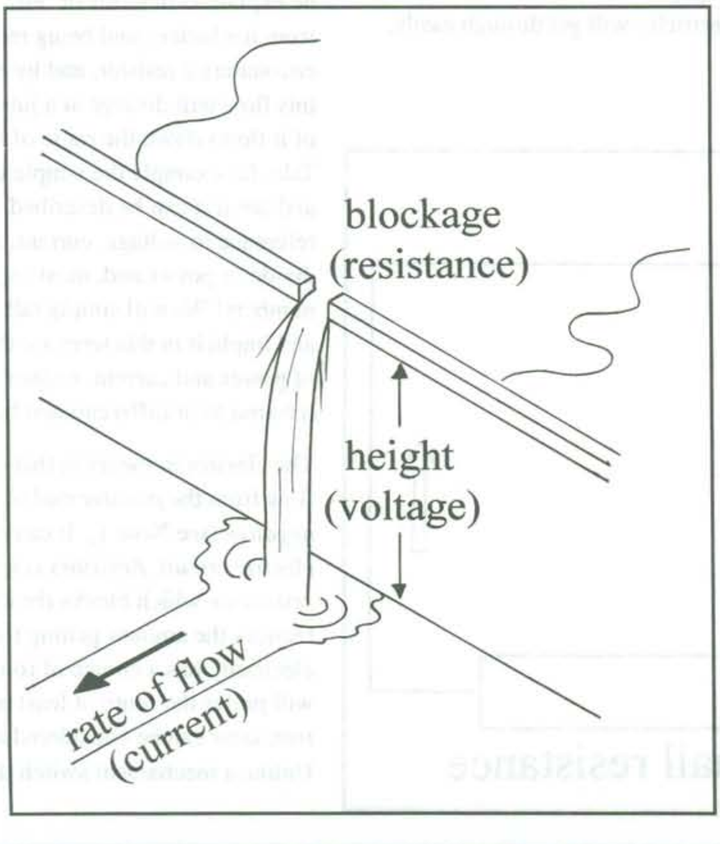
Voltless Electronics at Key Stage 3

Paul Jones

Ralph Allen School, Bath

For many students electronics seems abstract and confusing; Paul Jones suggests a simple way of introducing this area of technology to support work at Key Stage 3

Figure 1



According to the draft proposals for the National Curriculum for Technology, KS3 pupils will still be expected to carry out designing and making tasks involving the application of electrical and electronics control systems. For many teachers, however, the delivery of electronic design projects at KS3 presents something of a dilemma. Quantitative electronic theory would appear to be a fastidious and unnecessary extension of what is required by the National Curriculum, yet without some knowledge of electronic mechanisms, must often be restricted to prescriptive projects that give little experience of the nature of designing with electronics. Enthusiasm can thus be dampened for this important and powerful area of technology, and frustrations may arise when circuitry fails and the student is not equipped with sufficient knowledge to find and cure the fault alone.

Is it possible for students to understand and design elementary electronic circuits (and also carry out some fault-finding procedures) without being overwhelmed by complex and quantitative electronic theory?

■ Simplifying the problem

For many students problems begin when electronic circuits are explained in terms of the three dimensions of voltage, current and resistance. In some simple but important circuits, however, the voltage can be considered constant and the problem then becomes two-dimensional. The behaviour of the electric circuit can then be explained by imagining 'electricity' travelling around the circuit and by considering the diminishing effect of each resistance, in turn, on this flow. The term 'electricity' may, in later studies, when Ohm's law is introduced, be characterised as having both power and current. In our simplified case, however, these two quantities rise and fall with each other proportionally, and there is little need to differentiate between them.

It is important that the limitations of this sort of analysis are understood by the teacher in order to avoid applying it to inappropriate situations. There is, therefore, no escape for teachers trying to avoid grappling with Ohm's law themselves, because only a full understanding of this elementary principle can avoid them wandering unaware into areas where a simplification breaks down.

First of all, then, let's look at the basis and limitations of the 'voltless' simplification. In the analogy of a waterfall flowing from an infinite reservoir, the voltage (V) can be considered as the height of the waterfall (see Figure 1). The resistance (R) is the amount of 'blockage' at the top of the waterfall. The current (I) is the speed of the water hitting the ground. Ohm' s law (R=V/I) tells us that a measure of the resistance (or blockage) is the ratio of the voltage (height) to the current (speed of the water). For example, if the water is flowing away from the waterfall very slowly and yet the waterfall is very high, there must obviously be a very large blockage at the top.

If the height of the waterfall is constant, however, then the speed of the water hitting the ground varies *only* with the blockage at the top. In this case the power with which the water hits the ground will also only be affected by the blockage, rising and falling with the speed of the flow.

Similarly, in the electronic circuit, if the voltage is constant, then the problem becomes two dimensional, since any change in current can be explained in terms of a change in resistance. Also, the power will vary simply with current, being affected only by the resistance at that point. For many small, simple circuits this simplification can be justified and allows an explanation in terms of 'electricity'

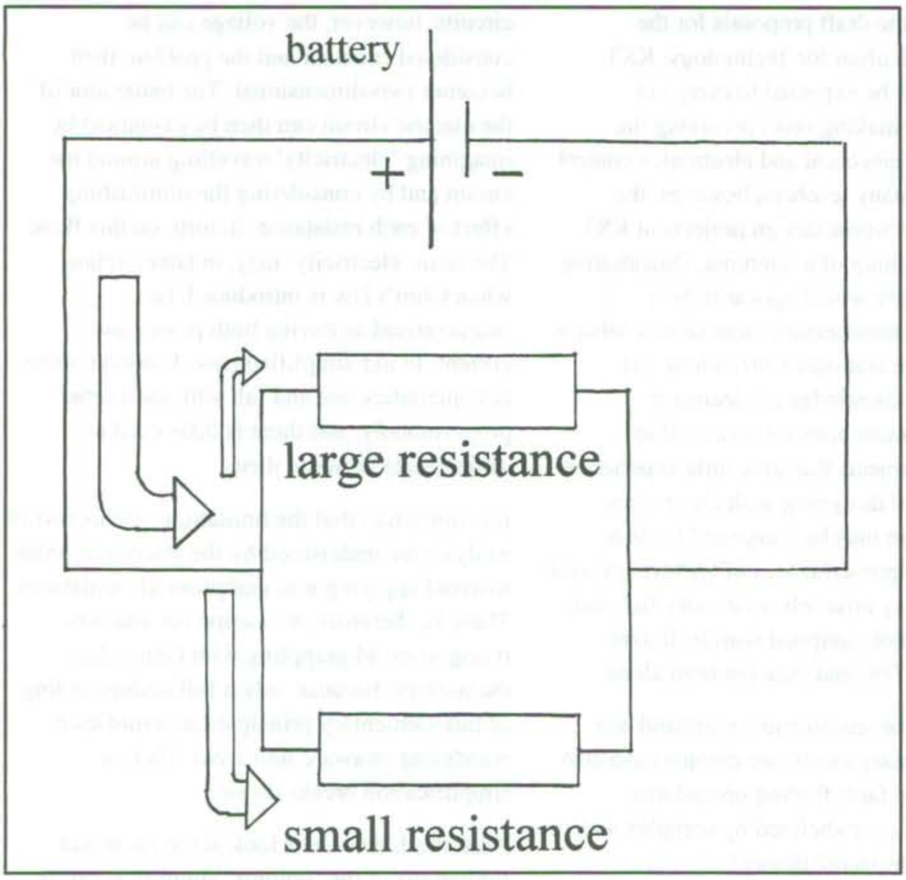
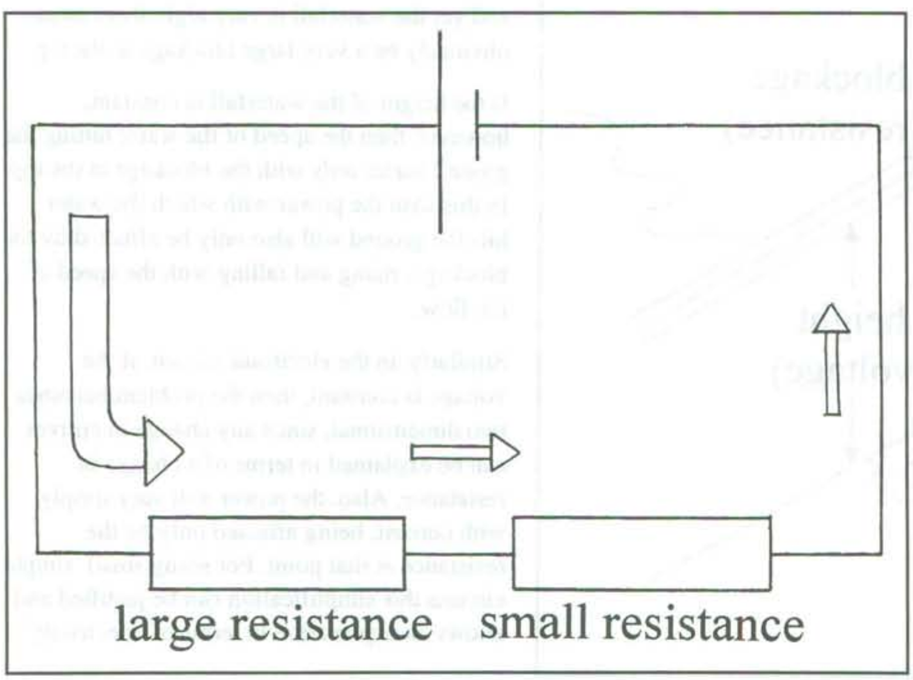


Figure 2

being reduced by blockages at each separate stage. In a parallel circuit (see Figure 2) one can say that the electricity prefers to pass through the path of least resistance, so most of it passes through the smaller resistor. One resistor may be very large (i.e. a large and serious blockage) but if the other resistance is small then electricity will get through easily.

Figure 3



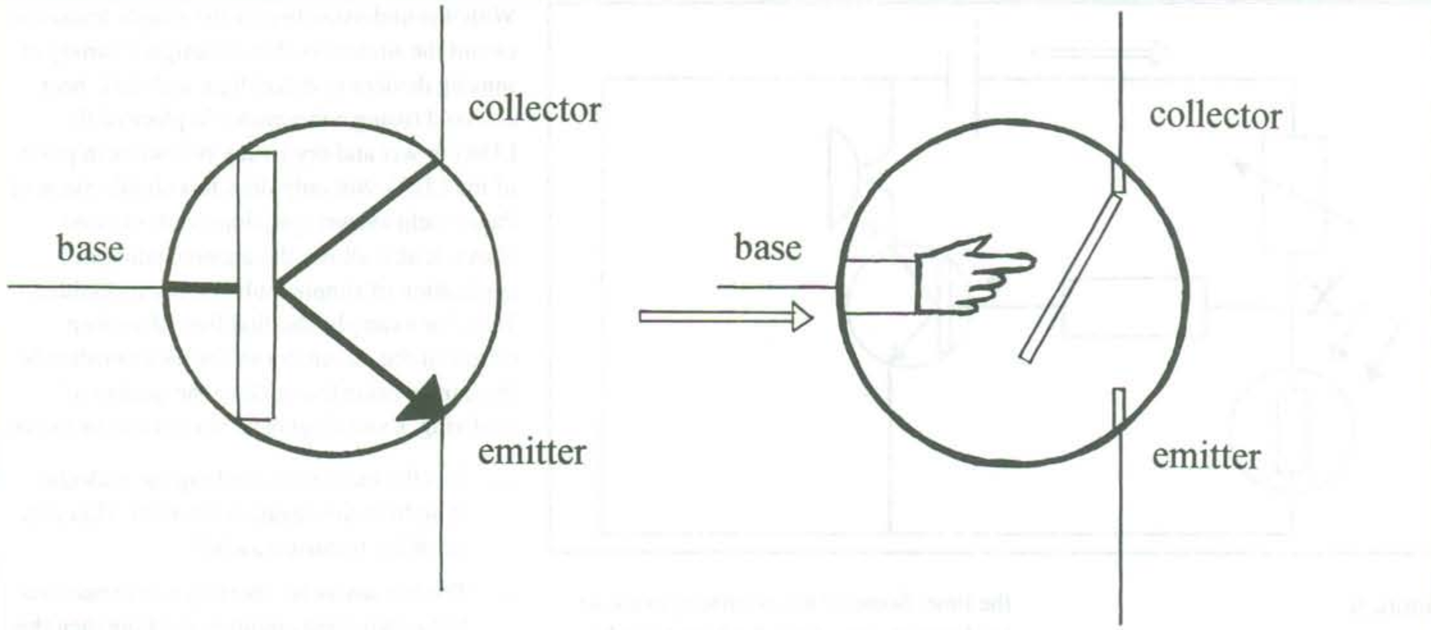
In a simple series circuit (as in Figure 3), the electricity that can flow through the circuit is reduced when either resistance is increased. It only takes one resistor to be very large and very little electricity will flow. This behaviour is in keeping with our simplistic idea about electric flow.

In this case, however, the teacher knows that the voltage of the battery is now split into two parts, one part of the voltage of the battery across each resistor. There may therefore be problems if you start considering the 'electricity' in each resistor separately. An inspired student may ask, 'If one resistor was set, how would you choose the other so as to maximise the amount of electricity in it?'. The 'voltless' student may suggest reducing it so that there is as much electricity flowing through the circuit as possible. The teacher who knows about volts will be aware that this is only true if we are discussing the current rather than the power, since these two quantities are no longer simply proportional to each other. (In fact, to maximise the power, calculus shows that the two resistors should be the same.) Here then, is a fundamental limitation to 'voltless' electronic theory: it should not be used where discrete voltage drops are a central issue.

■ A 'Voltless' transistor circuit

Many important simple circuits, however, can be explained in terms of 'electricity' flowing from the battery and being reduced when it encounters a resistor, and by emphasising that this flow will diverge at a junction so that most of it flows down the route of least resistance. Take for example the simple transistor circuit and see if it can be described without making reference to voltage, current, amps, potential divide or power and, most especially, no numbers! We will simply talk about electricity and implicit in this term are the two concepts of power and current, neither of which will be referred to or differentiated between.

The classroom theory is that electricity tries to flow from the *positive* end of a battery to the *negative* (see Note 1). It can only do this in an *electric circuit. Resistors* contain *electrical resistance* which blocks the electricity and reduces the amount getting through. When the electricity has a choice of route, the larger part will prefer the route of least resistance. The *transistor* can be considered as a switch. Unlike a mechanical switch that allows



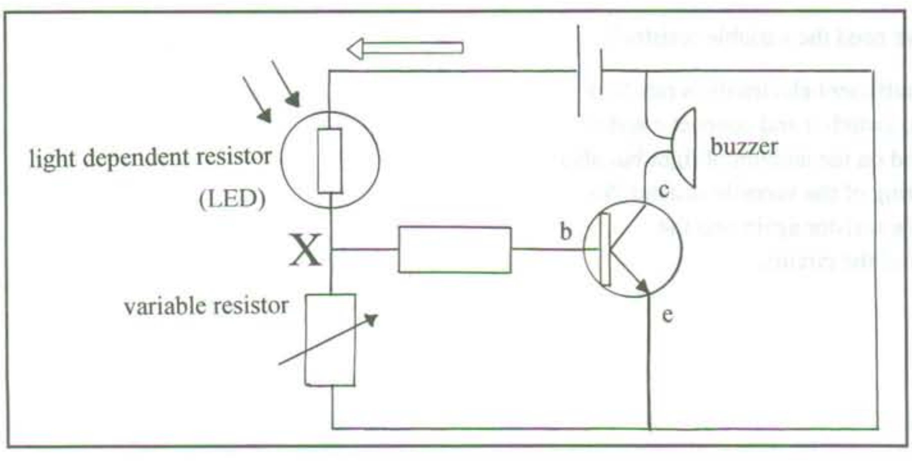
When a small amount of electricity reaches the base, you can think of an imaginary hand pushing a switch to connect the collector to the emitter.

Figure 4

electricity through when you turn it on with a finger, this electronic switch lets a large amount of electricity flow between the *collector* and the *emitter* when a small amount of electricity reaches the *base* (see Figure 4).

So, a transistor circuit can be considered as two separate circuits. The first provides an electronic signal to a switch which completes a second circuit.

Figure 5



■ Explanation of a light-detecting circuit

Electricity flows from the positive end of the battery through the LDR (light dependent resistor). If the LDR has a high resistance (i.e. it is dark) then the electricity is blocked there and nothing more happens (see Figure 5).

If the LDR has a low resistance (because there is some light) then electricity flows through it to junction X. It then has a choice. It can either go through the variable resistor OR go through the resistor to the base and switch the electronic switch connecting c and e. This completes the buzzer circuit. (So, for the circuit to turn the buzzer on in the light, the variable resistor must be turned up just high enough so that sufficient electricity prefers to go to the base and turn the transistor on.)

This explanation may throw up questions:

Q Why do you need the resistance of the resistor? Why not just connect the base straight to junction X?

A If there was no resistance at all then all the electricity going through the LDR would reach the base. Even the small amount of electricity that goes through the LDR in the dark would be sufficient to turn the transistor on, so the buzzer would be on all

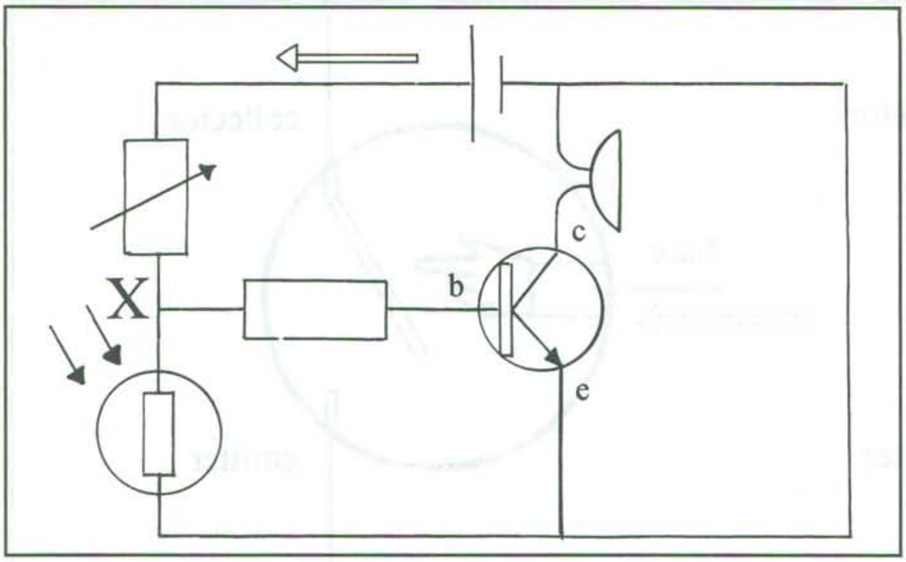


Figure 6

the time. Some of the electricity needs to be diverted away from the base to make the circuit *sensitive.*

Q Why do you need the variable resistor?

A Again, this would result in no choice at junction X, and even the small amount of electricity going through the LDR in the dark would turn on the transistor.

■ Explanation of a dark-detection circuit

The electricity flows from the positive end of the circuit and gets most through the variable resistor if it is turned down low (see Figure 6). It then has a choice. If it is light then the LDR resistance will be low, so most will flow through it and continue round to the negative terminal.

If it's dark, then the LDR resistance will be high and the electricity will be diverted through to the base in its attempt to find the easiest route to the negative terminal. This may, of course, switch on the transistor and sound the buzzer by connecting c and e and completing the buzzer circuit.

Q Why do we need the variable resistor?

A Whether sufficient electricity is reaching the base to switch it and connect c and e will depend on the amount of light but also on the setting of the variable resistor. So the variable resistor again sets the *sensitivity* of the circuit.

With this understanding of the simple transistor circuit the student is able to design a variety of sensing devices to detect light and dark, heat and cold (using a thermistor in place of the LDR) or wet and dry (using two wires in place of the LDR). Not only does this simple piece of theory help answer questions such as those above, it also allows the understanding and application of simple fault-finding procedures. Take, for example, the first light-detecting circuit: if the circuit doesn't work immediately then, in addition to checking the quality of soldering, some diagnostic checks can be made:

- Test the buzzer by touching the collector straight to the negative terminal. This gets rid of the transistor switch.
- Test the sensor by shorting its connections. If the switching circuit is working then this should feed the base with electricity and switch on the buzzer.
- Touch the negative end of the buzzer to the emitter. If the emitter is properly connected to the negative rail then this should sound the buzzer.

These are quite crude tests but they are a useful way of helping students to help themselves and at the same time gain a greater insight into the workings of the circuit. They also allow the teacher more time to teach by reducing time spent helping students diagnose faults.

Note 1: It is convenient in this case to talk about a positive flow of electricity flowing from the positive to the negative terminal. In reality, electricity is made up of negatively charged electrons travelling from the negative terminal to the positive, and science teachers often prefer this convention. There is no contradiction of course, since two negatives make a positive!

