PRE-SERVICE TEACHERS' MISCONCEPTIONS ABOUT CURRENT AND POTENTIAL DIFFERENCE IN ELECTRIC CIRCUITS – USING MICROSCIENCE KITS IN A POE ACTIVITY

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ABSTRACT

Third year BEd students in a Physical Sciences content course answered a questionnaire about basic concepts of electric circuits, prior to attending lectures and practicals on the subject. Several well-known misconceptions were found to be prevalent. This led us to design a Predict-Observe-Explain (POE) practical activity, using microscience kits. The results from this activity confirmed the prevalence of misconceptions, but also the reluctance of the student-teachers to change them. Our discussion of one important misconception, namely the confusion between current and potential difference, suggests that treating the cell as simply a store of energy and a source of energy without explanation may be the cause of the confusion. A chemist's approach to this part of physics could avoid the misconception. *[African Journal of Chemical Education—AJCE 9(3), November 2019]*

INTRODUCTION

The South African national curriculum (since 2011) provides for teaching about electricity from Grade 5 onwards. In the school subject Natural Sciences grades 4-9, there is a content strand called Energy and Change within which all the electricity-related content is developed. Beyond this level, in the school subject Physical Sciences grades 10-12, there is a strand called Electricity and Magnetism, within which the great majority of electricity-related content is developed further. However, in these higher grades another strand called Chemical Change deals, amongst other things, with redox reactions (mostly grade 11) and electrochemistry (in grade 12). In preparing new teachers to teach these subjects, it is a priority for our BEd science content courses to ensure that the students leave with a correct understanding of all the electricity-related concepts embodied in the curriculum statements.

This seemingly obvious expectation is however questioned by literature reports of the conceptions about electricity held by pre-service in in-service teachers in both primary and secondary school in South Africa [1-4].

It was therefore apparent that we should investigate the situation within our BEd content courses and, depending upon the outcome, make changes to our courses accordingly.

LITERATURE REVIEW

The well-known advice “find out what students know and teach them accordingly” [5] has inspired a wealth of research into the science conceptions held by learners. No domain of science education can surely offer a better example of this than that of electricity. All students encounter electricity in their daily lives and are thereby exposed to the conceptions held by the general public. Furthermore, all students completing primary school are taught some of the basic understandings, and thereafter a diminishing but substantial number continue to study this domain more deeply. The wealth of research devoted to the teaching and learning about electricity therefore makes sense. Despite this, there is abundant evidence in the literature that misconceptions about electricity continue to abound.

There are many reasons for this disappointing state of affairs, amongst which we have to consider teacher education and the school curriculum as prominent. Thus although early research was dominated by investigating the conceptions held by school learners, there has been increasing attention given to teaching strategies and teacher conceptions.

Early research showed great similarity in the misconceptions held by school learners in different education systems [6]. This study reported marked similarity across five European countries as regards belief in the consumption of current, the cell as a constant source of current, and the failure to differentiate current from voltage. Such research was undertaken also in other regions and countries, such as Australia and South Africa [1], Turkey [7], [8], and Israel [9] and included pre-service and in-service science teachers as well as students. In all cases the same misconceptions were found to be prevalent.

A number of the research studies made use of written questionnaires [9-11, 6], but there have also been individual interviews [8].

The identification of several common misconceptions has stimulated debate as to faults in curriculum design and teaching and learning strategies. For example, early in the history of this field, [12] argued for a new approach that stressed the electric circuit as a system, saying that the traditional sequential introduction of concepts (starting with current and concluding with voltage and resistance) was perhaps the underlying cause for the widespread commonality of misconceptions. The system approach proposed by Härtel is accompanied by a model in which an 'electroparticle' features. Psillos, Tiberghien and Koumaras [13] have stressed that the traditional sequence in which current appears first is in any case a mistake: voltage should be the primary concept. The development of their teaching approach, was aided by pupils who were asked their views about this before, during, and after its implementation. Interestingly, pupils "demanded to know how the battery works" (page 40), an aspect of DC circuit teaching that seems universally to be ignored. With reference to the argument that the electric circuit should be presented as a system [12], the pupils' demand seems very appropriate! Garnett and Treagust [14], starting from their research into conceptual difficulties experienced by high school students of electrochemistry, by implication would agree.

The models used in teaching and learning about DC circuits have been reviewed and related to the historical development of textbooks on the subject [15]. Subsequently (1996), the same authors also compared the models used by novices with those used by experts [16]. Arising from these analyses, macro-micro relationships emerge as an important consideration [17-18], partly because they help link electrostatics with electrodynamics – something that is traditionally missed out and which, Eylon and Ganiel suggest, "may explain why students cannot conceptualize the electric circuit as a system". Borghi, Ambrosis and Mascheretti [19] have described in detail a teaching and learning sequence aimed at establishing this link.

Apart from debate on how best to teach the topic, there is the urgent need to develop strategies for correcting what has already gone wrong. Practical activities have often been embodied within a predict-observe-explain strategy as proposed by Gunstone and White [20] and Liew and Treagust [21]. Both Zacharia [22] and Jakkola, Nurmi and Veermans [23] have reported on the efficacy of practical activities in this regard and found limited benefits. However, when offered in parallel with computer simulations there are indeed significant benefits.

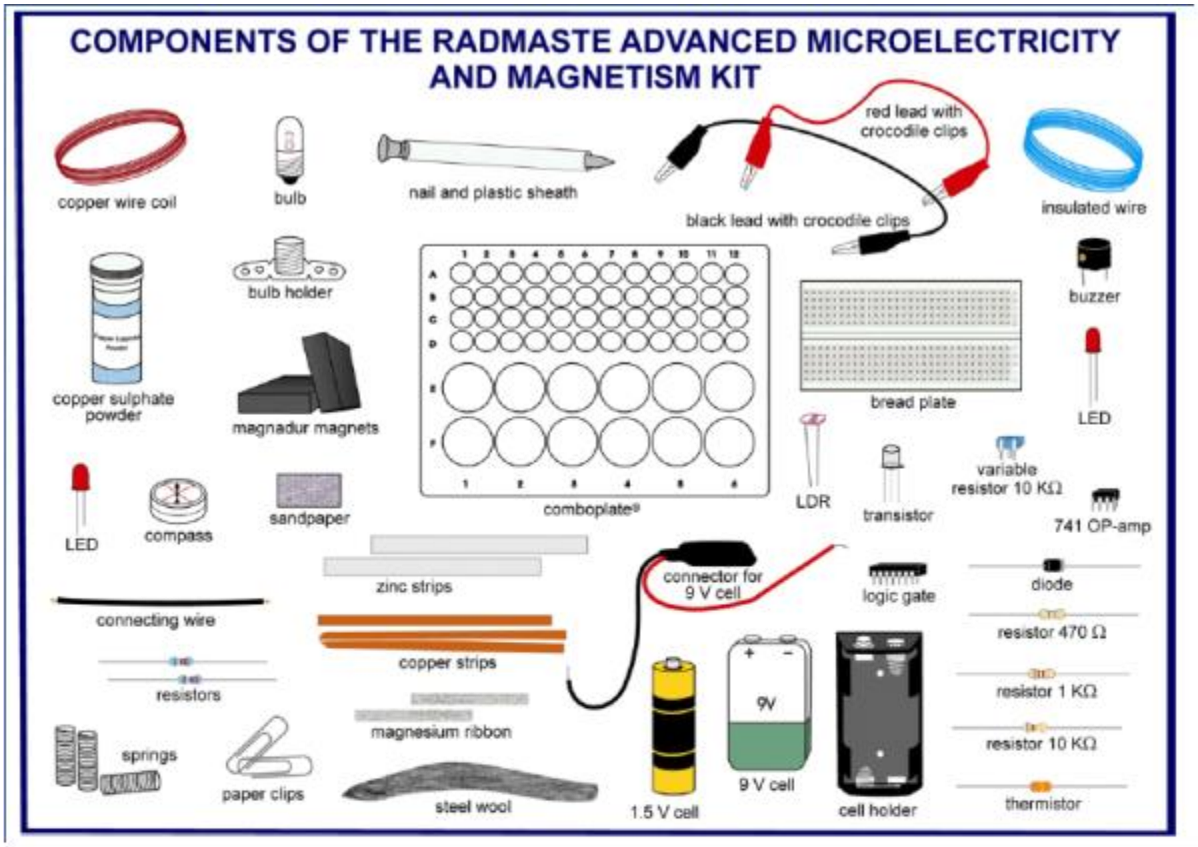
RESEARCH DESIGN

We decided to focus on the third year course for Physical Sciences in our 4-year BEd curriculum. At the present time this course attracts about 80 students. These students took Natural Sciences and Physical Sciences in secondary school and, formally at least, this was a requirement for entry to the Physical Sciences option in the BEd. In their first year of the degree, they have three lectures on electricity, covering some of the high school content. Their next exposure to electricity is in the third year, when they have nine lectures on electric fields and circuits, and two lab pracs on circuits. Our research began just before the students had lectures on electric circuits.

It is very important to note that the Physical Sciences course is not taught as physical science but taught in the traditional separation of physics and chemistry, each with its own time allocation in the academic year. The lecturers own academic background is generally either physics or chemistry and so it is no surprise that the lectures are based on the frameworks of ideas that are most useful in either physics or chemistry. We discuss the implications of this below.

We designed and administered a questionnaire on circuits in advance of the start of the lecture course (in September 2018), to identify the students' understandings of basic electricity concepts. In this way we hoped to identify actions that could be taken almost at once within the lectures and practicals that were to follow.

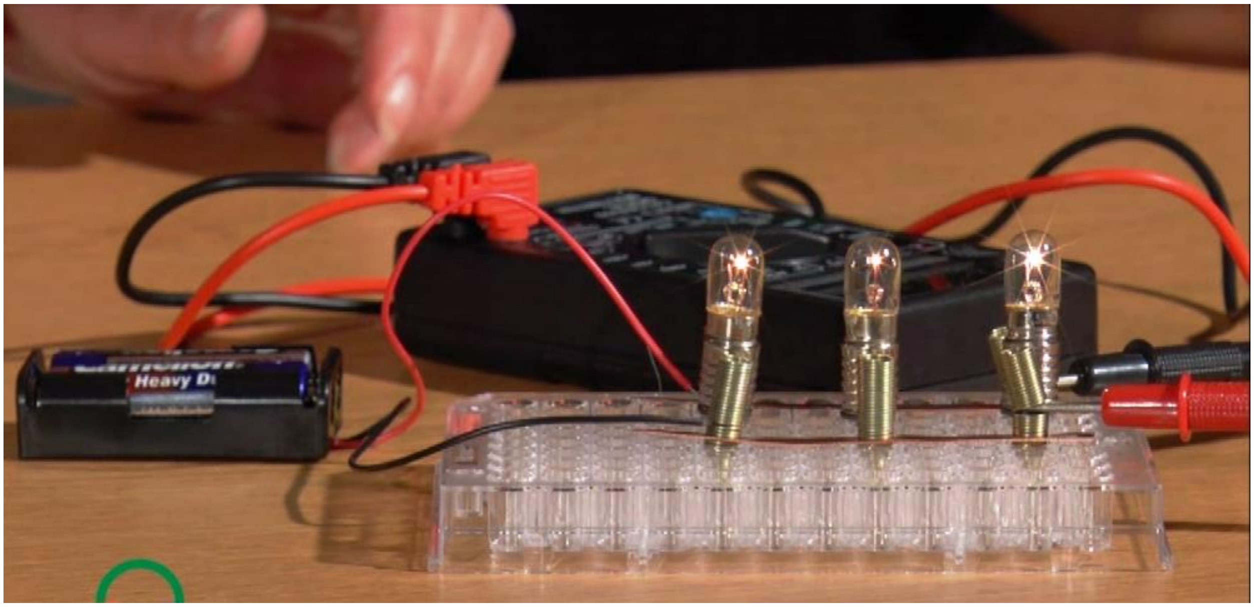
Anticipating that we would find misconceptions among the students, we planned to use the practicals as an important context in which to address these. In particular, it seemed likely that we might adopt a Predict-Observe-Explain (POE) approach using simple hands-on experiments with microscale electricity kits. Using these kits, we were able to prepare for students to work in pairs and thus approach the personal commitment level of engagement the POE method requires. The diagram below shows the kit components. The traditional circuit board of large-scale kits is replaced by a plastic microwell-plate that is also used in the RADMASTE micro-chemistry kits. Springs placed in the smaller wells (see Figure 2) act as connectors for battery leads, bulb-holders, etc. and multimeter probes.



The students, before the lab practical, were able to watch a video showing how to connect series and parallel circuits and take measurements of voltage and current using the multimeter. (https://youtu.be/B6aQYEOXkTU)

The making of this video was funded by ESKOM, the South African electricity utility.

Figure 2 A screen shot from the RADMASTE training video



In the following sections we describe firstly, the design of the questionnaire and the results derived from its administration, and secondly, the design of the POE activities in the practical sessions that followed subsequently and the results arising from these.

The Questionnaire

The questionnaire was constructed from 14 questions drawn from the literature. An important source was the 29-item questionnaire designed by Engelhardt and Beichner [9] which was used in a study of American high school and university students. They reported discrimination indices for their test items which helped in our choice of 6 questions with high indices from this source. Other questions were derived from papers [9, 11, 24].

The 14 chosen questions were of the true/false or multiple-choice type, with 3 of them requiring reasons for the choice made. 45 students completed the questionnaire, prior to them beginning the course on electric circuits.

THE RESULTS

We found strong support among these students for the idea that a cell supplies current and that the current is consumed in the circuit. For example, Question 1 asks them whether they agree with the statement A new battery stores a certain amount of electric current. As you use the battery, the current will be consumed by appliances such as bulbs, loudspeakers and motors.

This statement is translated from a probe by researchers in Germany. In that research 85% of 13 to 15 year-olds agreed with the statement but more to the point, 40% of 36 university students planning to become physics teachers also agreed with it [24]). So the 68% agreement with the statement we found among third-year aspirant science teachers is disturbing but not totally surprising. The prevalence of this mental model remains a serious conceptual problem: these students using the model do not have a mental picture of electrons being conserved as they drift around the circuit, and we may expect to find this misconception as a component in other mental models they have.

A second mental model that was evident from the questionnaire was the idea that the potential difference across a component was the result of the current through that component. The questions that elicited this idea were drawn from a questionnaire by Cohen, Eylon and Ganiel [9]. We probed this in more detail as we will discuss further on in the paper.

Table 1 Incidence of misconceptions among B.Ed. students in the sample

Description of the misconception The misconception is often a cluster of ideas that are applied selectively to each problem; these ideas act like a mental model.	No. of questions	Incidence in this group N = 45
A consumer model: The current is consumed by components in the circuit; the cell is like a tank that stores current until it runs empty.	2 questions	68%
An attenuation model: the current/electricity is consumed, and it is thus attenuated at each resistor in sequence, so that very little returns to the cell.	5 questions	31%
A sequence model: the current upstream doesn't know what it will meet downstream; any changes at a circuit component (e.g. letting the circuit branch into parallel resistors) take effect only after the current passes that point	5 questions	32%
The current is the cause of the potential difference across a resistor. If there is no current through a part of the circuit, then the PD across that part is zero.	3 questions	53%

We were naturally concerned that this set of misconceptions is held by students who will soon be employed to teach science pupils in the final years of school. We followed up the questionnaire with a lab practical, aided by the video described above, that allowed students to familiarize themselves with the micro-electricity kit. They had to connect series and parallel circuits and take measurements of voltage and current. Our interaction with them and their lab reports afterwards showed that they had a reasonable ability to use the micro-kit in these ways.

The second lab prac was designed to probe their understanding and misconceptions more deeply.

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The POE Activities in the second lab prac

The POE (Predict-Observe-Explain) methodology followed that described by Gunstone and White [20] and Liew and Treagust [21]. The prediction worksheets we designed are shown in the appendix. Students first worked singly, writing their predictions on the worksheet. Having completed this, they were given the microelectricity kits to use and to work with in pairs. The circuits and questions in the practical tasks (also shown on the task sheet in the appendix) were the same as those in the prediction worksheet; thus they were able to test each prediction by observation and compare the result with the predictions they had made initially.

Results of the POE activities

In this paper we focus on one particularly troubling misconception, namely that a current through a component of a circuit is the cause of a potential difference across the component. This was the subject of Question 6 on the worksheet.

Figure 3 shows Question 6 from the prediction worksheet

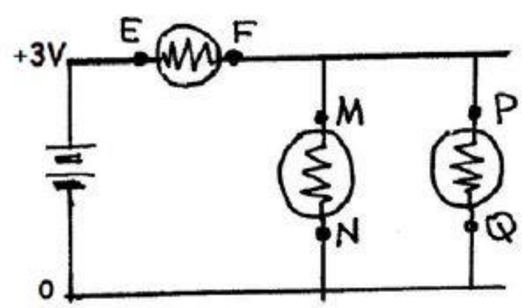
6 In Figure 3, you are going to remove bulb PQ. Then the voltage (the p.d.) across the contacts P and Q will

(a) increase

(b) remain the same

(c) become zero

Figure 3 .



In the 35 lab reports we have as data, 82% of the students **predicted** that the potential difference, V_{PQ} , across the terminals P and Q would become zero. The **observed** V_{PQ} across P and Q was about 1.2 to 1.4 volts, but this was not always the value the student recorded. In several cases, the students insisted that they measured V_{PQ} and found it to be zero.

The following sample of responses is taken verbatim from the students' lab reports.

Response 5

Q6.1 *There is no work done between point P and Q, thus potential difference is zero*

[Comment: this is a variation on the idea that a flow of charges (on which work is being done) causes the PD. The student misses the point that potential means work could be done on a charge. Or the student could just be grasping at a definition of PD without understanding it]

Response 17

6. *In Figure 3, we predicted that if PQ is removed the voltage across the contacts P and Q will be zero. We thought that because there will be no current flowing across it.*

After our connection we found out that it is true, there were no readings.

[Comment: students may "find" what their conceptual model tells them to find; measurements don't always challenge preconceptions. Probably the student took measurements in such a way as to confirm his prediction]

Response 18

6.1 *The voltage (p.d.) is zero because there is no resistor (bulb) across P and Q so their resistance is zero therefore p.d. will be zero since they are directly proportional.*

[Comment: This is a new version of the reasoning that V=R x I = R x 0 = 0; student states that if R is zero then V= 0 x I and so V = 0. Student does not see the gap at PQ as a resistance; there is indeed no **resistor** in the gap at PQ but the air is a super-high **resistance** in that gap.]

The students in most cases (apart from response 17) did not explicitly say that they believed a current was the cause of a PD but we infer that this is what they believe. Such responses, above, are consistent with the view of Eylon and Ganiel [17]: "Students tend to be 'current minded' rather than 'voltage minded' (Cohen et al. 1983 [9]), thereby confusing cause and effect."

In using the POE method, we intended that in cases where a misconception had led to a wrong prediction, students would feel challenged and adjust their mental model. In fact this was not always the response, the students often explaining discrepancies by some insubstantial argument. Such behavior confirms that the misconception concerned exists and is tenaciously held.

DISCUSSION

This outcome requires a response from us and from our institution's curriculum designers. Our results from the POE intervention indicate that solving this problem is not going to be easy. At the third year level, our students have a variety of conceptions built up over maybe 15 years or more of formal education, together with the informal education they have obtained from their everyday environment. Changing concepts is well known to be difficult and our students are not unusual in showing their resistance.

It is argued [9] that many students are introduced to electric circuits in primary school where teachers predominantly use the notion that a complete circuit is necessary for current to flow. In our experience this is a common approach in schools – voltage is not mentioned in lower grades and there is no significant exploration of the insides of a cell. In junior high school, the voltage concept is troubled by its ratio definition, which typically goes as follows:

> The voltage or potential difference is the energy transferred per unit charge. 1 volt = 1 joule per coulomb; in other words, 1 V = 1 J/1 C

This definition is usually enough incentive for the teacher to avoid the definition and even the topic of voltage as much as possible and stick to the notion of current, for which there are analogies such as water in pipes.

In the South African national curriculum, the topic of the voltaic cell occurs formally only in the second half of Year 8, in a physics context with passing references to chemical reactions. To quote:

• cells/batteries are chemical systems that are sources of energy

-- cells store chemical substances (potential energy)

-- when the circuit is completed, the chemicals react together to produce an electric current

-- an electric current is the flow of charges (kinetic energy) along a conductor

So while there are (unexplained) references to energy, the emphasis remains on the concept of current, to the detriment of the voltage concept.

This pedagogic state of affairs results in a simplistic view of the cell as merely a current source; the effects of the current, such as high or low *voltages*, are the result of electron flow.

The particular misconception which we focus upon in this paper, namely that current is the cause of PD, by any reasonable judgment is a fundamental or primary misconception about electricity. In our view, it seems to point to ignorance about the cell. It is here, one may argue, that it all begins (as it did for Volta some 200 years ago!). The PD of the cell is an expression of the energy change associated with the chemical reaction inside the cell; the electric current in an external circuit is a demonstration of that reaction (an electron transfer reaction) taking place inside the cell. Traditional physics course introductions to current electricity only say the cell is a store and a source of energy; they do <u>not</u> say the reactants change to products because the potential energy decreases; they do not say that the chemical reaction involves electron transfer between reactants and, because of the way the cell is constructed, this happens through the external circuit.

These omissions may hinder development of a concrete model relating current and PD in which it is abundantly clear that PD causes current and not the other way around. Chemistry can help to make the correct link between these two most basic concepts in current electricity.

One must bear in mind that the students in our study have done and are doing chemistry as part of their Physical Sciences course, yet their ideas in chemistry remain separate from what they learn in physics.

Chemists, even when dealing with macroscopic observables, refer continually to models of molecular, atomic or electronic behavior. Physics instructors at school and undergraduate level do this much less often; of course they do describe current as electron flow but soon move to the conventional current direction that defines all electromagnetic theory and many circuit symbols such as diode symbols. Current in physics then is a “flow of charge” (where charge can be either positive or negative) and they treat conduction and PD of batteries as macro phenomena, with ammeter and voltmeter readings standing for the unseen activity of electrons.

We intend to work on a proposed new piece of the BEd curriculum that would not be called Physics or Chemistry but Physical Science, in which chemistry concepts and models of electron movement, oxidation/reduction and energy changes in reactions are drawn all the way through physics topics such as potential difference, energy transfer in components, electrical power and internal resistance of batteries. In the accompanying paper in this journal (Bradley, Khulu, Moodie, Mphahlele [25], we outline our basis for one of the lab practicals in such a Physical Science unit, using components from both microchemistry and microelectricity kits.

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APPENDIX

B.Ed. III Prac 4 19 September 2018

Practical 4 Learning parallel circuits and voltage dividers with the micro-electricity kit

Name or student number: ____

The kits you are using were developed here in the Wits RADMASTE Centre and you will find them in most schools where you might teach, because they were supplied in large numbers by several provincial Education Departments. (The video is at https://youtu.be/B6aQYEOXkTU)

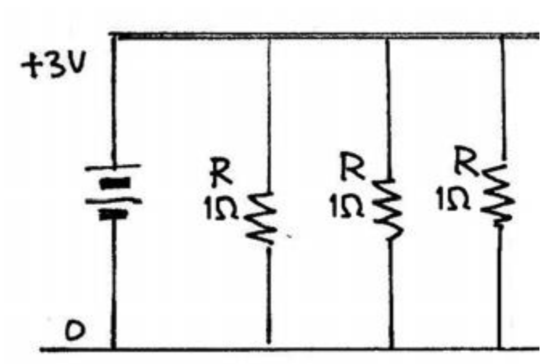
In this lab prac we use the POE approach; POE stands for Predict – Observe – Explain. You will make some predictions on this sheet, **copy them to the task sheet**, hand in this prediction sheet, and then receive your group's kit.

PREDICTION SHEET

Draw a circle around the (a) (b) or (c) as usual, but copy the circles to your lab task sheet. This is because you must hand in all the group's predictions to your demonstrator. Then you will get your kit (it has your group's names on it).

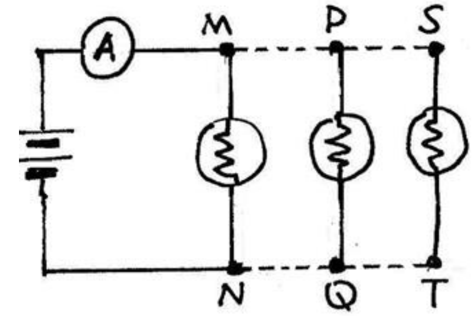
1 In Figure 1, what is the resistance in the circuit?
Assume the battery has no internal resistance.
(a) 1 ohm
(b) 3 ohms
(c) a ohm (0.33 ohms)

Fig. 1



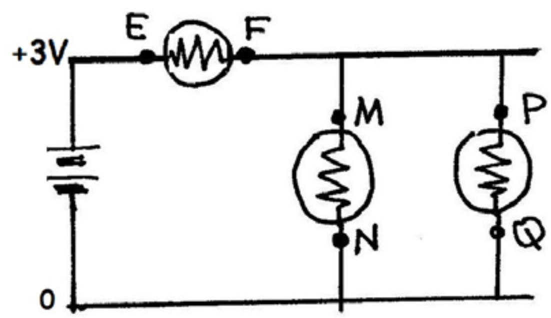
2 In Figure 2, the bulbs all have the same resistance. You will add extra bulbs, one at a time, between points PQ and ST. As you add the bulbs, the ammeter reading will:
(a) increase
(b) decrease
(c) remain constant

Fig 2.



3 In the same circuit you see in Figure 2, as you add extra bulbs, the voltage across MN
(a) increases
(b) decreases
(c) stays constant
(d) becomes significantly smaller than the voltage across PQ

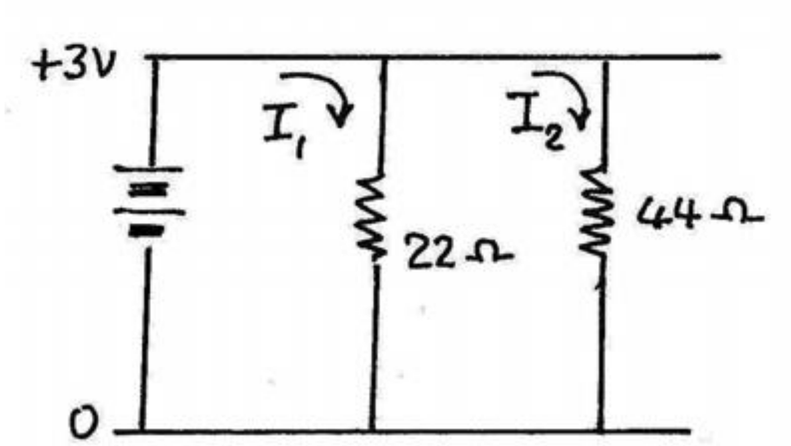
Fig. 3



4 Figure 3 shows a circuit with bulbs of the same resistance. Predict the voltages
Figure 4 .
EF = volts
MN = volts
PQ = volts
5 In Figure 3, if the bulb at PQ is removed,
(a) bulb EF will go out
(b) bulbs EF and MN will both go out
(c) bulb EF will become brighter
(d) both bulbs EF and MN will become dim
6 In Figure 3, you are going to remove bulb PQ. Then the voltage (the p.d.) across the contacts P and Q will
(a) increase

(b) remain the same
(c) become zero
7 In Figure 4, predict the currents I_1 and I_2 through the 22 ohm and the 44 ohm resistors.
I_1 = mA
I_2 = mA

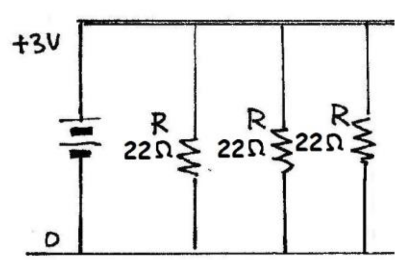
Fig. 4



LAB TASK AND REPORT

- Have you copied your (a), (b) or (c) predictions onto this sheet? Draw a circle around your predictions, to remember what they were.
- You can complete your lab report at home, but record all measurements of voltage and current, brightness or dimness before you leave.

1 In Figure 1, what is the resistance in the circuit? Assume the battery has no internal resistance. What was your **prediction**?
(a) 1 ohm
(b) 3 ohms
(c) 1/3 ohm (0.33 ohms)
Circle O the answer that you predicted.
Fig. 1

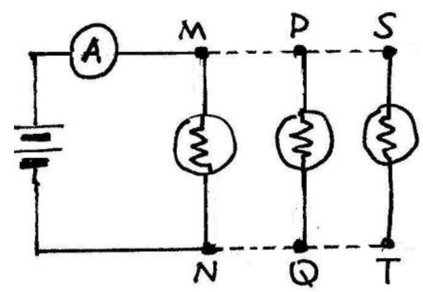


You don't have 1 ohm resistors so use the 22 ohm resistors instead.

Q1.1 The resistance you measure across the parallel circuit is close to . . . . . .
Q1.2 Imagine a learner asks you, "Why is the circuit resistance not 22 ohms?" Write an explanation (don't quote a rule).
Q1.3 What would the resistance be if you removed one of the 22 ohm resistors? Predict, then try it and see what you get. Write your prediction . . . . and your actual measurement . . . . Explain the measurement, as though to a learner.

2 In Figure 2, you will add extra bulbs between points PQ and ST. The bulbs all have the same resistance. As you add the bulbs, one at a time, the ammeter reading will:
(a) increase
(b) decrease
(c) remain constant
[what did you **predict**? Draw a O]

Fig. 2

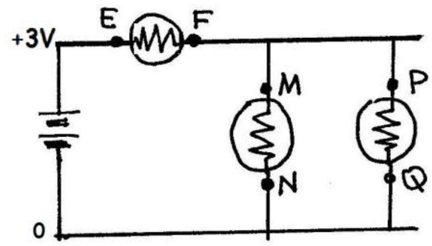


Set up a circuit like this and
Q2.1 record the current each time you add a bulb. . . . . .
Q2.2 What is the reason the ammeter shows this? Write an explanation to a learner (that is, don't answer by quoting a rule.)
Q2.3 Why are bulbs PQ and ST just as bright as MN, the first bulb? Answer by using the concept of potential difference.

3 In the same circuit you see in Figure 2, when you add extra bulbs, the voltage across MN [what did you **predict**?]:
(a) increases
(b) decreases
(c) stays constant
(d) becomes significantly smaller than the voltage across PQ
Keep your circuit as in Figure 2 and measure the voltage (the p.d.) across MN with one, then two
and then three bulbs in parallel.
Q3.1 Record your findings here. . . . . . .
Q3.2 You probably found that the p.d. across MN drops a little as you add bulbs; explain this using the concept of the battery's internal resistance.
Q3.3 Compare the potential differences (p.d.) across MN, PQ and ST; write a true statement about them.

4 Figure 3 shows a circuit with bulbs of the same resistance. What voltages did you **predict**?
EF = volts; MN = volts; PQ = volts
Set up the circuit and measure the voltages
EF = ... volts
MN = ... volts
PQ = ... volts

Fig. 3



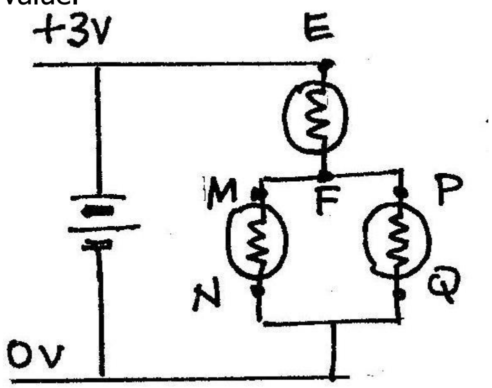
Q4 You could predict the voltages without knowing the resistance of the bulbs. How?

5 In Figure 3, if the bulb at PQ is removed
(unscrewed), you predicted
(a) bulb EF will go out
(b) bulbs EF and MN will both go out
(c) bulb EF will become brighter
(d) both bulbs EF and MN will become dim

Q5.1 Set up the circuit and observe bulb EF when you unscrew PQ.

Q5.2 Measure the p.d. across EF **before** you unscrew PQ and again **after** you unscrew PQ. . . . .

Q5.3 Explain why EF changes like that when you remove bulb PQ. Use the concept of terminal voltage and potential difference (p.d.) across in your answer. To help you, the circuit in Figure 3 has been redrawn in this diagram. Think of MN and PQ as a single resistor that can change value.



6 In Figure 3, if bulb PQ is removed, you **predicted** that the voltage across the contacts P and Q will
(a) increase (b) remain the same (c) become zero

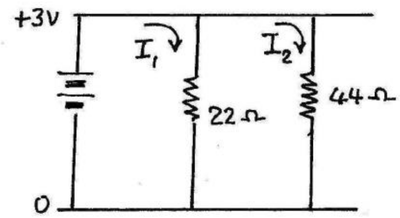
Q6.1 Measure the voltage (the p.d.) across P and Q when the bulb is out of its holder. Explain why the p.d. is like that.

7 In Figure 4, you **predicted** the currents I_1 and I_2 through the 22 ohm and the 44 ohm resistors.
I_1 = mA and I_2 = mA

Q7.1 How will you get a 44 ohm resistor?

Q7.2 Set up the circuit and measure the two currents.
I_1 = ... mA and I_2 = ... mA

Fig. 4



Switch the multimeter to the "off" position.
Take the black wire from the battery and tie a loose knot in it so that it is shorter than the red wire.