Electronics

Teacher Notes for Sessions 3 & 4

Introduction

These notes provide background information about the practical work in the students' work book. If you are new to working with electricity/electronics you may find the work a little daunting; but fortunately it is possible to do all of the activities without having to know very much of the theory. Indeed, the students' work book avoids technical explanations of the various 'chips' that are used. This is for several reasons: first, students don't need to know what is happening inside to discover what the chips do; secondly, what is happening inside the chips is far too complicated to explain at school level. However, it is very likely that you, and some students, will want to know more than is written in the work book. The notes that are provided below are designed to give a basic explanation of how the circuits work without getting too technical and worrying about such things as the structure of semiconductors.

Please remember that D&D is a practical course that gives students theory on a 'need to know' basis, rather than treating knowledge/understanding of theory as an end in itself. Thus the 'theory' in these notes is not to be taught as part of the D&D lessons.

Also, experience shows that D&D works best when students work in groups, rather than as individuals. Do encourage them to share their ideas; e.g. in the brief revision of electricity, it is sensible for students to answer thequestions in their groups rather than on their own.

We begin with suggestions about timing of the various activities, followed by a revue of basic electricity. You will find answers to the questions posed in the students' work book on page XX.

Suggested timing of activities

It is in the nature of practical work with groups that some will complete tasks more quickly than others. For this reason not all students are expected to complete all activities. Also, the speed with which students complete the work will vary with their intellectual ability, and with the level of their manipulative skills. However, it is suggested that:

By the end of two D&D sessions, everyone should have completed the introductory work on electricity and activities 1 through 5.

It is likely that many students will comfortably complete these activities. It is then up to you to set them working on one (or both) of the two activities that remain. (Of course, if you have others in mind, feel free to use them instead.)

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Basic electricity
The key ideas that students should have met at Junior Certificate Science are those of current (I), voltage (V) and resistance (R). It is enough for them to know that voltage is a measure of the 'push' that a battery, power pack etc. has to move an electric current through a circuit. They should also have learnt about Ohm's law, which is usually stated in symbols as R=V/I.[1] However, what they aren't usually told that almost all the components in circuits that are of any use don't obey Ohm's law. This is especially true of components that contain semiconductors; e.g. light emitting diodes (LEDs), and 'silicon chips' of all kinds. For this reason there are no Ohm's law calculations (or any others) to be done in this module of work!

Indeed, when trying to explain how the circuits work it is best *not* to think about them in terms of patterns like 'a higher voltage will cause more current to flow' etc. Many of the circuits are best considered to work as switches, which are either 'on' or 'off'. A key idea that you will need is that the 'chips' the students will use are electronic switches that are switched 'on' or 'off' according to the *voltage* that is applied to them. For much of the time you will not need to think in terms of current (and certainly not in terms of resistance as defined in Ohm's law).

A point that sometimes troubles students is that it is possible to measure a voltage without a current flowing. In fact, the ideal voltmeter would have absolutely no current flowing through it. A good analogy here is with a car tyre pressure gauge at a garage. The gauge will only be accurate if there is no air escaping from the tyre. Similarly, if you put your finger over the nozzle of a water hose, you can feel the water pressure acting on your finger even though no water is flowing through the hose.

Another point, mentioned in the first page of the students' work book: for some reason students will persist in trying to describe electric circuits using phrases like 'the voltage goes through here', or 'the power goes in here', or 'the battery is not very powerful'. It is essential that such ideas are not reinforced (you may not be able to stop them entirely, but try to encourage students not to talk in such terms). Voltage does not 'go through' anything—voltage does not 'travel'; it is the current that travels through a circuit. However, we can talk correctly about measuring the voltage *across* a component, or about the voltage *at* a point. Think of an analogy with water pressure in a house: if water is fed from a tank in an attic, the pressure of water at a tap in an upstairs bathroom will be less than the water pressure at a tap in a downstairs kitchen. We could measure the difference in pressure, but it makes no sense to say that the pressure is flowing through the pipes: only the water (current) will flow.

Much the same goes for students' use of 'power'. For physicists, 'power' related to electric circuits has a very restricted meaning. It is one that need not concern us here, except to say that use of the term is best avoided. It almost 100% certain that if students do try to use 'power' to explain what is happening in the circuits then they will be wrong.

Finally, a last word about voltage, and batteries.[2] The 9V battery that we recommend of ruse in this module has one terminal marked + (plus) and another – (minus). If you use a voltmeter to measure the voltage between the terminals of a new battery you should find that it is near to 9V. However, please try to understand that this is a *difference*. Strictly we know nothing from this measurement about the *absolute* voltages of the terminals. For example, one could be at +20V, the other at +11V and the difference would still be 9V. Alternatively, if one were at +4.5V and the other at –4.5V, again the voltmeter would measure 9V. The circuit itself doesn't care about our conventions of assigning voltages; but it makes a big difference to how we explain how it works.

1. Actually, to write Ohm's law like that isn't strictly correct; but that is not too important here.
2. At this point physicists will have to accept that we are not going to develop the important distinction between voltage and potential difference.

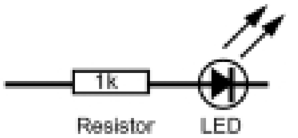
Electronics (continued)

It is best to use this convention: assume that (in spite of the label) the negative terminal of the battery is at 0V, and the positive terminal is at +9V. You will see later that another way of applying this convention it say that a voltage of +9V (or roughly 9V) is given the label 'high' and a voltage of 0V (or nearly 0V) is given the label 'low'.

Light emitting diodes (LEDs)
LEDs are found in very many devices in homes, and elsewhere. For example, almost any remote control for a television or video will have an LED indicator. More elaborate LEDs are being used in traffic lights, where they are arranged in rows/columns of individual lights rather than having one large lamp behind a coloured screen.

An LED has to be put in a circuit the 'right way round'. It has two leads: a cathode that must (eventually) be connected to the negative terminal of a battery, and an anode that must (eventually) connect to the positive terminal. Note: the anode and cathode does not have to connect directly to these terminals.

An LED will switch on only if the voltage across it is (in round numbers) at least 2V. If the voltage is less than that, it will not work. On the other hand, if the voltage goes up much higher, so much current flows through the LED that it will glow very brightly and promptly 'burn out'. For this reason, LEDs are often used in circuits in partnership with resistors. The resistor prevents too much current flowing through the circuit (or put in other terms, it stops the voltage across the LED going up too high).



Standard circuit diagram symbols for an LED with its protecting resistor

If you have looked at some of the diagrams in the students' work book, you will see that where LEDs are used there are no protecting resistors. the reason is that the LEDs that we recommend for use have such a resistor already built into them. Please note: it is most important that you do not use just 'any' LED in place of those that have been recommended for use. "Ordinary' LEDs can be used, but only if protecting resistors are used in series with them. (However, to include the resistors on a bread board makes life much more complicated, and is best avoided.)

CMOS Logic gates
The main 'chip' used in the practical work is labelled as '4093' in the students' work book. In fact the full description of this chip is that it is a 'Schmitt Quad, 2-input NAND CMOS logic chip, code number 4093B'. (Perhaps you can see why the shortened label is used!) Here is a brief explanation of what this chip does. We will take the various terms in the full title in turn, but in a different order.

CMOS
CMOS stands for 'complimentary metal oxide semiconductor'. It is one family of semiconductors that is very widely used in the electronics industry. The details of CMOS need not concern us except for one important point: CMOS chips are very hard to wreck because they can be used with a very wide range of voltages, perhaps as high as 50V. Likewise they are quite tolerant of varying sizes of current flowing through them. However, as all teachers now, nothing is student-proof, and if your students mess with the circuits that have been suggested they will surely find a way to 'blow' the chip. So, it is best to warn them of the consequences of doing other than is suggested in the activities.

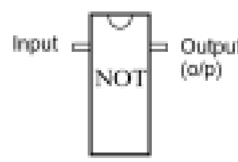
Electronics (continued)

On the other hand, it is always possible that a chip will cease to work through no fault of the students. (There is more about this point below.)

Logic chips and gates

Logic chips are generally found with either 14 or 16 'legs' or 'pins'. Two of these are used to connect the chip to the power supply. Just what the others do varies greatly with the specific chip. Let us consider a simple case of a chip that performs a NOT function: see the diagram and table below.

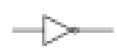
In the diagram opposite is shown a schematic diagram of a 'NOT' logic chip with just one input and one output shown (the connections to the power supply are omitted). If you were to connect the input to the positive terminal of, say, a 9V battery you would find that the output was about 0V. That is, a 'high' at the input gives a 'low' at the output. Similarly if you made the input 0V, the output would be near to 9V; i.e. a 'low' at the input gives a 'high' at the output. This pattern is shown in the table.



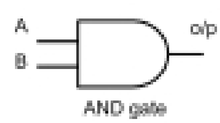
NOT Gate

A	NOT A
0	1
1	0

A circuit that works in this way is called a 'NOT gate', but typically the chip itself might have seven or eight pairs of inputs and outputs. The symbol for a NOT gate looks like this:



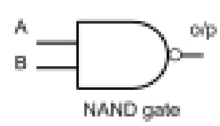
Now let us turn to a more complicated logic gate an AND gate. The pattern here is shown in the table opposite together with the standard symbol for the gate. The key thing about an AND gate is that the output is high only if the two inputs are both high.



AND Gate

A	B	A AND B
0	0	0
0	1	0
1	0	0
1	1	1

This brings us to a NAND gate. Essentially this is an AND gate whose output is put through a NOT gate. The outcome is shown opposite. Note the small circle on the output (as shown on the NOT gate above) indicates that the output has gone through a NOT operation.



NAND Gate

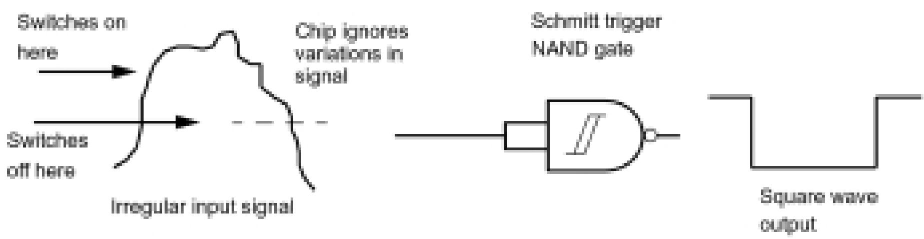
A	B	A AND B	A NAND B
0	0	0	1
0	1	0	1
1	0	0	1
1	1	1	0

Schmitt versions of CMOS chips

It is possible to buy 'ordinary' CMOS chips, but the Schmitt versions have advantages. Specifically, the output is 'cleaned' from any 'noise' in the input signals. The diagram below should give you a sense of what this means.

The two inputs are connected, so that the chip receives only a pattern of two highs or two lows. In practice the inputs can be used separately (as is the case with the students' circuits). Using the Schmitt versions of logic chips can help to make the circuits more stable and perform consistently.

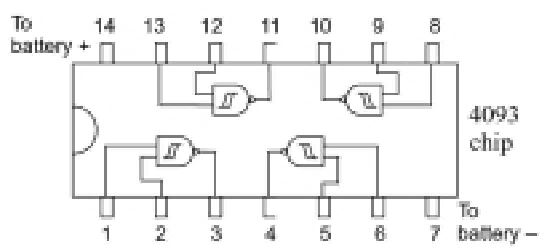
Electronics (continued)



A Schmitt trigger can be used to 'clean up' a signal

Code numbers
There is a wide variety of CMOS logic chips available. Every type has its own unique code number. For example, a 4049UB is a chip with six NOT gates, and a 40106 is its Schmitt equivalent. If you have to order logic chips from a supplier, it is essential to view the catalogue, and make sure that you order the chips using the correct CMOS number. (See later for information about suppliers of components.)

The 4093 circuitry
The 4093 has 14 'legs' or 'pins'. Two of them are used to connect the chip to the battery, the other 12 are used to make four NAND circuits, each with two inputs and one output. The arrangement is shown in the diagram opposite. The student activities only use the NAND gate using pins 1, 2 and 3. However, there is no reason why the other gates should not be used.

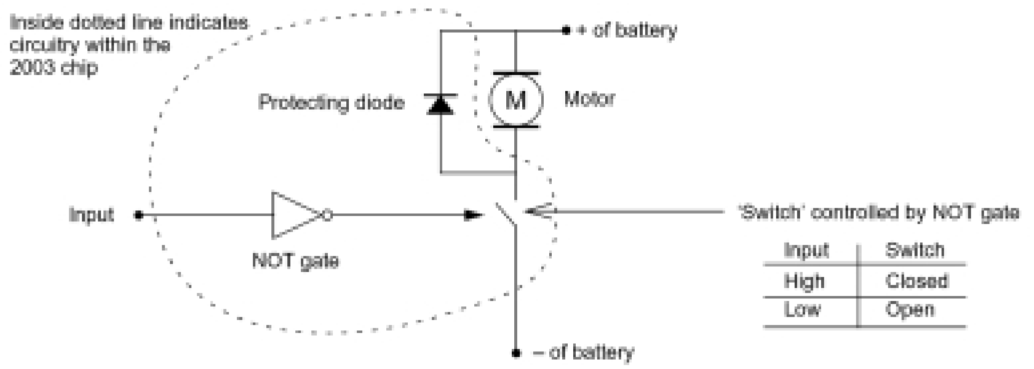


Indeed, if you find that a group's circuit is not working and you can't find any obvious fault with it, then the reason may be that the logic gate has ceased to work properly. It is worth getting the students to try one of the other gates instead. If that doesn't work either, then the entire chip may have 'blown' and should be replaced.

Using motors
Using electric motors with logic chips can cause problems. the reason is that whenever an electric motor switches on or off very high voltage 'spikes' can occur. They may last for only very short times (e.g. 1/10000th of a second), but they can be sufficient to 'blow' the chip to which the motor is attached. This problem can be addressed by using a diode in the circuit. However, even small motors can have relatively large currents flowing through them (say 0.5A), and most logic chips are not able to withstand such currents (well, not for long at any rate). For these reasons, motors should not be connected directly to logic chips.

One solution is to use a chip that goes between the motor and logic chip. Such a chip is the 'ULN2003A Darlington Array', given the code number 2003 in the students' work book. It has protecting diodes built into it, and is able to withstand currents up to 0.5A. This chip also has logic gates built into it so it can 'talk to' other logic chips. A simplified diagram illustrating the operation of the chip is shown below.

Electronics (continued)



The chip is designed so that a ‘high’ at the input causes a complete circuit to be made to the motor thus causing it turn on. Likewise, a ‘low’ at the input opens the (electronic) switch, which breaks the circuit and causes the motor to switch off.

Actually the 2003 has seven inputs (and outputs), so it could be used to control up to seven different motors (or other devices); but one would have to be careful not to exceed its maximum current rating.

Resistor colour codes

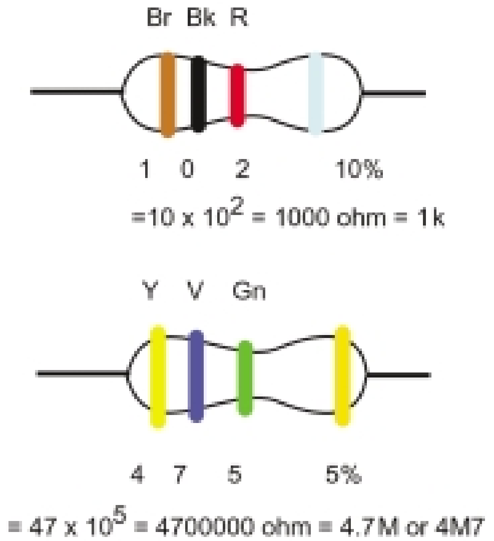
Resistors come in two series—4-band and 5-band. The 4-band are more commonly used in simple work. The 4-band code is as follows:

Bands 1 and 2 give the first two digits of the value; band 3 gives the powers of 10. The 4th band establishes the quality of the resistor—usually 5% or 10% in general purpose resistors. 5% shown by a gold band, and 10% by a silver band. The 4th band is separated from the others, which fact allows us to tell at which end to start counting from.

Resistors come in ‘preferred’ values; e.g. it is possible to buy a 1k, 1.1k and a 1.2k resistor, but not a 1.05k, or any other value in between the preferred values. You will find out the preferred values by looking in an electronics catalogue. Note that values can be written in two ways e.g. 2.2k or 2k2, 4.7k or 4k7, and so on.

In 5-band resistors, the first three bands are the digits and the fourth band gives the powers of ten.

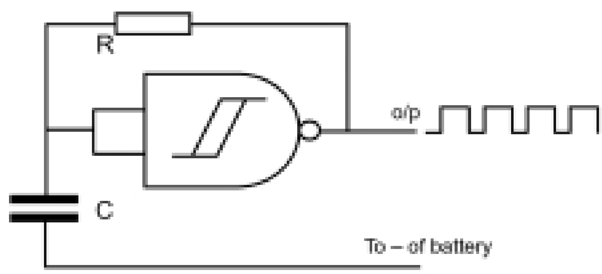
Colour	Value
Black	0
Brown	1
Red	2
Orange	3
Yellow	4
Green	5
Blue	6
Violet	7
Grey	8
White	9



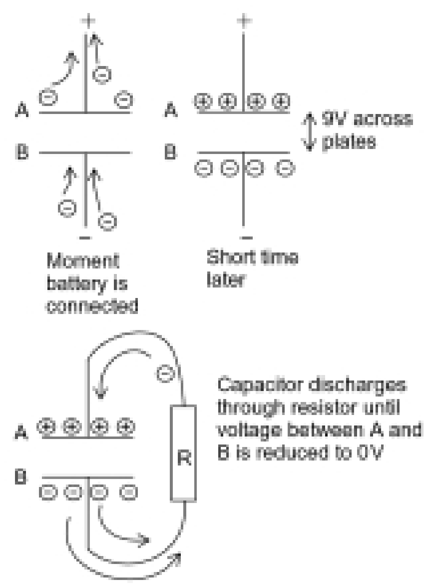
Electronics (continued)

Flashing LEDs

The circuit that some of the students might build to make an LED flash is really a simple pulse generator made from a Schmitt trigger NAND, a resistor and a capacitor. The circuit is shown opposite. The square wave is produced by the repeated charging and discharging of the capacitor through the resistor. Many combinations of resistor and capacitor values may be used.



To understand how the circuit works, you need to know a little about capacitors. Capacitors store charge. You can think of them as having two metal surfaces that are separated by an insulator. (However, the actual construction of capacitors is very different.) On its own, a capacitor will not be charged, so the voltage across its terminals will be zero. However, if you connect the terminals to a battery, one of the surfaces (labelled A on the diagram) connects to the positive terminal and one (labelled B) connects to the negative terminal. Electrons that are free to move on A will be attracted to the positive terminal of the battery, so will travel towards the battery. When they leave A, a positive charge is left behind. This positive charge will attract electrons on B, and from the negative terminal of the battery towards it. Eventually all the electrons that could move off of A will have done so, at which stage the process comes to a halt with a layer of positive charge on A and a layer of negative charge on B. Where there is a separation of charge there is a voltage difference, and you would find that if you were using a 9V battery, the voltage across the terminals of the capacitor would be 9V also.



In principle, you could disconnect the capacitor from the circuit, and the extra charge on A and B would remain until you connected a conductor between the two terminals. Then the electrons on B would rush round to A, and the capacitor would have discharged. The charging and discharging of a capacitor can be slowed down by putting a resistor in the circuit—here the resistor lives up to its name by resisting the flow of current.

The ability of a capacitor to store charge is measured by its capacitance, and is measured in ‘farads’. A capacitance of one farad, 1F, is in practice a very a large value, and in most work with logic chips etc. values of

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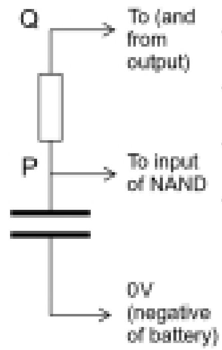
microfrarads (µF) and picofarads (pF) are more common (1 µF = 10 –6 F; 1pF = 10 –12 F). The larger the value of the capacitor, and the larger the value of the resistor in series with it, the longer it takes for the capacitor to charge and discharge.



	Start	Next	Then	And then
Voltage at Q	9V	1V	1V	9V
Voltage at P	9V, i.e. 'high'	starts to fall	reaches a 'low'	9V
Output of NAND	'low', say 1V		goes 'high', say 9V	'low', say 1V

Now, let us return to the circuit that uses the logic gate. Suppose the capacitor has become fully charged. Then the voltage at P will be equal to the battery voltage, 9V. This represents a 'high', so the output of the NAND will be 'low' (say 1V). But as soon as the output goes 'low', the voltage at Q will also be 'low'. The charge on the capacitor will then 'leak' out through the resistor and at the same time the voltage across the capacitor will fall. That is, the voltage at P will start to drop. However, when the voltage goes low enough the NAND gate will recognise that the input has gone from a 'high' to a 'low'. Then the output will immediately change in the reverse direction—to a 'high'. At once the current will flow from the output through the resistor to recharge the capacitor. The voltage at P will gradually rise to 9V again, and the whole cycle repeats.

The time it takes to charge and discharge the capacitor changes if the values of the capacitance and resistance are changed—higher values, longer times (and vice-versa). Students should find that a 1k resistor with a 1000 µF capacitor gives a sensible rate of flashing (1 per second or so), as does a 47k resistor with a 10 µF capacitor. A 1k with 10 µF appears to stay on permanently because the flashing is so fast; the 47k with 1000 µF may give the impression of not flashing because the delay is so long.

Using bread boards

It may be that you have never used bread boards before. If so, you may find the following 'hints and tips' useful. First, if the bread boards are new, it may be difficult for the students to get the wires to go into the holes because the connectors underneath are too stiff. The connectors can be eased by pushing one of the legs of a resistor into the holes that are found to be difficult to use.

On the other hand, if the same holes are used a great deal, the connectors can become quite loose. If this happens, the wires go in very easily, but may not make good connections. It can be necessary to 'fiddle' with the wires before a good connection is made.

Emphasise to the students that the bread boards should all be aligned in the same way (as shown in the photographs). that is, with the rows of five holes going vertically, and the long lines of holes (where the battery is connected) going horizontally. If they don't all use the same orientation of the bread board it makes it very difficult for them to build the circuits properly, and for you to check them if/when necessary.

Electronics (continued)

The wires connecting the battery to the bread board may become frayed after a few uses. If so, the plastic coating will need to be stripped back to revel more of the wire. If you are used to soldering, it can be useful to apply a little solder to the ends of the wires in order to stiffen them.

When new, the chips that have to be used will not fit directly into the holes in a bread board. the legs are splayed out, as shown in the diagram (A). Before you give the chips to the class, you (or a trusty student) should push the legs inwards, e.g. by pressing them down gently (!) against a table top until they are almost vertical (B).

Also, in order to avoid the students making mistakes about the correct orientation of the chips. It is best to label them (as shown in the photographs). There is almost always a small indentation in one end of the top face of the chip (often a small semicircle) that marks where the numbering of the pins begins. The label should read correctly from left to right with the indentation on the left hand side of the label.

Motors
The motor that we suggest using in this work is fairly robust. It will run off of a 1.5V battery, and draw a current of about 0.5A. It has the advantage of being fixed to a metal platform, which could be screwed down to a larger wooden base. Using it with a 9V battery for short periods does not do it any harm; but it should not be left running for long periods; i.e. a minute or more. Please emphasise this point to the students.

The motor has a speed of nearly 4000 rev/min. (as stated in the students' work book). This is too fast to be used to drive (say) a small buggy. However, the final rotation of the wheels to which it might be attached can be reduced by suitable gearing.

Before the motor is given to students it should have two connecting leads soldered to its terminals. (Advice will be available if you have had no experience of soldering.)

There is more work on motors in the mechanics section of the course.

Coping with components
The number of components that students need to use is not large; but owing to their small size, they are easily lost and/or damaged. It can be useful to give each group of students a set of equipment in a plastic 'lunch box' or food container that has a tight-fitting lid. Also, it can be very handy to have one or more pieces of (flat) polystyrene foam (e.g. as used in packing). The components can be safely pushed into the foam to keep them from getting jumbled up.

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The following is list of equipment that should be provided for each group. The data refers to the Maplin 2003/4 catalogue.

Item	Number	Maplin part no.	Page
Breadboard	1	AG10L	165
9V battery (PP3)	1	AR46A	483
clip for battery	1	NE19V	502
4093B CMOS chip	2	QW53H	208
2003A Darlington Driver chip	2	AD93B	208
Small 3V lamps	2	L81AH	534
Lamp holders	2	VW65V	536
Resistors, 1K, 10K, 22k, 47k	2 of each	G1K, G10K, G22K, G47K	177
Capacitors, 10mF, 22mF, 47mF, 100mF	2 of each	VH22Y, VH26D, VH32K, VH37S	81
LEDs, red, green	2 of each	J64U, CJ65V	136
Motor	1	HA83E	644
Reed switch and magnet (sold as pair)	1	YW47B	558
Push switch	1	FH59P	241
Micro switch	1	N96AQ	239
Buzzer	1	FL39N	761
Selection of wires—best purchased as a kit that should supply enough for all groups.	8 (say)	FS65V	166

Suppliers of electronics components
There are many suppliers of electronics parts; but we list just three here:

Maplin Electronics, Unit 1–4 Jervis Street, Dublin 1 and Unit 413, Blanchardstown Retail Park, Dublin 15. Maplin has a very wide range of equipment and a comprehensive catalogue; but it doesn't always carry a complete range of stock. However, it has an efficient mail order system via the web at www.maplin.co.uk.

Peats World of Electronics, 197/200 Parnell Street, Dublin 1.

Radionics, Glenview Industrial Estate, Herberton Road, Rialto, Dublin 12.

Explaining the behaviour of the students' circuits
The first point to realise is that the D&D course is not about students' reaching a good theoretical understanding of the circuits they build. Rather, the emphasis is on them getting practical experience of building circuits, and knowing what the circuits do. They should also be able to link their observations to wider contexts; especially in

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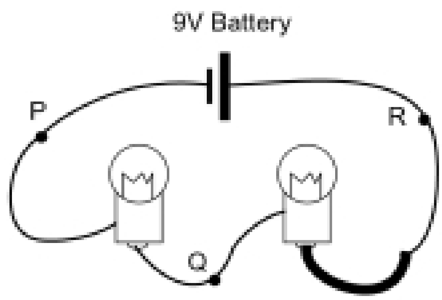
relation to possible uses of the circuits in their later projects, and in industry or the home. Thus, we think there is no harm in saying that at Transition Year level, the working of the chips is just too complicated to explain. This happens to be true; but it doesn't mean the students can't make the circuits work.

Suggested answers to questions in the student work book



Q.1 The diagram show a battery and lamps connected with some wires.
(i) Why won't the bulbs light?
(ii) What would you do to make the circuit work properly? (You can draw on the diagram if you want.)
(i) Circuit not complete; (ii) Link wire and bulb as shown.

Q.2 We measure the amount of current flowing through a circuit in amps (A). Suppose the circuit is made to work properly so that both bulbs light. Also suppose we measured the current flowing through the wire at P as one amp (1A).
(i) What would you predict the size of the current to be at point Q?
(ii) What would you predict the size of the current to be at point R?
Correct predictions are 1A at all three places.
Current is not 'used up' in a circuit! (Many students believe it is.)

Q.3 Assume you had built the circuit so that both bulbs were glowing. What do you think would happen if you connected a wire from point P to point Q?
The bulb would 'go out'. The wire from P to Q would have a much lower resistance than the bulb, so almost all the current would go through the wire and not the bulb. Incidentally, the other bulb would glow much more brightly.

Q.4 Imagine that the circuit was working properly, with both lamps glowing. Now imagine you replaced the 9V battery by a 90V battery. Write down what you think would happen, and why it would happen.
The 90V battery could drive a much greater current through the circuit (about 10 times as much). It is likely that so much current would 'burn out' the filaments of the bulbs; i.e. they would glow very brightly for a brief moment and then stop working.