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.

Author: Alan Attwood

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.

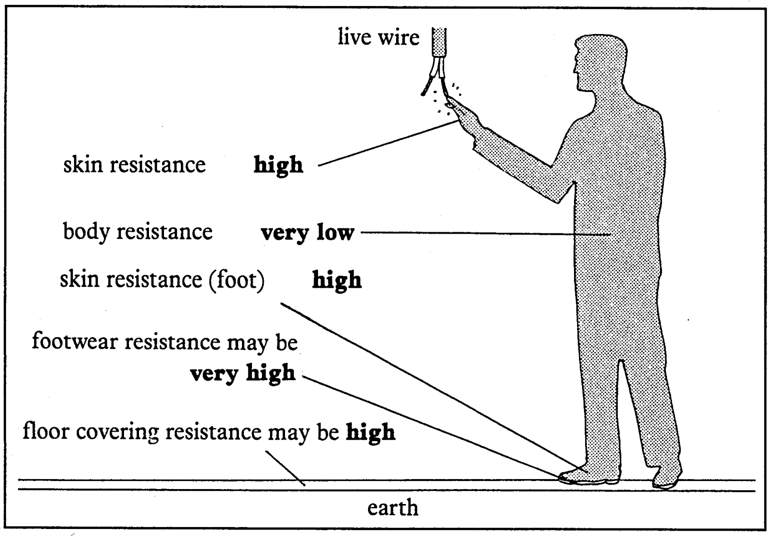


Figure 2

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?

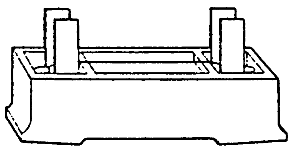
Fuses are included in electric circuits for safety. A fuse is a thin piece of wire which 'blows' if too big a current passes through it. When a fuse 'blows', the metal wire melts. This breaks the circuit and cuts off the current.

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.

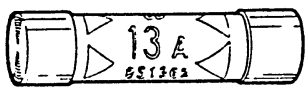
A 13-amp fuse must stay cool when the current through it is 13 amps. The fuse will only blow if the current is **much** bigger than 13 amps.

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).**

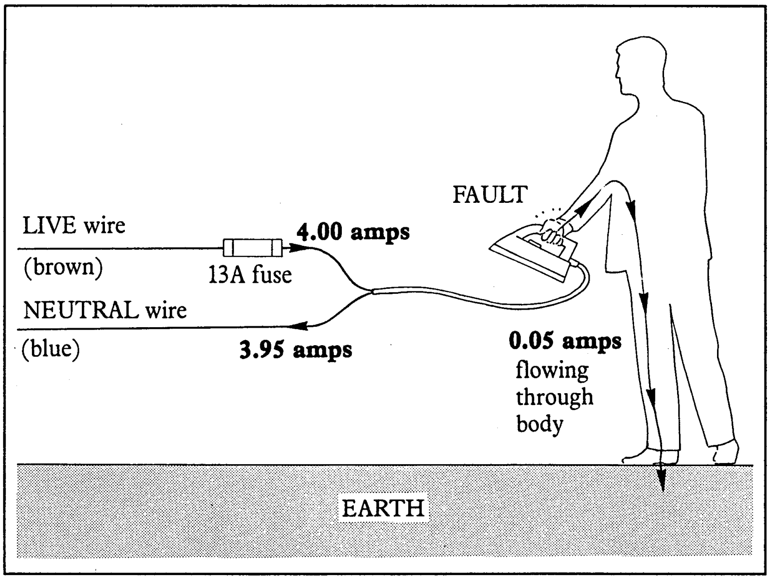


Figure 5 If a person gets a shock from an appliance there is a small current through his or her body to earth. This means that the current in the neutral wire is no longer the same as the current in the live wire. An RCD detects this difference.

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.

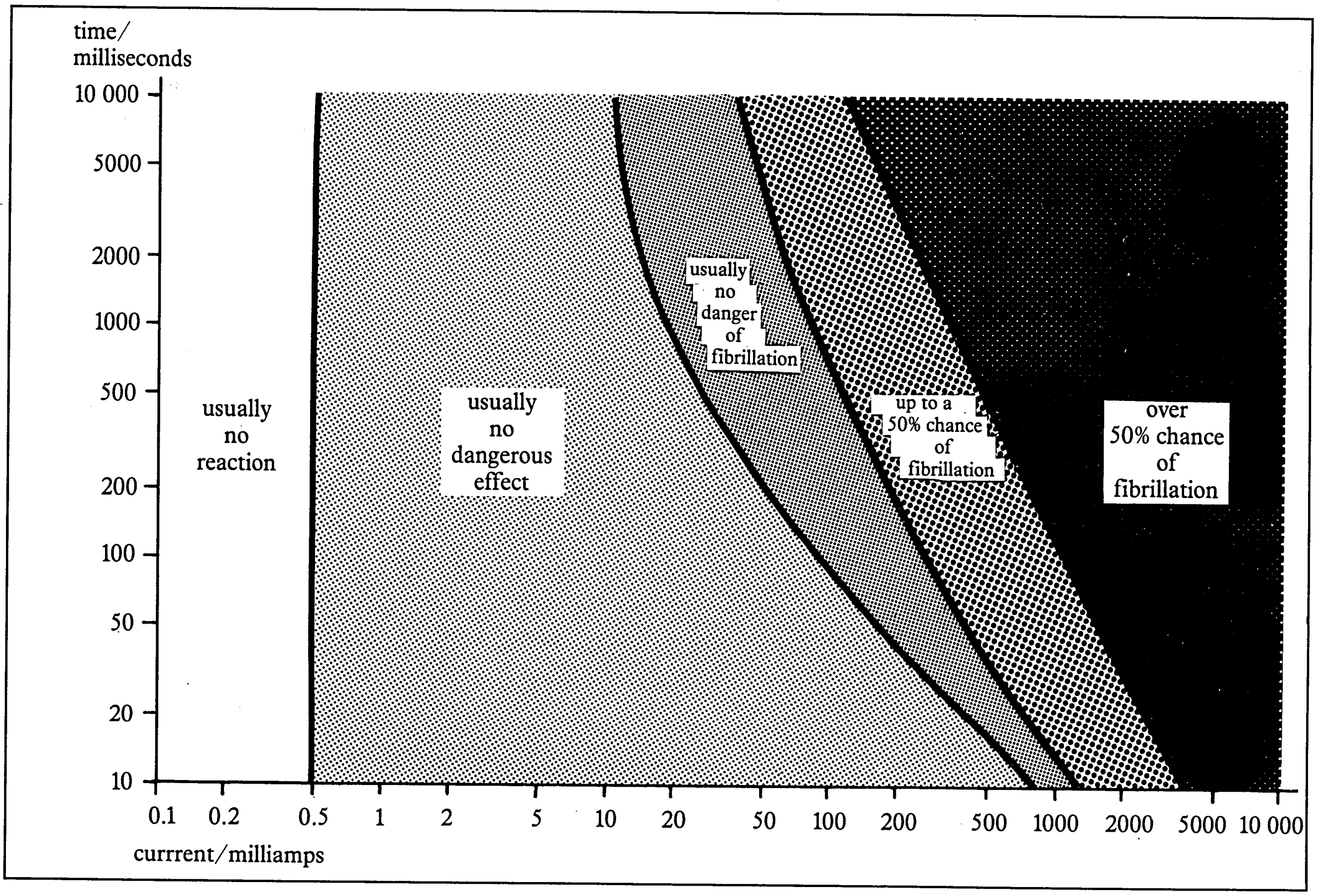


Figure 6 A graph to show how a.c. currents affect adults. This graph is for supply with a frequency of 50 Hz. The times are measured in milliseconds and the currents in milliamps

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?

Why 240 Volts?

Contents: Reading, information, questions and practical work on the choice of a suitable standard for the mains voltage.

Time: 2 to 3 periods.

Intended use: GCSE Physics and Science syllabuses. Links with work on electric power, and the heating effect of a current.

Aims:

- To complement work on electric power, current and voltage by developing a qualitative awareness of the practical significance of these concepts
- To provide an opportunity to plan and carry out a practical investigation
- To provide an opportunity to consider the balance between conflicting criteria in a context where there is no one 'right answer'.

Requirements: Students' worksheets No.1008. The requirements for the investigation are listed below.

Author: Alan Attwood

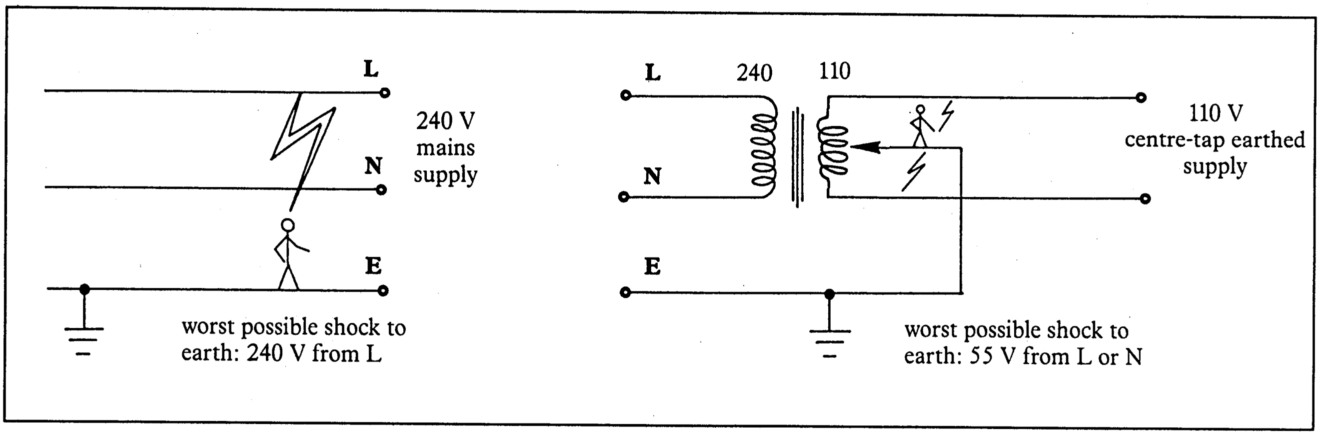
This unit is designed to follow No.1007, *240 Volts Can Kill.* It also complements unit 701, *Electricity in Your Home,* which helps to give students familiarity with the power requirements of various household appliances.

The unit is about voltage and current and the way they affect us, particularly in relation to the domestic electricity supply. There is a trade-off between voltage and current when supplying equipment with a specified power rating.

One approach to current electricity is based on Ohm's law and a constant resistance with current varying in proportion to the applied voltage. In practice the requirement is almost invariably for a stated *power,* with the current varying inversely with the supply voltage. The resistance is then chosen to match the requirements.

Introduction

The diagram below can be used to show why a 110 V centre-tap earthed supply limits the maximum shock to 55 volts.



When was 240 volts chosen?

It is easier to discover *when* 240 V was chosen as the standard than to find out *why* this particular voltage was chosen. The need for standardisation was clear. The general feeling of the supply authority was that voltages less than 200 V would cause too great a voltage drop in the cables along the street. The voltage drop is proportional to the current, which has to be higher to deliver the required power if the voltage is lower.

The original chaos of voltages arose from many companies all independently supplying electricity in competition with one another under no overall effective control. This kind of situation is often advanced as a justification for state monopoly over such concerns of national influence. It is possible that the electricity supply industry may once again become privatized; if so, it will be interesting to invite students to discuss the problems which may arise. Will we see a variety of supply voltages again?

What would a lower mains voltage mean ?

By filling in Table 1, students will find that for a given power rating the current must increase if the voltage is lower. This means that thicker cables must be used. Here there is an opportunity to compare the thickness of 5 A, 13 A, 30 A and 45 A cable, if samples are available.

Students can be asked to think about the practical limits to currents for portable appliances. What would be the dangers of having high-current cables trailing about the home?

If the mains voltage were lower, it might be possible to save lives by reducing the risk of fatal electric shock. On the other hand, the current requirements of all devices would be higher, and abuse of the system could lead to more fires when cables overheat.

Question 9 raises the possibility of having high and low voltage sockets. A high voltage device will not work if plugged into a low voltage socket. A low voltage device is likely to be damaged if plugged into a high voltage socket.

Investigation How does the voltage affect the efficiency of light bulbs?

Minimum requirements:

- low voltage, 12 V d.c. supply
- 36 W car headlight bulb in holder with leads
- 40 W mains bulb in holder with mains lead and plug (the wattages of these bulbs are chosen as the nearest readily-available equivalents)
- light meter

Students may be surprised by the higher light output from the low voltage bulb. The explanation raises many physical principles and provides an interesting topic for discussion at a more advanced level.

The trade-offs to be considered when reviewing the unit can be summarized as follows:

voltage : current
risk of shock : risk of fire.

Acknowledgement Figure 1 supplied by the Central Electricity Generating Board.

WHY 240 VOLTS?

Introduction

Why is the mains voltage 240 volts? Why not 12 volts, or 100 volts, or even 1000 volts?

We know that 240 volts is dangerous. It can kill. Yet 240 volts is used to supply electricity to our homes. Why? In America they use 110 volts.

On building sites, in this country, 240 volts is not used for portable tools because it is too dangerous. The supply is 110 volts. The supply is 'centre-tap earthed'. This means that it is taken from a transformer in such a way that the maximum shock to earth is 55 volts.

Answer questions 1 to 3.

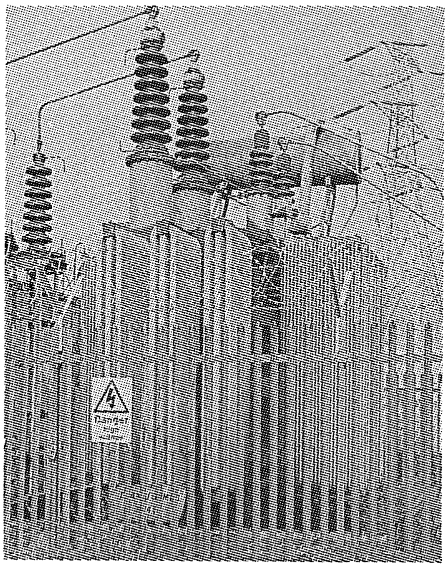


Figure 1 An electricity sub-station

When was 240 volts chosen?

The electricity supply industry was nationalized in 1948. Before that time electricity was supplied by many companies using different voltages. 100 V, 110 V, 200 V, 210 V, 220 V, 230 V, 240 V and 250 V were all used, and others too.

The new nationalised industry had to choose a standard voltage. There was a big job to be done. They had to modify many of the electric appliances in the homes affected by the change. So it was important to get the new voltage right.

There were reasons for wanting a high voltage, to avoid a large voltage drop along cables. There is a drop in voltage along a cable or wire because the cable has resistance. The voltage drops between the transformer in the street and the plugs in the house. This drop is more serious with low voltage supplies. Many experts thought that the drop would be too big if the voltage was less than 200 V. In the end they settled on 240 V, even though it is high enough to cause fatal electric shocks.

Answer questions 4 to 6 on the next page.

Questions

1 *Why do we seem more concerned to protect people at work than at home? Employers are expected to protect their employees by using a safer voltage. When they get home the same people are free to risk their lives with 240 V.*

2 *Try to find the voltages used by these devices: pocket torch; hand calculator; transistor radio; car; lorry; telephone; electric kettle; TV set; table light; street light; trains on the London Underground; trains on BR Southern Region and Mersey Rail; trains with overhead power lines.*

3 *Why do you think that different voltages are used for the various devices listed in question 2?*

Power

Each of the electric appliances we use has to have enough power to do its job. More power is needed by a washing machine than a razor. More power is needed by an electric fire than by a light bulb.

The size of the current taken by an electric appliance depends on its power and on the voltage. You can usually find the power (in watts, W or kilowatts, kW) printed somewhere on the appliance.

power (watts, W) = voltage (volts, V) × current (amps, A)

This formula shows that if the supply voltage is **lower** then the current has to be **bigger** to get the same power.

What would a lower mains voltage mean?

We might save lives if the mains voltage was lower because fewer people would be killed by electric shocks. One hundred people were killed by shocks at home in 1982.

However, if the supply voltage was lower, the currents in all wires and cable would have to be higher, in order to keep the same power. You can see the effect of working at three different voltages by completing the current ratings in Table 1. Work out the values using the formula:

$$\textbf{current (A)} = \frac{\textbf{power (W)}}{\textbf{voltage (V)}}$$

The formula is the same as the one in the previous section. It has just been rearranged.

The first row of the table has already been done as an example.

Appliance	*Power rating*	*Current rating at:*		
		240 V	110 V	12 V
Clock radio	9 W	0.04 A	0.08 A	0.75 A
Light bulb	60 W			
One-bar fire	1000 W			
Kettle	3000 W			
Electric shower	7000 W			
Cooker	10 000 W			

Questions

4 *What would it be like if we still had different household voltages in different parts of the country?*

5 *Why does it matter if there is a drop in voltage along the cables connecting transformers to homes?*

6 *Very high voltages (up to 400 000 V) are used in the cables of the national grid. Why is such a high voltage used?*

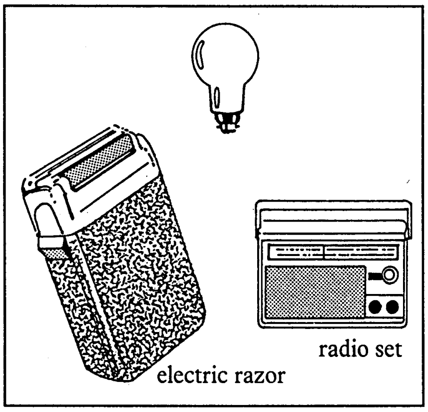


Figure 2 Low power devices

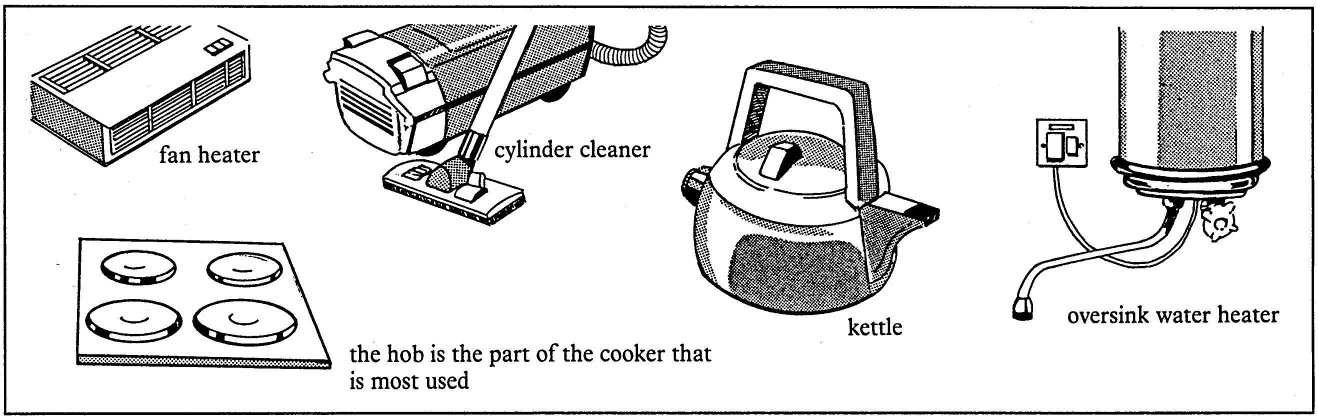


Figure 3 High power devices

An electric current heats up the wires it flows through. The bigger the current, the hotter the wire gets. There is more danger of cables overheating if the current is high. So higher currents create a fire risk. In 1983 there were 25 000 fires started by electrical faults in Britain. About 175 people died as a result.

To cut down the heating effect of high currents, thicker wires have to be used.

So if you have a lower standard voltage, like 110 V, there is a problem with high power devices. They take a high current, so they need thick cables. Thicker cables cost more, and they can be unwieldy.

One way round this problem might be to have a dual-voltage supply. Houses could be fitted with lots of low voltage sockets and a few high voltage ones. The high voltage ones would be used for high power devices like cookers and heaters.

Answer questions 7 to 9.

Questions

7 *What is the largest current which can be taken safely from a standard power point at 240 V? (Think about the fuse in the plug.)*

8 *Which of the appliances in Table 1 require a dangerously high current:*
(a) at 110 V
(b) at 12 V?

9 *Imagine living in a house fitted with high and low voltage points.*
(a) What would happen if you plugged a high voltage device into a low voltage socket? Would it be dangerous?
(b) What would happen if you plugged a low voltage device into a high voltage socket? Would it be dangerous?
(c) How could you make sure that people did not make these mistakes?
(d) Would it be inconvenient to have special sockets for high power appliances? How many special sockets would you need? Where would you choose to have them?

Investigation How does the voltage affect the efficiency of light bulbs?

Plan an investigation to compare the efficiency of different light bulbs. Which bulbs are most efficient at turning electrical energy to light?

Compare a 36 W car headlight bulb at 12 V with a similar power mains bulb at 240 V.

How will you measure the light output of the bulbs? How will you arrange to make a fair test of the different bulbs? What safety precatuions will you need to take?

Should we all install transformers in our homes to convert 240 V to 12 V so that we could use headlight bulbs? Would it be more efficient? What would be the other advantages and disadvantages of low voltage lighting systems?

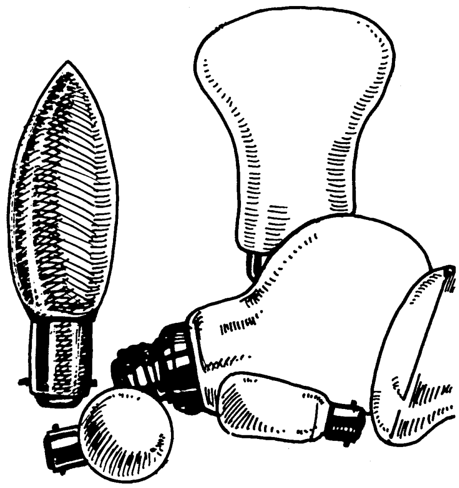


Figure 4

Further questions

10 (a) *What do you think is the* **maximum** *voltage for safety in the home? (If you have done the unit* 240 Volts Can Kill, *think about the questions you answered in that unit.)*

(b) *What do you think is the* **minimum** *possible voltage in the home? (Think about the currents needed by high power appliances.)*

11 *Imagine that you are an electrical engineer. You are in charge of a project to set up an electricity system in a country which does not yet have a power supply. What voltage would you choose for people's homes? Give your reasons.*

12 *How does your answer to question 11 compare to 240 volts? So now try to answer the question in the title of this unit:* Why 240 volts ?