240 Volts Can Kill

Contents: Practical work, information and questions about the problem of mains electrocution.

Timing: 2 to 3 periods.

Intended use: GCSE Science, Physics and Biology. Links with work on fuses, Ohm's law and mains electricity in Physics. Links with first-aid and the heart in Biology.

Aims

- To provide an opportunity to apply basic ideas about current electricity including Ohm's law
- To develop awareness of the dangers of mains electricity and of the first aid appropriate in case of an accident
- To explain the difference between fuses and RCDs
- To provide an opportunity to practise certain skills, including experimental skills and the interpretation of data.

Requirements: Students' worksheets No.1007. Access to multimeters for the investigation. The teacher may need additional apparatus for demonstrations as explained in the notes below.

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This unit can be used on its own but has been designed to lead into unit No.1008, *Why 240 Volts?*

How well do you conduct electricity?

Use of a multimeter to measure the resistance of the body is simple but not ideal. The results will illustrate the point that the overall resistance varies little with the position of the contact points. The presence of moisture makes a significant difference.

For a given path through the human body the danger to life depends on the value of the current. The relationship of current to voltage is not linear because body resistance varies with touch voltage. For a.c. up to 100 Hz the following values apply under typical conditions involving an accident with hand to hand, or hand to foot, contacts. The table is taken from a report of the International Electrotechnical Commission (1974).

Touch voltage/V	*Body resistance/Ω*
25	2 500
50	2 000
250	1 000

The values for dry skin (with no perspiration) are higher. Dry skin at 50 Hz can have a resistance far in excess of 100 000 Ω/cm^2. When fully hydrated the resistance can drop to as low as 100 Ω/cm^2. The bulk internal resistance of the body is about 150 Ω and is roughly independent of the area of contact.

What this shows is that the resistance of the body is largely in the skin layer: the watery interior has a relatively low resistance. As a result, the resistance of the body is approximately constant between any two contact points. The resistance falls when the skin is wet and so there is an increased danger in moist areas such as bathrooms.

Figure 2 should help students to appreciate the dangers of using mains electricity out of doors when they are in direct contact with the earth. Wearing boots or shoes with rubber soles is a wise precaution because they insulate the body from earth.

Why are electric shocks dangerous?

At 50 Hz a.c. the following sensations are observed:

Current/mA	*Effect*
1 – 6	Harmless tingling
7 – 24	'Can't let go' current range. Distressing but survivable.
25 – 29	Borderline
Above 30	Ventricular fibrillation. The heart becomes desynchronized and will not re-synchronize on its own. It must be sorted out in 2 to 4 minutes or irreparable brain damage occurs.

Electric shock may cause the heart to go into fibrillation; yet, paradoxically, defibrillators used in emergency treatment to restart normal heart beats operate by giving a massive electric pulse of 50 A across the chest for 50 ms. Something like 400 J is delivered from a supply voltage of up to 3kV. This causes all the muscles, including the heart, to go into spasm and then relax. The body's own mechanisms can re-synchronize a relaxed heart.

Can a fuse save you?

The main purpose of fuses is to protect cables and prevent fire. Wherever there is a change in the current-carrying capacity of a cable there should be a fuse of appropriate rating.

The currents involved in electric shocks are measured in milliamps, and are far too small to blow a fuse. In this sense, fuses do not provide protection, though they do protect life by blowing whenever any exterior metal part of an appliance becomes live.

The purpose of fuses is often misunderstood. It is common to find extension leads made up with 2A or 5A cable connected to a plug with a 13A fuse. If such a lead is used with a high-power device, such as a 3kW fire, the cable is protecting the fuse rather than the other way about.

The ring main in a house is protected by a 30 A fuse. Hence the need for a fuse in each plug to protect the wire from the plug to the appliance. The fuse is designed to run without overheating at its current rating. A 13A fuse in a plug may not 'blow' until the current is in the range 20 – 50 A.

Teacher demonstration

The current needed to blow a fuse can be demonstrated using a 1 A fuse in series with an ammeter, resistor and low-voltage d.c. supply. The results will show that the current needed to melt the wire is well above the fuse rating.

Most physics and science textbooks at this level explain how to determine the correct fuse for a particular appliance and so this aspect has been omitted from the unit.

What can protect us?

An RCD illustrates Kirchoff's first law: it is designed to switch off the supply if the currents in the live and neutral wires are not the same. If they are not the same there must be a fault.

RCDs work by passing the current from the live and neutral wires through the coils of two opposing electromagnets. Any imbalance in the two electromagnets trips a switch, breaking the circuit.

Teacher demonstration

The effectiveness of an RCD compared with a fuse might be illustrated by wiring up two mains lamp sockets with a three-core cable and a standard fused plug protected by an RCD. Wire up the plug correctly in the normal way. Make connections in the lamp holder as follows:

Correct wiring — brown and blue wires connected to the lamp terminals — the lamp will light normally

Incorrect wiring — brown and green/yellow wires connected to the lamp terminals — this will trip an RCD but **not** blow the fuse. (This has the same effect as pressing the test button on the RCD. When the button is pressed the live wire is connected to earth and the device trips.)

The data for the non-fatal zones in Figure 6 is based on experiments carried out by a German scientist on himself. He was protected by RCDs and surrounded by assistants. The effects were recorded on film. Thus the standards for RCDs are set by results for a healthy, adult, European male.

The data in the fatal zones is based on experiments with dogs.

Figure 6 shows that currents up to 200 mA are unlikely to be dangerous if interrupted within 200 ms. A typical RCD sold for domestic use is rated to trip if the current leakage exceeds 30 mA for more than 40 ms.

When someone cuts a cable accidentally with an electric mower it is quite likely that an RCD will not trip if the blade cuts through the wires in a fraction of a second. The fuse will certainly not blow. However, if the operator picks up the cut cable and touches the live wire before switching off, he or she will probably be saved as the RCD trips.

Acknowledgements Figure 1 supplied by the Central Electricity Generating Board; Figure 3 supplied by the Royal Society for the Prevention of Accidents.

240 VOLTS CAN KILL

Introduction

Every year about a hundred people are killed by electric shocks in Britain. Many of these accidents involve electrical appliances such as lawnmowers, hedgetrimmers and drills.

In this unit you will find out more about how your body is affected by an electric current. You will also discover the difference between a fuse and a circuit breaker. After working through the unit you should have a better idea of how to save yourself from electrocution.

Figure 1

How well do you conduct electricity?

Investigation What is your body's resistance?

Use a multimeter to measure the electrical resistance of your body between various points. Make a copy of the table below and record your results in it.

First take the measurement with dry skin. Then work up a sweat by taking vigorous exercise and take a second set of readings. Finally make your skin thoroughly wet and make the measurements a third time.

Contact points	*Resistance/ohms*		
	dry skin	*sweaty skin*	*wet skin*
Hand and hand Hand and foot Finger and finger (on the same hand)			

Answer questions 1 to 4.

Questions

1 *Compare the resistance of your body with dry skin between different points on the body. Are there any* large *differences?*

2 *How does the resistance change if your skin is dry, sweaty or wet?*

3 *Use Ohm's law to estimate the current through your body when you receive a shock from the 240 volt mains when your skin is dry. Use the resistance value you have measured using the multimeter, between hand and foot.*

4 *A current less than about 0.025 A will probably not kill you. What can you conclude from this information and your answer to question 3?*

Ohm's law

The relationship between current, voltage and resistance:

$$\text{Current (amps, A)} = \frac{\text{Voltage (volts, V)}}{\text{Resistance (ohms, }\Omega\text{)}}$$

If you get an electric shock the current flows through your body to earth. The size of the current depends on the total resistance. This is made up of several parts as shown in Figure 2. If the total resistance is high, the current will be small. Dry skin has a much higher resistance than wet skin. The *inside* of your body has a very low resistance. This is because it contains so much water.

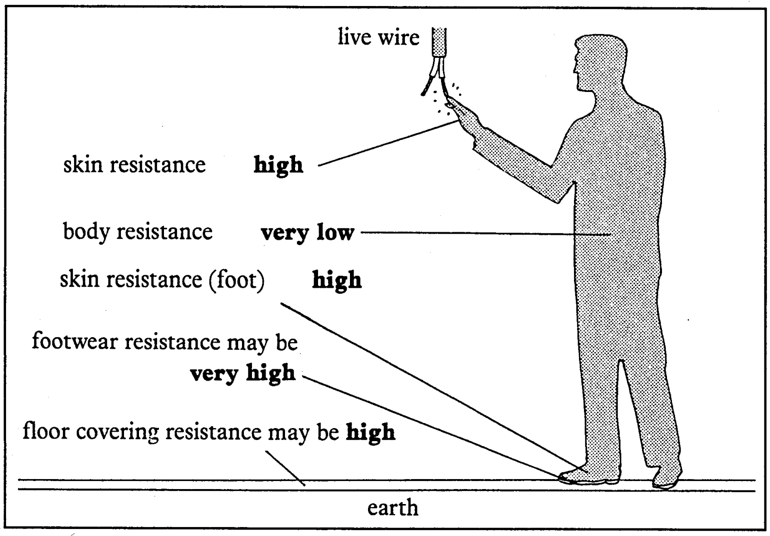


Figure 2

The resistance of the human body varies. The resistance changes when the voltage is altered. The average total resistance of your body is about 2000 ohms at 240 volts if your skin is dry. The resistance of the body is lower if the skin is wet. With wet skin, the average total resistance is 1000 ohms.

Answer questions 5 to 8.

Why are electric shocks dangerous?

What happens to your body when you get a shock? There are four possible ways in which you may suffer.

- Your muscles may contract suddenly. You may even be 'thrown across the room'.
- Your heart beat may be upset and become irregular. This is called **fibrillation.** Most deaths from electric shock happen because the heart starts to fibrillate. Permanent brain damage occurs in 2 to 4 minutes after the fibrillation starts.
- Your skin may be burnt at the point of electrical contact. This normally only happens at high voltages — voltages above about 1000 volts.
- You may go into a state of clinical shock. Your pulse becomes weak and your breathing is irregular. This too can be a killer.

Questions

5 *It makes little difference to the body's resistance if the contact points are close together or far apart. Suggest a reason.*

6 *Repeat question 3, but this time work out the current that will flow at 240 V:*
(a) With dry skin (assume the body resistance is 2000 ohms)
(b) With wet skin (assume the body resistance is 1000 ohms)

7 *Why is it dangerous to install a power socket in a bathroom?*

8 *Use Figure 2 to explain why:*
(a) you are more likely to get a serious shock when using an electrical appliance out of doors
(b) gardeners are advised to wear shoes with rubber soles when using electrical appliances out of doors.

What can you do to save life?

If someone has had an electric shock from the mains, **the first thing to do is to switch off the electricity supply.** You can then give first aid (Figure 3).

Answer question 9.

Figure 3 First aid for a person suffering from electric shock

Question

9 *What would you do in each of the following situations?*
 (a) *You are standing at a station. A person falls across the conductor rail of the electric railway.*
 (b) *Your father is doing the ironing. He gets a shock from a worn flex. His muscles contract and he cannot let go of the iron.*
 (c) *You are looking out of the window watching a neighbour cut a hedge with electric shears. You see him cut into the cable.*

Can a fuse save you?

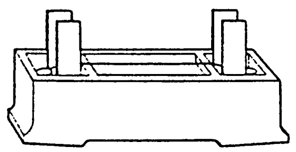
Fuses are included in electric circuits for safety. A fuse is a thin piece of wire which 'blows' if too big a current passes through it. When a fuse 'blows', the metal wire melts. This breaks the circuit and cuts off the current.

A fuse blows when something is wrong. The circuit may be overloaded with too many appliances. One of the appliances may have a fault. There may be a short circuit somewhere. The fault must be put right, or the faulty equipment disconnected, before a new fuse is fitted.

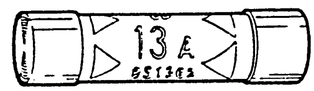
A 13-amp fuse must stay cool when the current through it is 13 amps. The fuse will only blow if the current is **much** bigger than 13 amps.

The main purpose of fuses is to protect electric equipment and cables. Fuses break the circuit before the current gets too big so it could damage the equipment and cable and perhaps cause a fire.

Answer questions 10 and 11.



fuse with wire that can be replaced



cartridge fuse — a metal wire inside a ceramic tube

Figure 4 Some examples of fuses

Questions

10 *Look back at your answer to question 6. What current flows when you get an electric shock? Is this enough to blow a fuse?*

11 *Do fuses protect people or equipment?*

What can protect us?

An electric shock is caused by 'a current going somewhere it shouldn't'. So we need a device which can detect that some of the current is 'leaking away'. This can be done by making something which can compare the current going out with the current coming back. Both currents should be the same if all is well (Figure 5). These devices are called **residual-current devices (RCD).**

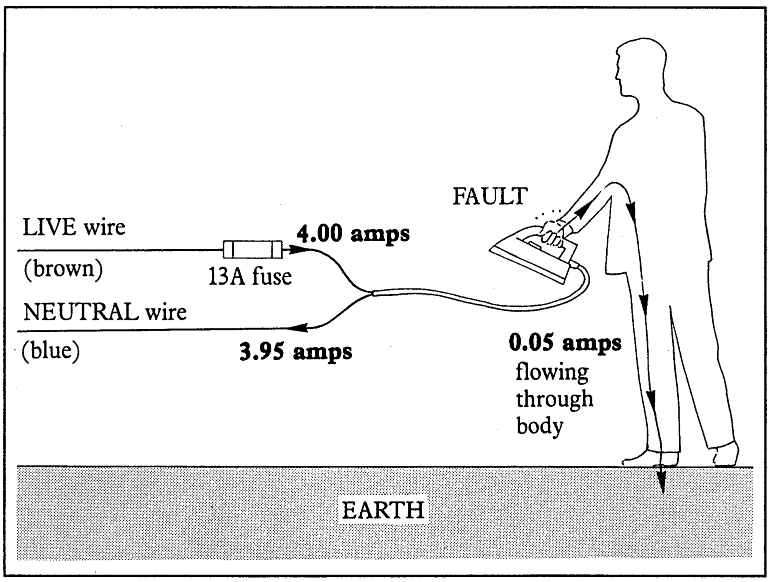


Figure 5 If a person gets a shock from an appliance there is a small current through his or her body to earth. This means that the current in the neutral wire is no longer the same as the current in the live wire. An RCD detects this difference.

Figure 6 on the next page shows the effect of different electric currents flowing for different times.

If you study Figure 6 carefully you will see that it is not just the current which is dangerous. The length of time is also very important. A residual-current device works by cutting off the current **quickly** enough to avoid danger.

An RCD is designed to cut off the supply quickly if the leaking current rises above a certain value.

Now answer questions 12 to 14.

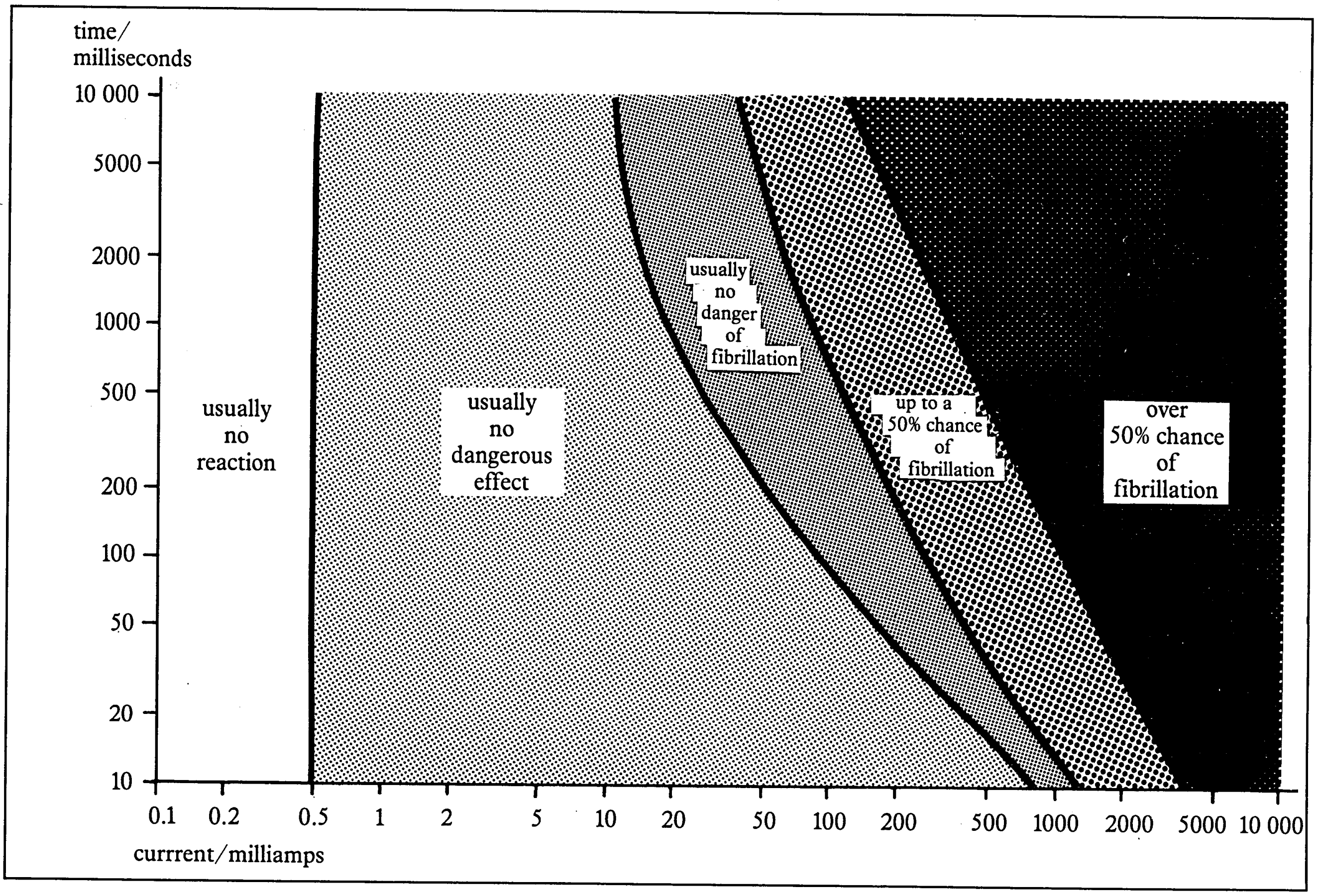


Figure 6 A graph to show how a.c. currents affect adults. This graph is for supply with a frequency of 50 Hz. The times are measured in milliseconds and the currents in milliamps

Questions

12 *A residual-current device is designed to cut off within* **x** *milliseconds when the current leak is greater than 30 milliamps. If you were designing an RCD what value would you choose for* **x**? *Use the chart in Figure 6 to choose a suitable value.*

13 *How do you think the chart in Figure 6 was drawn up ? Would you volunteer for the measurements? How could measurements be taken without risk to human life?*

14 *RCDs should always be installed in science laboratories. Why?*