Why Icebergs Float

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'Why do batteries go flat?' asked Sonya. This simple question launched an avalanche of further ones and began a long series of discussions about electricity. What’s inside a battery? Why are there three holes in a socket? Why doesn’t electricity leak out? What are volts and amps and watts? What is static electricity? How is electricity made? Little wonder there are so many questions, given the major role electricity plays in almost every aspect of modern life. There is the obvious setting of the household with its various devices and circuits. Then there’s the various types of communications apparatus – radios, TV, mobile phones – and all the electrical parts in cars, planes and ships too. Many biological systems are also electrical – that’s how nerves send their signals and muscles make their movements. The cosmos itself is electrical with its cosmic rays, lightning strikes and the Aurora Borealis (or Northern Lights). All these manifestations to contemplate before we even enter into what electricity actually is and where it comes from!

Amps and volts

Where should we begin? Perhaps the best way would be to establish what we already know from common conversation and everyday life. ‘Well, let’s see,’ said Sarah, rising to the challenge. ‘I suppose it must be something that flows. After all, we talk about electric current just like the water in a river.’ It does indeed flow; we know electricity has to move to get from the power station where it is produced to our homes, or from the battery to the screen of our mobile phones. Roughly speaking, then, an electric current is a flow of electricity even as a river current is a flow of water (though there are differences). The amount of water that flows through the River Thames at London Bridge is around
70,000 litres every second on average. This is a measure of the rate at which the water flows, and that’s basically what amps are about – they tell us how much electrical charge passes every second. ‘That’s a useful metaphor, which I can grasp,’ interrupted Mary, ‘but I am always baffled when anyone mentions the word “charge”. What exactly is it? It’s what puts me off electricity – whenever the word comes up I just lose the plot.’

That question is as deep as it is simple, and we’ll tackle it further on. For now, let’s just get a picture in our heads of electricity as something that flows. The rate at which it flows is the current, and that’s measured in amps. The tiny current in our mobile phones is just a few thousandths of an amp; the massive current passing from pylon to pylon through the overhead cables might run to hundreds of amps. Just one hundredth of an amp passing through your body will give you enough of a shock to make your muscles contract.

‘OK’, we might say, as Julie did cautiously on one occasion, fearing a torrent of technical terms, ‘why do you need volts then?’ This fundamental question brings us to the next important idea about electric current – its power. It is this that really matters for most practical purposes, not just the rate at which it is passing by. A torrent cascading down a mountain and a leisurely river meandering across a plain may each be moving a thousand litres of water every second, but the torrent would have greater strength. This is the reason why early water mills were usually located in hilly regions. They powered the machines of the early industrial revolution. The greatest power in a river comes from fast flow combined with a sharp drop in height. We might have noticed this at home. Sometime the taps higher up a house are less powerful than those at the bottom because there’s less of a drop from the water tank in the roof space. Bathroom showers can sometimes be rather weak because there’s not much of a drop from the tank that is supplying them.

Similar considerations apply for the power of electricity, which depends both on the flow and the ‘drop’. Current is the flow and voltage is the ‘drop’. Imagine a water mill: the drop in height from the feeder stream to the wheel is like the voltage. Increase the drop and you increase the power of the turning wheel. The power of the wheel would also become greater if the rate at which the water was flowing (the current) were to increase. The AAA battery used in many mobile phones is rated at 1.5 volts, which means there is a ‘drop’ of 1.5 between its two ends. When we connect the battery to our mobile phone, a drop of 1.5 volts is created across the phone. If it uses two batteries, a drop of three volts is created.
So much for batteries and low power devices. Significantly more power is needed for our dishwashers or vacuum cleaners because they have motors to drive. For this, the electricity that comes through the mains – the sockets in the wall – is needed. This comes at a much higher voltage – like having the water tank much higher above our shower. We’d get more water flowing per second and it would hit us more powerfully. In the UK it is agreed that the standard voltage of the mains is 230 volts. This latter point struck the discussion group as bizarre. ‘Are you saying that voltage is matter of choice? Is it up to governments to decide?’ asked Malcolm. Dominic, a former international journalist, recollected: ‘I thought it was 240 in the UK and 110 or something in the USA’. ‘Yes’, added Sonya, on a more practical note. ‘I have never been sure whether my hairdryer will work if I take it to France.’

It’s true that fixing the level of the mains voltage is ultimately a political decision. In the UK it used to be 240 volts and now is 230 volts as a result of EU harmonisation, while in the USA it is 120 volts. It’s not really the voltage that matters for practical purposes, however; it’s the power the electricity delivers that counts. As we have already concluded, the power is a combination of the flow and the drop – more precisely, the current and the voltage. So, to get enough power for your house, electricity could come at a higher voltage and lower current or the reverse – it’s a matter of choice. The UK system has a higher voltage so the current is lower. Once a country has adopted a standard it must stick to it, however, as all electrical equipment has to be manufactured to that standard.

What matters from a practical point of view is the power rating of an electrical device, rather than the current or voltage. The electric motor in your washing machine or vacuum cleaner needs a certain amount of power to work properly. The power is measured in watts. A light bulb may operate at 60 watts (60W) for a medium light or 100W (for a brighter one), for instance, while your washing machine may require 500 watts of power from the mains. If you want to try some simple maths, the power is simply the voltage multiplied by the current. If your mains electricity at 230 volts lights up a 100 watt light bulb, the current must be 100 divided by 230. In other words, 0.43 amps.

**Static**

Another common experience of electricity is static electricity. This type can give us a bit of shock when we point our fingers at an object such
as a door handle in a dry room. ‘Yes, I’d heard that in hospitals they have chains running from trolleys to the floor to prevent static electricity building up. Is that right?’ queried Mary. ‘I’d heard that it makes the electricity run down to the Earth, by-passing the rubber wheels,’ Malcolm recalled. We may notice static electricity in other places; for instance, people with fine hair may find that it doesn’t settle down when they comb it because of the static charge repelling the hairs from each other. ‘Isn’t that why you sometimes get a crackling noise when you take off a nylon jumper in a dry room? It’s static electricity causing little sparks, isn’t it?’ Sarah added. The idea of static electricity leads us neatly into the next big question: what exactly is it that does the flowing when electricity flows? ‘Is it something physical? Is it charges or atoms or something abstract like energy?’ as Michelle put it. Nor should we forget Mary’s earlier question, which we haven’t yet answered: what exactly is charge, anyway?

The properties of static electricity were investigated and analysed long before people understood what charge was. This fact came as a bit of a surprise to the group. ‘How can you investigate something if you don’t know what it is?’ Rosie asked. On reflection, however, it becomes clear that this is very much what science is like: we play around with things, try out experiments, explore the unknown, well before we understand what is actually going on – that, indeed, is why we do it. In practice it’s full of uncertainties and partial understanding; very different from the impression of science as rigid, all-knowing and rule-bound that is so easily picked up. A classic example was Gregor Mendel’s research on peas in the mid-nineteenth century, which conceptualised the idea of a heritable factor long before people knew about genes or DNA.

Originally the most widely accepted idea was that electricity was a kind of fluid in metals. As with the even earlier theory of ‘caloric’, a supposed fluid that explained the flow of heat, this intuitive early model of electricity had to be abandoned when experiments disproved it. What we now know is that all substances are made of electrical constituents. More precisely, all substances are composed of atoms (under normal conditions) and the interior parts of atoms are electrically charged. The modern concept of an atom, developed in the early twentieth century, is of a tiny, hard nut of positively charged particles (called protons) sitting at the centre (called the nucleus), with an equal number of negatively charged particles (called electrons) existing around the nucleus. These negative electrons are spaced apart, far from the centre, and are normally held in place by attraction to the positive nucleus. Overall, atoms and the substances that are made up from them are perfectly neutral;
that’s because the amount of positive and negative charge in them is exactly equal – it balances out. A good thing too. It’s why ordinary things such as tables and chairs, people and planets are just there, sitting around in uncharged neutrality, rather than rushing around in a frenzy of mutual attraction.

However, in special circumstances some otherwise neutral materials can become charged. The plastic of a comb is one of these, and so is the polythene of supermarket bags. Have you ever been irritated trying to open up a carrier bag or bin liner, when both sides seem to stick firmly to each other? Some electrons from the atoms on the outer surface of these materials can be pulled off, leaving the material electrically unbalanced. A charged-up sheet of plastic can then attract a neighbouring piece. You can check this with a comb. Run it through your hair to charge it up, then bring it close to some small scraps of paper or hairs or dust. They are drawn to it.

So electric charge is carried by particles – usually electrons in the situations we are talking about now. It’s these electrons that flow in a wire or any piece of metal. A distinguishing feature of metals is that they have electrons in them that are permanently detached from the atoms they came from and are free to move around. They are buzzing around inside pieces of metal all the time, in random directions, getting nowhere. But, if we connect the two ends of a battery across a piece of metal, the voltage drop that we have applied makes the electrons everywhere in the metal drift towards the positive end of the battery. This flow is the electric current. It’s caused by the voltage drop that the battery provides. An AAA battery gives a 1.5 volt drop and causes a certain level of current to flow; two batteries would give three volts and would double the level of current. The same goes for electricity from the mains, but in that case we are applying a much larger voltage drop of 230 volts.

‘OK, but you still haven’t told us what you mean by charge,’ Mary repeated patiently. She had noticed that plenty of people use the word freely, but when she had asked a friend what it actually meant he had no real idea – he had just picked up the word and got used to using it with his car battery and mobile phone. It’s not just to be awkward that I’ve delayed answering the question: it’s to avoid having to introduce too many concepts at a time. It’s easy to get confused or forget something mentioned earlier and then give up. Remember learning to drive: gear, clutch, brake, accelerator, steering wheel, indicators, mirror? To recap: the main idea we have now put in place is that electricity flows because charged particles (electrons in the case of metals) flow freely through
conducting materials such as the copper in a wire, when a voltage drop is applied across it.

Now we can tackle Mary’s question: it’s a fundamental one and, to some extent, philosophical. Charge is a property that we have invented to explain what we observe; it’s not a visible thing, such as colour, nor anything tangible, such as stickiness. It’s a concept that was developed in the eighteenth century to explain what happens when electrical substances are brought close together. Etymologically the word arose to imply ‘filling up with electricity’, in the same way as we might charge a cannon. The original substance was the precious stone amber (the Greek name for which, elektron, was adopted to name the particle). When a piece is rubbed with a cloth it becomes electrically charged. We can try the same sort of experiments today with bits of plastics or, better still, pieces of polystyrene foam used in packaging.

This observation alone shows there must be some kind of force acting between materials in this situation. But how can we account for the fact that this electrical force sometimes attracts and sometimes repels? After all, not every force is like this: a falling stone is always attracted towards the Earth, never repelled. So, although electricity was not well understood at the time, scientists came up with an ingenious theory to explain all this. They imagined the cause of the electrical force comes in two flavours; when they are both the same we get repulsion, when they are opposite we get attraction. They could have called these two flavours anything – ‘blue and red’ or ‘Fred and Ginger’ – but the names finally assigned were ‘positive and negative’. These names indicated that the ‘flavours’ were opposite to one another, in the sense that equal amounts of positive and negative charge cancel one another out.

So charge is an abstract concept used to explain electrical force: the greater the force, the greater the charge that is causing it. Charges of the same type repel each other; unlike charges attract each other. There just isn’t any more tangible idea of what charge is; it’s a fundamental property of the particles of which matter is made that helps to explain electrical forces. I suppose the same applies more widely, for many concepts we use every day. What actually is gravity, for example? These are all abstract concepts introduced to make sense of what we observe.

Electronics

There’s another aspect of electricity that we’ve all become aware of in recent times, even though its meaning is not widely understood. Sarah
captured this when she asked, ‘What is the difference between electricity and electronics? Sometimes we’re talking about gigantic cables and pylons that can kill in an instant; then the next minute we’re talking about some tiny battery in a hearing aid that wouldn’t hurt a fly.’ It’s true, there are two quite different worlds from the everyday point of view: the world of ‘big’ electricity, where it’s the power that matters, and the micro world of electronics, where it’s information and control that count. Electricity macro sense began to be explored systematically in the eighteenth century, but the world of electronics only opened up in the early twentieth century after the discovery of the electron. Fortunately from a scientific point of view (and an educational one), exactly the same concepts are involved, and the same terminology and units as well.

Put simply, to light up our living rooms, heat up our irons or turn the motor in our vacuum cleaners we need quite a bit of power. One bulb needs 60 or 100 watts; so a few lights and a machine or two switched on means you typically need thousands of watts of power (called kilowatts, kW) to supply your needs at home. But to power up a mobile phone takes less than a single watt. The main job of an electronic device such as a computer is to send tiny bursts of current round circuits to represent numbers and codes for instructions. These minute bursts are controlled using transistors that are embedded in tiny pieces of silicon – the so-called ‘chips’. The small amount of power needed in these devices is mainly used to light up a screen, or to activate a loudspeaker or cooling fan.

‘Can we pause for breath here?’ suggested Mary. ‘We’ve covered a lot of ground; can we recap? Am I right: you’re saying that it’s the volts that drive electricity round a circuit and the amps that tells you how much is flowing past at any given time?’ She was right: that’s the broad picture. Don’t forget that it’s the power that counts for most purposes in the home, and we get that by multiplying the amps and the volts. For example, if the power rating of your cooker is 2000 watts and the voltage of mains electricity is 230 volts, the current must be 2000/230, i.e. 8.7 amps. This is useful when we need to work out which fuse to buy for a plug. ‘Hang on, hang on a minute,’ cried Julie, vigilant as ever for any new concepts slipped in unannounced. ‘What’s a fuse? What does it do? They lie around the house and occasionally one needs replacing. What’s going on there?’

Good question: it illustrates another important feature of electricity, as well as being of practical importance. The original meaning of the word fuse is to melt. In electricity it’s used to protect valuable equipment that could get burned out accidentally and to prevent electrical
fires in the cabling. If, by misfortune, an excessively large electric current were to pass through a device, say a washing machine, it could heat up the wires so much that they melt, destroying the interior workings. This time it was Sonya’s turn to raise a follow-up query. ‘Why should the wires heat up when a current flows through?’ Another fundamental issue had been opened up.

**Resistance and heating**

The answer is that, to some extent, everything that carries an electric current also offers resistance to it. It’s rather like a cyclist travelling along a road or a parachutist falling through the air: there’s friction or air resistance opposing them all the way. You have to overcome that, or at least balance it, to make progress. In a similar way there’s resistance to the flow of electricity. You may have noticed that overcoming resistance often has the effect of heating things up; think of when we rub our hands together or sandpaper some wood. It’s the same with electricity passing through a wire or any other conductor (apart from the very special case of ‘superconductors’). As the electrons move through the wire, they collide with the atoms of the metal – past which they have to travel, rather like a ball passing through a pinball machine. Some of the energy of the moving electrons is transferred to the atoms of the metal, causing them to jiggle about more – it’s this movement of the atoms that we experience as heat. We may have noticed this heating effect with our computer or mobile phone.

Getting back to our washing machine (or any other electrical device), the wires inside will offer resistance as a current flows around, but under normal conditions the small amount of heat this generates will easily dissipate. But if by some accident two bare wires were to touch, the current might suddenly surge, causing them to heat up sufficiently actually to melt. This could wreck the motor or even the entire machine. The job of a fuse is to melt first in any accidental situation where the current gets too high, before the precious machine does. By melting before the wires in the electric motor do, the fuse breaks the circuit, stops the current flowing and saves the washing machine.

We therefore need to choose a fuse that allows enough current to our washing machine, but not too much more. In the example above, the current was 8.69 amps, so we need to choose a fuse that allows this amount of current to pass, that is, a 13 amp fuse rather than a 3 amp one. These are the type of fuses that you buy in a shop and insert in the
plug attached to an appliance. If a piece of electrical equipment fails to work, it may be simply that the fuse in its plug has blown. If this is the case you can test the fuse by seeing if it works in the plug of a different device, such as a table lamp. There are also fuses that protect your mains or lighting circuits as a whole. These are the ones that can plunge your whole house into darkness if they blow. Nowadays many homes don’t have a central fuse box. Instead a box full of ‘trip switches’ operates to cut off the current if it gets too high by accident. This saves us having to replace a fuse.

The mains

‘I’ve got a simple question,’ interjected Sarah at this point. ‘I don’t know if it is relevant, but what are the three holes in an electric plug all about?’ Once again, an apparently simple question opens up an important scientific issue: where mains electricity comes from and how it gets to us. It also raises a point about the different ways in which electricity can move. Up until now we have talked about electricity moving in a circuit, meaning that the electrons flow round from point to point in an endless loop. On the way they pass through the battery that energises them and the various switches and devices in the circuit, such as a light bulb or a screen or a motor. They activate the device as they pass through – light up a bulb, spin a motor or whatever. This is how a torch or mobile phone works, for example, with the electrons driven by the voltage drop between the two ends of the battery.

But mains electricity doesn’t move in the same way. There’s no battery. Instead a large and powerful generator in a distant power station spins around at great speed producing a voltage. This voltage is not steady like a battery; instead it rises and falls regularly. A bunch of wires spinning in a generator in the power station rushes past a giant magnet 50 times a second. It is the interaction between these wires and the magnet that generates the voltage. The voltage not only rises and falls as the generator spins, but actually reverses every half turn. This alternating voltage gives rise to an alternating current which is depicted in the graph (Fig. 16.1).

As the graph goes from positive (above the line) to negative, the current reverses direction. One minute it’s flowing to our homes, the next minute it’s flowing back the opposite way.

‘I’m not sure if I get what you’re saying, but it does sound pretty ridiculous,’ intervened Julie, keen to grasp this bizarre world of
alternating current. ‘It sounds as though the power station is sending out a load of electricity and then you’re just sending it back again, all in a fiftieth of second – what’s the point?’ It’s true that this is what is happening to the electrons in the wires that run between the power station and our homes – they really are shuffling back and forth 50 times each second. But what such a description misses out is what the electrons in the wire are doing in this rapid hokey-cokey. If they are passing through a heater, for example, they are heating it up as they pass back and forth, just as much as if they were passing through continuously in one direction only. Think back to the analogy of sandpapering a piece of wood. As the movement goes back and forth, heat is generated with each stroke, regardless of the direction. The same goes for anything else the current may be passing through: a light bulb, a motor or a computer screen, for example.

‘Wait, wait, wait, Andrew,’ Julie cried out, expressing understandable disbelief. ‘Are you really saying these blessed electrons have to travel maybe hundreds of miles from the power station to your house 50 times a second – it’s crazy!’ I remember this foxing me when I was first told about alternating current at school. Later I was shocked to discover that this is not at all what happens. In turns out that electrons merely drift along a wire at extremely slow speeds – less than 1 mm per second typically; they don’t rush by as you might reasonably expect. ‘So how do they get all the way from the power station then, if they’re so slow?’ persisted Julie. The answer is that they don’t. What I had forgotten when
I first encountered this strange fact was that the wire is absolutely chock full of electrons all along its length, not just at the start in the power station.

Imagine an oil pipe completely filled with oil. As soon as we push some oil in one end, some more oil pops out the other end. It just moves a bit all along its length. So when the power station creates a voltage drop along the wire, all the electrons move together one way, then they all shuffle back the other way, 50 times a second. They don’t get far – a tiny fraction of a millimetre – but, just like sandpaper rubbing back and forth, they still have their effect on your light bulb or washing machine motor.

‘To get back to my question: what’s all this got to do with the three holes in the plug in my kitchen wall?’ insisted Sonya. First of all, a slight correction: it’s the socket in the wall, not the plug; the plug is what you put into it. More importantly, we now can understand what the so-called ‘live wire’ is (the brown one in the UK). This is the wire that connects your socket directly to the power station, through all the cables under the street and up in the air. This single wire connects the voltage that’s rising and falling 50 times a second at the power station to your socket. It’s live, it averages 230 volts and it’s dangerous – not to be touched. But for the electrons to rush backwards and forwards through your washing machine or bedside lamp 50 times a second there has to be a reservoir for them to empty into temporarily, 50 times a second. The entire earth acts as this reservoir. So, as the voltage from the power station rises and falls, it pushes the electrons back and forth at every point along all the wires from the power station to your washing machine and on into the earth. So the earth acts as a gigantic pool, taking in electrons then sending them back, 50 times a second.

To make this happen, there is a second wire in the socket, called neutral. This has been connected to the earth, literally, somewhere around your home. ‘You mean there is a wire actually stuck into the ground?’ Yes, seems strange, doesn’t it? It may be some kind of a spike that is driven into the earth, with a wire attached to it. Or the wire might be attached to a metal pipe used to bring gas into our homes that goes underground.

Reverting to the original question, we now see that one hole in the socket brings the wire from the power station (the ‘live’ wire), while another is connected to the earth locally (the ‘neutral’ wire). These two are the lower two holes in the socket. ‘OK, so what’s the third one for – you don’t always have three abroad, do you?’ Sonya asked. It’s true, not all countries use three wires. In the UK the third hole in the socket links to another wire that ends up in the earth, but it has a completely different
function to the neutral one. It’s a safety extra. When a radio, hairdryer or kettle is made, any outer metal surfaces that we might touch are connected to the third prong on the plug, called earth (or ground in some countries). This means that, if something went wrong and the outer surface of the device accidentally became live, it would just connect straight to earth (Fig. 16.2). This way, if we were to touch it, the current would barely pass through us, going along the easy route direct to earth instead. We would be spared a dangerous shock. The third hole is thus only used to protect us, in the very unlikely case of a device accidentally becoming live.

**Conclusion**

This foray into mains electricity – the sockets in our homes, the power station, the flow of alternating current – has introduced a plethora of concepts about the basic nature of electricity: electrons moving along a wire, the resistance they encounter, the generators that create the voltage to push them, and more. It proved more than enough for one discussion session, but still left many more questions hanging in the air. Mary wanted to know what all this has got to do with the way our nerves work. ‘They’re electrical too, aren’t they? Are they like wires linked up to batteries?’ ‘How do batteries work, anyway?’ interjected Sarah. ‘They’re completely different to mains, surely. After all, they run down after a
while.’ ‘Car batteries are filled with acid, aren’t they? Why’s that?’ asked Michelle. ‘What about those birds you see perched happily up on overhead cables – surely there must be thousands of volts across their bodies?’ And so the questions continued to flow. We’ll have to leave these and others (‘What are electrolytes?’ Sonya queried, in a last ditch attempt) to another occasion. There’s plenty more to talk about, but at least we’ve covered some of the basic concepts in this chapter. They should help you make more sense of some of the electrical mysteries you encounter in everyday life.

Electricity, like many aspects of energy, crops up as a topic in almost all areas of science. It is a central topic in physics, but is also key to understanding reactions in chemistry and the nervous system in biology. This is typical of many of the most fundamental concepts in science. The work of a professional scientist regularly crosses the boundaries of school subjects. A chemist may seek out a particular species of plant in search of chemicals for a new medicinal treatment. In so doing, she would find herself criss-crossing between botany, chemistry and pharmacology, quite possibly engaging with mathematics and computing in the process. Real life problems require multi-disciplinary responses.

What is true for the practising scientist also holds for us as ordinary citizens. Whether we are worried about a child’s illness or checking out a faulty heating system, we are more concerned about illuminating the problem than about confining ourselves to the subject matter of biology or physics. For this reason, conversations in a science discussion group that start from everyday concerns tend to range freely over the disciplines. What is more, they are just as likely to delve into the nature of behaviour and emotion as the structure of molecules or behaviour of pulleys. How we recognise faces, why we take risks, what makes us love our children are typical examples of issues that have arisen in discussion groups. With this in mind, the next chapter draws on a number of discussions that began with questions about behaviour. The intrinsic fascination of the topic led one group to arrange visits to a neuroscientist working in the field. She had been using the technique of functional Magnetic Resonance Imaging (fMRI) to investigate aspects of brain activity related to behaviour and emotion. We explore what emerged in the next chapter.