw a diagram to show the circuits that are used to compare the two resistances. **[2]**

b When resistor R_1 alone is tested the length of resistance wire for balance is 15.4 cm. There is an uncertainty in measuring the beginning of the resistance wire of 0.1 cm, and in establishing the balance point of a further 0.1 cm.

i Determine the uncertainty in the balance length. **[1]**

When R_1 and R_2 are tested in series the balance length is 42.6 cm. There are similar uncertainties in measuring this balance length.

ii Calculate the ratio of $\frac{R_1}{(R_1+R_2)}$. **[1]**

iii Calculate the value of the ration of $\frac{R_1}{R_2}$. **[2]**

iv Calculate the uncertainty in the value of the ratio $\frac{R_1}{R_2}$. **[2]**

[Total: 8]