TEACHING ELECTRICITY

Potential difference in colour

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Potential difference in colour

I was introduced to the technique of using colour in the teaching of potential difference in circuits by my former colleague and mentor John Marshall, who initially developed it to help explain certain op-amp circuits, notably the so-called 'relaxation oscillator' (or astable). It certainly enhanced my understanding of the concept and I have used it for many years with year 10 groups studying d.c. circuits.

Whilst analogies for current in terms of flow are plentiful (water flow, traffic flow) good analogies for potential which relate to the experience of young students are much more difficult to come by. Perhaps the nearest thing we can invoke is the use of contours on maps. Contour lines are all the same colour, and whilst it is easy to tell at a glance where an area of steep terrain is, it takes a closer look to determine the direction of the slope as we have to look at the values on the contour lines. If we were mapping an arid planet (with no public houses, green areas or other such features to contend with) we could then direct the available colours into coding the contours for different height levels, thus emphasizing clearly the difference between a hill and a valley. This is very much what we are doing when we colour in voltages to help in our understanding of a circuit. There are a very limited number of simple rules that must be obeyed when colouring in.

- Rule 1 When instructed to colour in a wire only stop colouring in when you meet a component other than a (perfect) ammeter or a closed switch. All wires that meet at a junction should be the same colour as one another.
- Rule 2 Identify the negative terminal of the battery. Colour all the wires connected to this point black. Black is our code for zero volts.
- Rule 3 Identify the positive terminal of the battery. Colour all wires connected to this point red. Red is our code for the voltage corresponding to the terminal p.d. of the battery.
- Rule 4 If there are any wires left uncoloured, use a hierarchy of colours to colour them in, e.g. red, yellow, green, blue and black. If a component has one red 'foot' then its other foot will be either
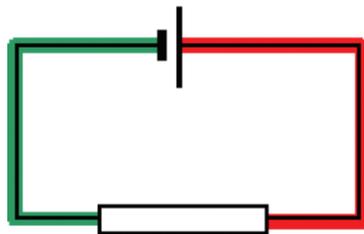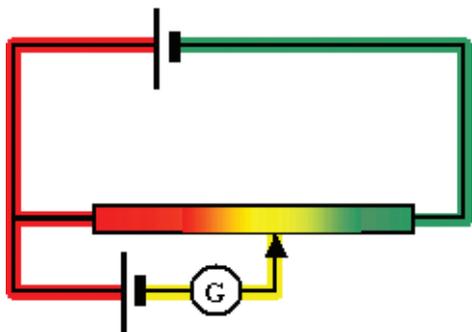

Circuit 1.
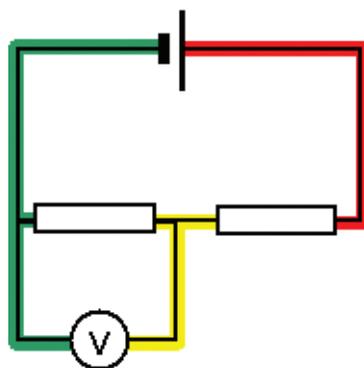
Circuit 2.

black or yellow if a current is to flow through the component.
- Rule 5 Once all the wires are coloured in, you can start to interpret the resulting diagram. Note the following consequences:
- a If a component's 'feet' are both the same colour then no current will flow through that component because there is no potential *difference* across it.
- b If no current flows through a component which does not have infinite resistance (ideal voltmeter, open switch) then its 'feet' will be the same colour.
- c If two or more components have the same colour feet then they are (effectively) in parallel with each other.
- d A voltmeter will give a reading of the p.d. across itself and all components that have the same coloured 'feet' as it.
- e We carry on colouring in through ideal ammeters because they have no resistance. An ammeter will

Circuit 3.

Circuit 4.

give a reading of the current through itself and any components in series with it.

f The actual values of potential associated with each colour will depend upon the resistances of the components. Standard formulae for resistors and conductors in series and parallel along with $V = IR$ or $I = GV$ can be used to evaluate the potentials.

The technique is best illustrated by practical examples and a few of these are outlined below. Owing to the costs of colour printing they are simulated in print as closely as possible. For the full colour version see the electronic version of this article at www.iop.org/journals/physed. I welcome the submissions of d.c. circuits for 'colouring'.

The first shows that two colours can often suffice. The addition of an ideal voltmeter and/or ammeter would not require the use of an additional colour in circuit 1—refer to Rule 1 and Rule 5e.

Circuit 2 is a simple potential divider circuit. It should be emphasized that we do *not* know the *value* of the yellow potential, but it must be lower than the red yet higher than the black.

This set-up can also be used to help in the explanation of internal resistance. The red potential corresponds to the emf of the cell but, due to the internal resistance of the cell (R2), we can only 'access' the lower (terminal) potential represented by the yellow potential. The more current we draw from the cell, the greater the discrepancy between red and yellow potentials.

Circuit 3 illustrates quite nicely the principle of the slide wire potentiometer. The right 'foot' of the galvanometer has its potential fixed by the two cells (driver cell and test cell) and the wire effectively
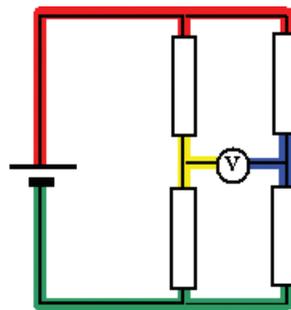
forms a 'continuous spectrum'. Only when we 'match the colour' of the two 'feet' does the galvanometer read zero.

Circuit 4 shows the principle applied to a Wheatstone Bridge circuit. The voltmeter gives a reading corresponding to the difference in the yellow and blue potentials, the values of which are controlled by the bridge resistors. The balance condition occurs when the yellow and blue potentials have the same value.

The following two examples are my favourites for illustrating how a complicated-looking circuit can be simplified by colouring the voltages. The original question was taken from a British Physics Olympiad Paper requiring the equivalent resistances of a network of three resistors with branching switches to be calculated.

Closing either switch causes the elimination of the blue and yellow colours—if S1 is closed but S2 left open then R2 and R3 can be treated as a single resistor combination through which no current flows since the red potential 'swamps' the yellow. Since no current flows through the R2–R3 series combination nor through the open switch S2 then R2's 'feet' must be the same colour. The blue potential thus becomes red by Rule 5(b). The effective resistance of the network is now R1. A symmetrical argument applies to the closing of S2 only. The effect of closing both switches is not inherently obvious to any but a trained topologist, but by following Rules 1 to 3 the result is immediately apparent as shown in circuit 6.

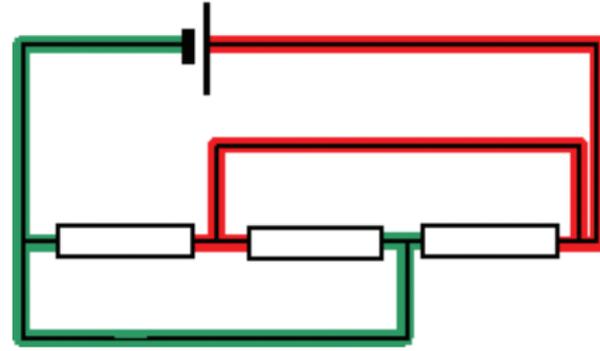*Voila!* The three resistors are effectively in parallel with one another.

Author's Note: Following the original submission
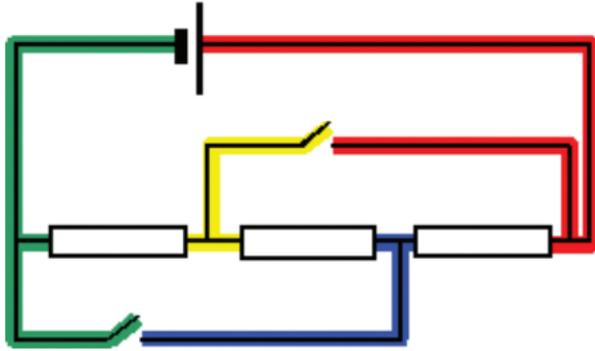
Circuit 5.

Circuit 6.

of this article I was made aware of a software circuits package (Livewire by New Wave Concepts—see www.new-wave-concepts.com/livewire.html) in which one of the optional settings is the use of colour to represent voltage levels. I was particularly impressed by a simulation of a *CR* circuit in which the capacitor's top 'foot' changed colour as it charged up or discharged.

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Diagrams adapted from Keith Gibbs