Chapter 11-Practical Circuits

1. Internal Resistance

1.1. A power supply or other source of e.m.f., cannot be assumed to provide the exact voltage across its terminals as specified by the value of its e.m.f.

Some the possibilities are listed below:

- the supply may not be made to a high degree of precision, batteries become flat, and so on
- All sources of e.m.f. have an ***internal resistance***
  - ✓ For a power supply, this may be due to the wires and components inside,
  - ✓ for a cell the internal resistance is due to the chemicals within it
- 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 displays a circuit used to investigate this effect, along with a sketch graph showing how the voltage across the terminals of a power supply might decrease as the supplied current increases.

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 heat

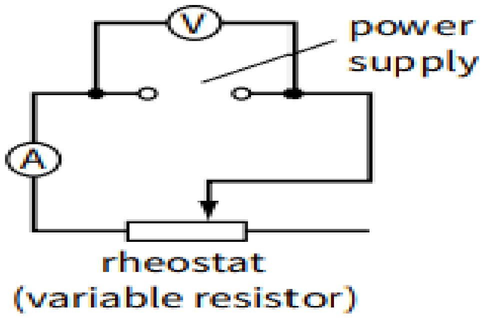

Figure 11.2 (a) A circuit for determining the e.m.f. and internal resistance of a supply

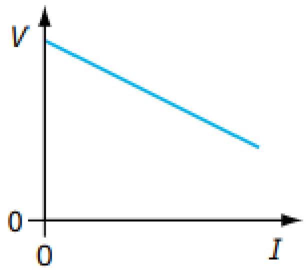

Figure 11.2 (b) Typical form of results.

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.

Analogy: Connecting a cell to light a small torch bulb and feel the cell before connecting to the bulb again after the bulb has been lit for about 15 seconds.

Heating effect is due to some of the electrical potential energy of the charges being transformed to internal energy as they do work against the internal resistance of the cell.

In practice, a cell is represented as if it were a **'perfect' cell of e.m.f. E**, together with a separate resistor of resistance r, as displayed in Fig.11.3
The dashed line enclosing E and r represents the fact that these two are, in fact, a single component.

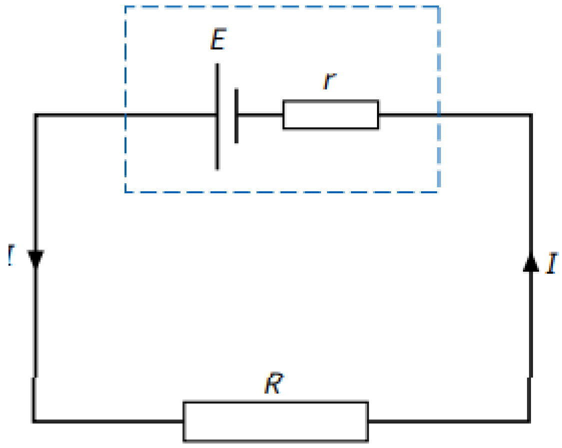

Figure 11.3 The internal resistance ***r*** of a cell (or a supply) as represented in a circuit diagram.

The current is determined with this cell connected to an external resistor of resistance R.
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,
Hence E = I(R+r) or E = IR+Ir
The e.m.f. E of the cell cannot be measured directly, as the voltmeter can be

connected only 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 and is referred to as the lost volts.

If we combine these two equations, we get: $V = E - Ir$ or

terminal p.d. = e.m.f.−'lost volts'

The 'lost volts' 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 shows that a power supply can be damaged by forcing it to supply a larger current than it is designed to give.

QUESTIONS

1. A battery of e.m.f. 5.0V and internal resistance 2.0Ω is connected to an 8.0Ω 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 'lost volts' for each cell, and the terminal p.d

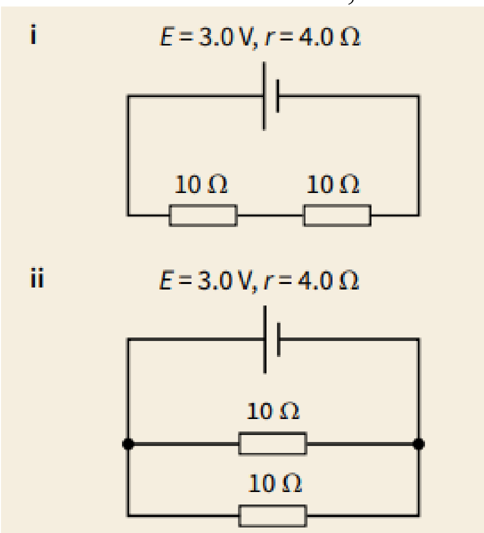

Fig 11.4 for Question 2

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

WORKED EXAMPLE

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

   Step 1

   Substitute values from the question in the equation for e.m.f.: E = 6.0V, I = 0.40A, R = 13.5Ω

   $E = IR + Ir$ $6.0 = 0.40 \times 13.5 + 0.40 \times r = 5.4 + 0.40r$

   Step 2

   Rearrange the equation to make r the subject and solve:

   $6.0 - 5.4 = 0.40r$

   $0.60 = 0.40r$

   $r = 0.60 / 0.40 = 1.5\Omega$

   BOX 11.1: Determining e.m.f. and internal resistance

   The e.m.f. of an isolated power supply or a battery by can be reasonably measured by connecting a digital voltmeter across it.

   A digital voltmeter has a very high resistance ($\approx 10^7\Omega$), which allows only a tiny current to pass through it. The 'lost volts' 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 $-r$

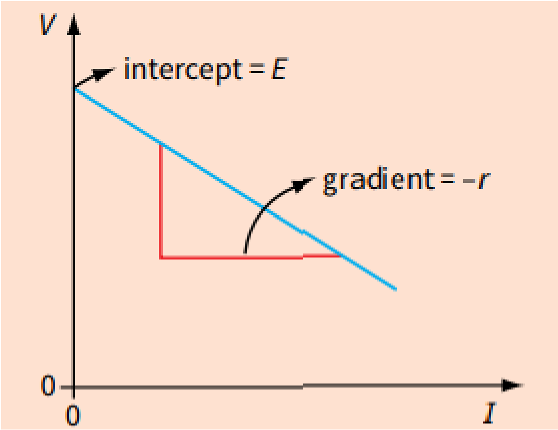

Figure 11.5 E and r can be found from this graph.

QUESTIONS

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

1.1. The effects of internal resistance

The effects of internal resistance cannot be ignored .
Consider a battery of e.m.f. 3.0V and of internal resistance 1.0Ω.
The maximum current that can be drawn from this battery is when its terminals are shorted-out. (The external resistance R ≈ 0.)
The maximum current is given by:
maximum current = E/r=3.0/1.0=3.0 A

The terminal p.d. of the battery depends on the resistance of the external resistor.
For an external resistor of resistance 1.0Ω, the terminal p.d. is 1.5V – (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.

Example
A resistor of resistance 1000Ω connected to the battery gives a terminal p.d. of 2.997V. 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.

QUESTIONS

6. A car battery has an e.m.f. of 12V and an internal resistance of 0.04Ω. The starter motor draws a current of 100A.
   - **a.** Calculate the terminal p.d. of the battery when the starter motor is in operation.
   - **b.** Each headlamp is rated as '12V, 36W'. 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.)

2. Potential dividers

The arrangement used to get the specified part of the Voltage required from a the available emf of the Battery is called a potential divider circuit.

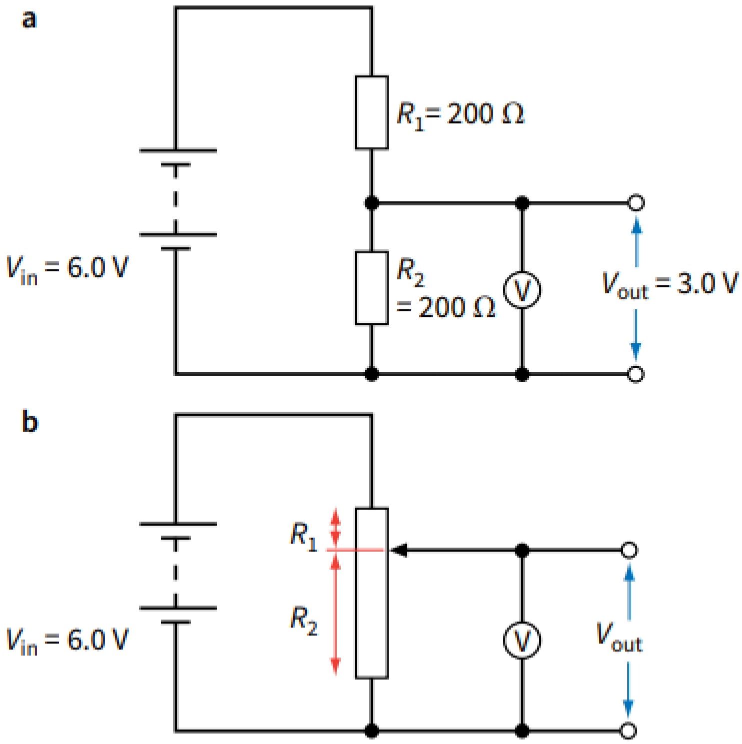

Figure 11.6 Two potential divider circuits.

Figure 11.6 shows two potential divider circuits, each connected across a battery of e.m.f. 6.0V and of negligible internal resistance. The high-resistance voltmeter measures the voltage across the resistor of resistance R2. We refer to this voltage as the output voltage, Vout, of the circuit. The first circuit, a, consists of two resistors of values R1 and R2. The voltage across the resistor of resistance R2 is half of the 6.0V 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 Vout between 0.0V (slider at the bottom) and 6.0V (slider at the top).
The output voltage Vout depends on the relative values of R1 and R2. You can calculate the value of Vout using the following potential divider equation:

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

In this equation, Vin is the total voltage across the two resistors the headlamps dim.

QUESTIONS

7. Determine the range of Vout for the circuit in Figure 12.7 as the variable resistor R2 is adjusted over its full range from 0Ω to 40Ω. (Assume the supply of e.m.f. 10 V has negligible internal resistance.)

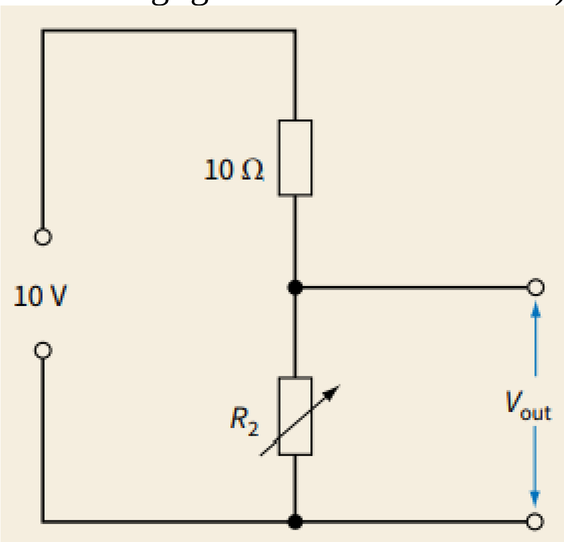

Figure 11.7 For Question 7.

3. 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 1m in length, stretched horizontally between two points. In Figure 12.8, 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. Eo of 2.0V. We can then say that point

A is at a voltage of 2.0V, B is at 0V, and the midpoint of the wire is at 1.0V. In other words, the voltage decreases steadily along the length of the wire.

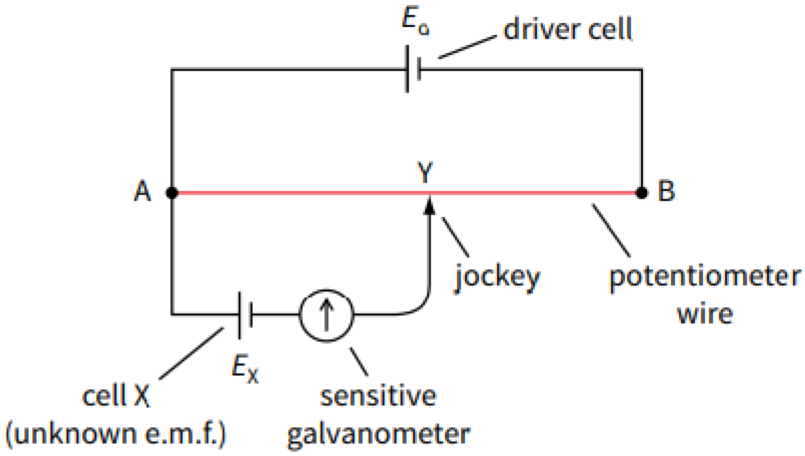

Figure 11.8 A potentiometer connected to measure the e.m.f. of cell X.