

Exploring Physics Teachers' Concepts of Simple DC Circuits

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Abstract

This research article depicts the result of a conceptual diagnostic test on simple DC Circuits undertaken by 26 physics teachers teaching at senior secondary level. Analysis shows that the teachers do have alternative conceptions related to simple DC circuits.

Qualitative analysis of their explanation justifying their answers reveals the cause of the alternative conception and the associated mental models. To bring in conceptual clarity a teaching strategy based on "Physics by Inquiry" has been developed which proved to be a successful one.

Introduction

Students mostly rely on teachers and their knowledge. A teacher with misconceptions can mislead the whole class and fail to bring in conceptual clarity. For improving the quality of the teaching–learning process in science, attention has to be focused on the training of teachers (in-service & pre-service), and their level of performance in the classroom and laboratory. For teacher training alternative conceptions in a specific subject area are to be ascertained and training packages should be prepared, which will give them conceptual clarity and long term memory. In this research paper, electricity is chosen as the focus area. Many researches have been conducted to identify the misconception/alternative conceptions of students and teachers. Students' conception of electric current has been extensively studied at different levels of education (Duit *et al.*, 1985; Shipstone *et al.* 1998; Fleer 1994; Borges and Gilbert, 1999; Shepardson & Moje, 1999). Students' concept of potential difference and current (Millar and Beh, 1993; Millar & King, 1993); electric circuits (Andre and Ding, 1991); electric diagrams (Johsua & Dupin, 1985); current and energy (Arnold and Millar, 1987) have been investigated. Comparatively fewer studies have been reported exploring teachers' understanding of the concept of electricity. However research done by Mc Dermott and Shaffer (1992), Webb, (1992) and Wiles & Wright, (1997) are worth noting. The present study evaluates the understanding of simple DC circuits by senior secondary physics teachers, which can not be ascertained directly without doing this descriptive research. Possible mental models associated with the alternative conceptions were identified. Finally the paper suggested an innovative teaching strategy for improving the learning situation of the teachers.

Conceptual frame work

Most of the research in the area under study are exploratory and descriptive. In some of the studies the researchers have used simple equipment like bulb, battery and connecting wires, and asked the students to connect the bulb and the battery so that the bulb glows. For individuals with previous knowledge of electricity, paper and pencil tests involving circuit diagrams of simple circuits, solution of problems followed by clinical interview and interactive sessions are generally preferred. For the present study a questionnaire containing diagrams of simple DC circuits have been used. Justifications for their answers to different questions were analyzed to know

the alternative conceptions and the associated mental models of the sample. The mean scores for different questions have been calculated taking the correct answers into consideration which were used for different statistical analysis. One of the innovative teaching strategies based on “Physics by Inquire” was adopted to improve the knowledge related to simple DC circuits and its effectiveness was ascertained.

Research questions

1. Do the teachers have alternative conceptions related to simple DC circuits containing (i) a single cell and multiple bulbs (ii) multiple cells and multiple bulbs?
2. What are the associated mental models to the identified alternative conceptions?
3. Is Physics by Inquiry (PbI) an effective teaching strategy to bring in conceptual clarity related to simple DC circuits?

Methodology

Sample

The sample consisted of 32 postgraduate trained physics teachers teaching the subject at higher secondary level. Twenty six of them could complete the given questionnaire hence final sample consisted of 26 teachers. The following facts about the sample may be noted.

- These teachers work in central schools run by the *Kendriya Viidyalyaya Sangathan (KVS)* an autonomous organisation under the ministry of Human Resource Development, Government of India. The major objective of KVS is to provide uniform pattern of quality school education to children drawn from different socio-economic background.
- The teachers were deputed to attend 21 days refresher course in physics to Regional Institute of Education, Bhubaneswar, a constitute unit of National Council of Educational Research and Training (NCERT). NCERT is an apex resource organization set up by the government of India. The chief function is to provide academic and technical support for improvement of school education. The teachers belong to central schools located in twelve different states of India.
- All of them have completed at-least Master degree in physics and have undergone one year of professional teacher training course. All have more than ten years of teaching experience.

Tool

A diagnostic test was developed to measure the proficiency in the area of simple DC circuits. It was try –out and a revised questionnaire was prepared. A team of experts examined the content validity. Reliability of the diagnostic test (Set. I & II, Part A & Part B, Appendix I) was ascertained by using Test-retest method. Seventeen teachers were taken for the reliability test. The test was administered after a gap of fifteen days. One hour time was allowed for the test. Reliability coefficient was found to be 0.87. The questionnaire contains two set of questions. Each question set contains three types of questions. The first part contains objective type questions carrying five marks. The second part contains a question related to comparison of brightness of

bulbs in different circuits and carries two marks. The third part is the explanation part; it is based on one's reasoning. The second part is given in order to avoid guess work. The third part is not evaluated and is used to know the conception/ alternative conception and the associated mental model of the individuals. Part A and Part B (Set-I & Set-II) of this test was taken as the pre-test..

Administration

The task is a pencil-on-paper task and one-hour time was allowed for the task. The teachers were not allowed to discuss during the test.

Scoring

Scoring was done for Part A & Part B of Set I and Set II. For Part A each correct option carries one mark and the Part B question carries two marks.

Analysis

The similar answers were grouped together. According to Gilbert and Watts (1983), "To generalize beyond the individual is to construct grouping of responses that are constructed as having similar intended meanings. The sample is divided into different categories and the % of response was calculated for both the set of questions and depicted in table1.

Table-1 : Percentage of teachers in different categories of responses

SL	CATEGORY	% OF RESPONSE	
		SET-I	SET-II
1	Could answer all the questions correctly, grade the bulb correctly and correct explanation given.	23.07	19.23
2	Could answer all the questions correctly but could not grade the bulb. Explanation given supporting their reasoning.	23.07	15.38
3	Could answer all the questions correctly and grade the bulb correctly but no explanation given.	7.69	11.53
4	Could not answer all the questions correctly. Could not grade the bulb and gave incorrect explanation.	46.15	53.84

The average score obtained for Set I is 4.38 and for Set II is 3.30. t-test for non-independent sample was undertaken. t-value was calculated to be 6.544 which is greater than the t-value given for $P=0.001$. Thus the two scores are significantly different at < 0.001 level. The Pearson correlation coefficient 'r' for Set I & Set II was calculated to be -.0065. However the value is very small and one can safely take that the scores in Set I & Set II are not at all related or the correlation is not significant. The transcripts of selected answers for the Set-I are depicted in Table-2.

Table-2 : Transcript of selected answers with associated explanation, Set-I

Q. NO.	QUESTION	ANSWER	EXPLANATION
1 a.	Bulb A is brighter than bulb 'B'	YES	Because 'B' is in series with another bulb (correct)
		YES	Because 'A' draws all current (incorrect, incomplete)
		YES	Because 'A' in parallel & 'B' in series (incorrect)
		YES	Because heat produced is more in 'A' (correct but incomplete)
		YES	Because effective resistance of the second circuit is more (correct, incomplete)
		YES	Because current in the Fig.1.a is V/R & 1.b. is $V/2R$ (Not correct as bulb is not a ohmic resistor) (Model : Universality of Ohm's law)
		YES	Because V is less, I is same in Fig.1.b. Hence brightness is less than Fig.1.a. (incomplete)
		YES	Because as connected in series bulbs B & C share the illumination in equal way (ambiguous)
		NO	Because bulb A, B, C all are in series with the battery hence will have the same illumination as for series circuit current flow remains the same (ambiguous) (Model : Constant current source model)
	YES/NO	No justification	
1b.	Bulb B is brighter than bulb C	NO	Because 'B' & 'C' have the same power. (Calculated power by assigning potential difference and resistance for the bulbs) (Correct)
		NO	Because potential across the bulb determine brightness (In complete)
		NO	Because they are in series (Incomplete)
		NO	Power in 'B' & 'C' is equal to V^2/R (Correct)
		NO	Because potential difference is same across both bulbs (Incomplete)
		No	Potential difference is $V/2$ and current is I , so power is $IV/2$ for both the bulbs (correct)

Analysis reveals that the teachers have a tendency to treat bulbs as Ohmic conductors or linear-resistances. The same tendency has been conformed for the college going students (Metioni *et al* 1996). Applicability of ohm's law, its limits and validity is at stake. Analysis of explanations as depicted in Table. 2 reveals that the teachers have the following alternative conceptions related to the question Set-I.

- Bulb nearer to the positive terminal of the cell is brighter than the other bulbs in the circuit. This alternative conception is due to "current consumption model" (Karrqvist, 1985; Borges & Gilbert, 1999). Current flows from positive to negative plate of the cell. Hence nearer the bulb to the positive terminal more is the current.
- Bulb is treated as a linear resistor. This alternative conception is due to "universality of ohm's law" (Metioui *et al*, 1996). According to this model, for ohmic resistance, resistance remains same irrespective of the value of V or I , which is also true for a bulb.
- Current from a cell does not depend on the number of bulbs in the circuit. This alternative conception is due to "Constant current source model" (Cohen *et al*, 1983).

Q. NO.	QUESTION	ANSWER	EXPLANATION
		NO	Because 'B' & 'C' have same current and same resistance, so I^2R is same for both the bulbs. (correct)
		YES	Because of series connection (incomplete) (Model : Current consumption model)
		NO	Due to distribution of voltage in series connection (Incomplete)
		NO	Voltage is divided so less bright (Incomplete)
		YES/NO	No justification
1 c.	Bulb D is brighter than bulb E	NO	'D' & 'E' are parallel so will be of same brightness (correct, incomplete)
		NO	Because power of both bulb are same (correct)
		NO	'D' & 'E' are in parallel current is divided but potential is same (Correct, Incomplete)
		NO	Current in each bulb is same so will glow with same brightness (incomplete)
		YES	'D' is nearer to the cell (Model: Current consumption model)
		YES/NO	No justification
1 d.	Bulb F is brighter than bulb G	YES	'F' is parallel and if the power is V^2/R , power of G and H will be $V^2/4R$ (Correct)
		NO	Because 'F' & 'G' bulbs are parallel with each other (ambiguous)
		YES	If power for 'F' is $I^2R/4$, power for G is $I^2R/8$ (incorrect)
		YES	Effective resistance is the cause (incomplete)
		YES	If current in bulb 'F' is V/R current in bulb 'G' is $V/2R$. (Model : Universality of Ohm's law) (Incomplete incorrect)
		YES	Because 'G' is in series with 'H' and 'G' is parallel to the cell (incomplete)
		NO	'F', 'G', 'H' will equally share the voltage as all are connected parallel to the cell (incomplete)

Q. NO.	QUESTION	ANSWER	EXPLANATION
1 e.	Bulb G is brighter than bulb H	NO	Power of both bulbs are same i.e. $V^2/4R$ (correct)
		YES	'G' is nearer to the positive terminal hence will glow brighter than 'H' (Model : current consumption model) (Incorrect)
		NO	Current is V/R in both (ambiguous)
		NO	'G' & 'H' have same current and resistance (incomplete)
		NO	'F', 'G', 'H' will glow equally bright because they equally share the potential (ambiguous)

Table-3 depicts the transcripts of selected answers with associated explanation for Question set – II.

Table-3 Transcript of selected answers with associated explanation, Set-II

Q. NO.	QUESTION	ANSWER	EXPLANATION
2 a.	Brightness of the bulb A and B will be same in all the diagrams.	YES	In Fig. 2C, the bulbs will not glow. In Fig. 2a, 2b, and 2d the cells are in series and hence emf adds up where as in Fig. 2.c the emfs oppose and net emf is zero (Correct)
		YES	Because of Kirchoff's second law. In any closed mesh of an electrical circuit, the algebraic sum of the products of the currents and resistances of the various branches of the mesh is equal to the total EMF of the mesh, (used the correct law but could not analyze)
2 b.	Brightness of the bulb B ₁ and B ₂ are not equal	NO	A ₁ , A ₂ & A ₄ are nearer to the positive terminal of the cell hence will glow brighter than B's (incorrect) (current consumption model)
		NO	There is no difference between Fig.2.a and 2.b. Hence they will glow with same brightness (correct, incomplete)
		NO	Cells are in series, bulbs are also in series (correct)
2 c.	Brightness of the bulb B ₂ and B ₄ are not equal	YES	Brightness of B ₁ is greater than Brightness of B ₂ , as the cells are nearer to each other in Fig.2a (incorrect)
		NO	Brightness of B ₂ and B ₄ are equal. Cells are in series and emf adds up (correct)
		YES	Due to change in position of the cell (incorrect, incomplete)
		YES	B ₄ is nearer to the positive terminal of the battery (ambiguous) (Model : current consumption model)
		YES/NO	No justification

Q. NO.	QUESTION	ANSWER	EXPLANATION
2 d.	Bulb B ₄ is brighter than bulb B ₃	YES	B ₃ will not glow at all where as B ₁ , B ₂ , B ₄ will glow with equal brightness. Because in Fig.2.c, same polarity of the cells are connected (Correct)
		YES	For bulb B ₃ potential difference is zero hence it will not glow, where as B ₄ will glow with same brightness as A ₄ . (Correct)
		NO	Both bulbs are connected in series. (Ambiguous)
2 e.	Bulb B ₄ is brighter than bulb B in Set I	YES	Two batteries in series so energy available is more (correct)
		NO	Same current passes through bulb B and B ₄ (incorrect, incomplete)
		NO	Both will glow with same brightness as both are in series with another bulb. (incorrect) (Constant current source model)
		YES/NO	No Justification

Analysis of answers related to Fig. 2a and 2b reveals that the teachers have a perception that changing the place of cells in the circuit affects the brightness of the bulbs. With this feedback one can see the loop hole in traditional teaching strategies. Hence to improve the teaching learning process some of the research based teaching strategies should be included in the pre-service and in-service teacher training programs. The identified mental model associated with alternative conceptions of the sample for question set II, is mainly due to current consumption model, universality of ohm's law and constant current source model.

Training module

Learning science usually involves fundamental restructuring of existing knowledge to bring in conceptual change. For conceptual change, it is important to understand the existing knowledge/ preconception, the learner carry to the classroom. It helps the facilitator to understand the thinking process of the learner and how they misinterpret when the facilitator/ instructor teach and they read. The teacher/ facilitator can help the student to acquire/ construct more productive models provided the teachers are equipped with knowledge of different mental models and teaching sequences (Borges *et al.* 1999). Constructivism approach of teaching-learning process helps in building mental models and is the root of long-term memory and recall. This research work reveals that though the teachers have content knowledge i.e. the theories of electricity but the functionality is missing. For constructing knowledge many instructional modules have been developed based on cognitive models like cognitive conflict and bridging. However development of physics by inquiry (Pbl) is a very strong research based method, which can be used to construct the related concepts by bringing in conceptual change. This process helps in discovering rather than memorising and teaching is by questioning rather than by telling. Inquiry based physics learning is nothing but active learning laboratories in which along with traditional laboratory work interactive approach has been associated. During these periods students work in pairs with simple equipment and are guided to

reason through physical examples with apparatus and carefully prepared worksheets. Trained facilitators help students to find their own path to understand by guiding them with carefully chosen question. Pbl provide the students with opportunity for

- Thinking
- Reasoning and
- Making sense of what they observe during the experiment in a coherent and consistent fashion.

Lillian Mc Dermott has reported the success of Pbl for pre-service elementary school teachers at the University of Cyprus for simple DC circuits. For the present purpose a module was prepared by directly following the relevant Pbl given in the book entitled “Physics by Inquiry” an introduction to physics and the physical sciences, Volume-II published by John Wiley & Sons. INC, 1995 written by Lillian C. Mc Dermott with Peter S. Shaffer and Mark L. Rosenquist and Physics Education Group, University of Washington. This module is prepared for understanding the circuits with single cell and multiple bulbs. However similar module can be prepared for multiple cells and multiple bulbs. One practical session of two hours duration had been utilized for the intervention, by dividing the sample into thirteen groups.

The students were instructed to go through the module (appendix III) and answer the questions which were followed by a group discussion.

Post Test

A post test was conducted. A gap of fifteen days time was in between the pre-test and post-test. The reliability of the post-test was ascertained to be 0.83 Its content validity was established by a group of expert. The learners were allowed to check their results with the staff members after depositing the post-test problem. The questionnaire used for post test has been given in appendix-II. It contains Part A & Part B similar to Set I & Set II used for pre-test given in appendix-I. The marking pattern is the same as the pretest. The mean score of post-test is 6.42. t-test was used to determine whether two means i.e. the mean of pretest and post test are significantly different? Here t-test for non-independent samples was used. t-value was calculated to be 5.645 for 25df. Thus one can safely conclude that after the intervention there is significant improvement. Thus the Pbl teaching strategy proved to be very effective.

Conclusions

- Physics teachers with highest formal education and long teaching experience possess alternative conceptions related to simple DC circuits.
- Mental models like current consumption model, constant current-source model and universal applicability of ohm’s law are prevalent with the teachers.
- Scores of Set-I and Set-II are not correlated.
- Mean score of Set-I and Set-II are significantly different. This indicates low performance in Set-II compared to Set-I.
- Physics by Inquiry is proved to be an effective teaching strategy for the Indian physics teachers for teaching DC circuits.

Suggestions

- In Physics teacher training programme (pre-service/ in-service) innovative teaching strategy like Pbl should be included.
- Teaching module based on innovative teaching practices should be developed for all concepts in physics and included in teacher training programme.

For appendix – I,II,III contact dr.mad.ma@gmail.com

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TEST ON SIMPLE DC CIRCUITS

Name:


School/College:

Gender:

Date:

Instructions

In the following circuits it is assumed that

- a. the cells are ideal cells i.e the internal resistances are zero.
- b. the connecting wires have zero resistance.
- c. all the cells are identical
- d. all the bulbs,  are identical.

Set-I

Study the following four circuit diagrams and answer the questions

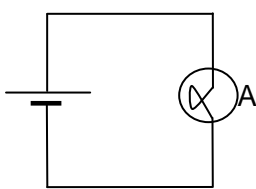


Fig. 1a

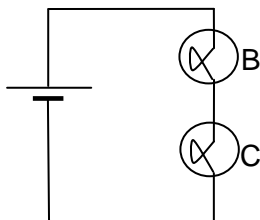


Fig. 1b

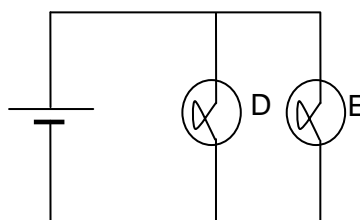


Fig. 1c

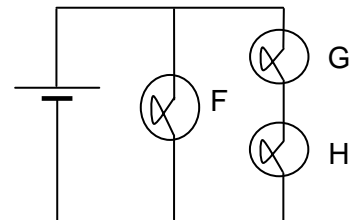


Fig. 1d

Part (A)

Choose the correct option (\surd)

- 1 a Bulb A is brighter than bulb B : YES/NO
- 1 b Bulb B is brighter than Bulb C : YES/NO
- 1 c Bulb D is brighter than Bulb E : YES/NO
- 1 d Bulb F is brighter than Bulb G : YES/NO
- 1 e Bulb G is brighter than Bulb H : YES/NO

Part (B)

Grade the bulbs A,B,C H in order of decreasing brightness.

Part (C)

Explain your answers for questions given in part-A.

Set-II

Study the following circuit diagrams and answer the given questions.

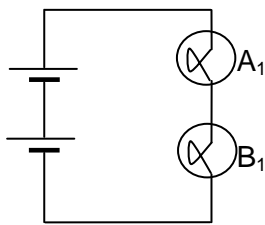


Fig. 2a

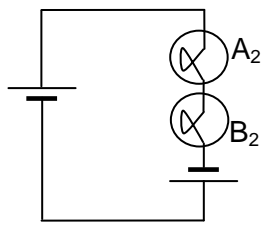


Fig. 2b

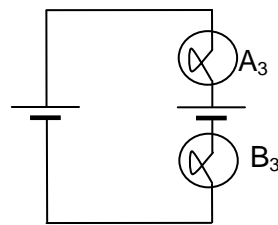


Fig. 2c

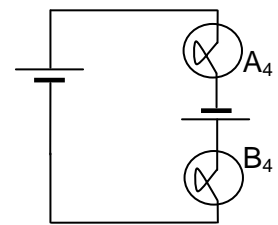


Fig. 2d

Part (A)

Choose the correct option (\surd)

- 2 a. Brightness of bulb A and B will be same in all the diagrams. : YES/NO
- 2 b. Brightness of bulb B₁ & B₂ are not equal : YES/NO
- 2 c. Brightness of bulb B₂ & B₄ are not equal : YES/NO
- 2 d. Bulb B₄ is brighter than bulb B₃ : YES/NO
- 2 e. Bulb B₄ is brighter than bulb B in set-I : YES/NO

Part (B)

Grade the bulbs B_1 , B_2 , B_3 , B_4 in order of decreasing brightness.

Part (C)

Explain your answers, given for the questions in part-A

Appendix-II

TEST ON SIMPLE DC CIRCUITS

Name:

School/College:


Gender:

Date:

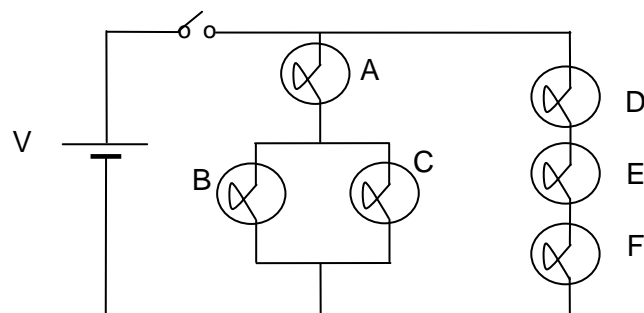
Instructions

In the following circuits it is assumed that

- a. the cells are ideal cells i.e the internal resistances are zero.
- b. the connecting wires have zero resistance.
- c. all the cells are identical

- d. all the bulbs,  are identical.

Study the following circuit diagram and answer the questions.



Part A

Choose the correct option (✓)

- 1 a. Bulb A is brighter than bulb C : YES/NO
1 b. Bulb B is brighter than bulb C : YES/NO
1 c. Bulb D & E glow with equal brightness : YES/NO
1 d. Bulb D is brighter than bulb F : YES/NO
1 e. If bulb C is removed brightness of bulb A will increase : YES/NO

Part (B)

Grade the bulbs A, B, C, D, E, F in order of decreasing brightness.

Appendix III

The module

Experiment No-I

Connect a battery with a single bulb using wires so that it will glow. Use a key to increase the longevity of the battery.

Exercise I-a

Is a complete circuit necessary for a bulb to glow? Does this observation suggest that the glow in an electric circuit is one way or round trip? Can you explain how a bulb glows?

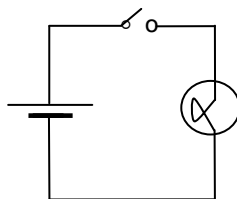


Fig. I

Experiment No-II

Connect another bulb in series with the first bulb. Close the switch

Exercise II-a

Compare the brightness of the bulbs with the brightness of an identical bulb in a single bulb circuit.

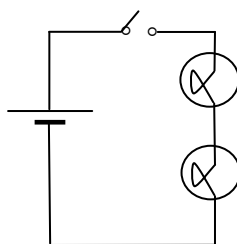


Fig. II

Exercise II-b

Compare the brightness of the bulbs in a series circuit with each other. What can you conclude from this observation about the amount of current through each bulb ?

Exercise II c

On the basis of your observations and reasoning you used to answer the above questions, respond to the following question-

Is current "used up" in the first bulb or the same amount of the current flow through both bulbs?

Explain your reasoning to a staff member/ facilitator.

Experiment No-III

Add a third bulb in series.

Exercise III b

Explain your observation with reasoning to a staff member.

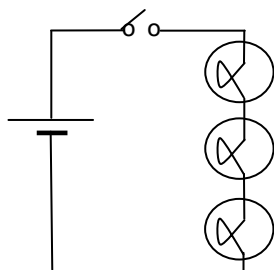


Fig. III

Experiment No-IV

Connect a bulb in parallel to the bulb in Fig I.

Exercise No-IV a

Compare the brightness of each bulb with the brightness of the bulb in Fig. I

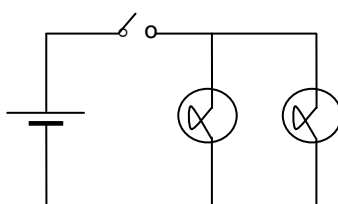


Fig. IV

Exercise No-IV b

Compare the brightness of the two bulbs in the two bulb parallel circuit with each other. What can you conclude from observation about the amount of current through the bulb?

Exercise No-IV c

On the basis of your observations and reasoning you used to answer the above question respond to the following question.

- Compare the brightness of the bulbs when the two bulbs are both on the same side of the battery and when they are on different sides.
- Compare the brightness when each bulb has separate leads to the battery and when the terminals of the bulbs are connected together and then connected to the battery.

Exercise No-IV d

Describe the flow around the entire circuit for the two bulb parallel circuit. What do your observations of bulb brightness suggest about the way the current through the battery divides and recombines at the junctions where circuit splits into the two parallel branches?

Exercise No-IV e

What can you infer about the relative amounts of current through the battery in a single-bulb circuit and in a circuit in which two identical bulbs are connected in parallel across the battery?

Exercise No-IV f

Does the amount of current through a battery appear to remain constant or to depend on the number of bulbs in a circuit and how they are connected?

The learner after using the above module will realize that

- Brightness of the bulbs in Fig. I and Fig. IV are the same indicating that current passing through them is the same. In Fig. IV current from the battery is divided equally between the two bulbs. The

flow of current through the battery for the circuit as given in Fig. IV is more than circuit given in Fig. I.

- Adding bulbs to a circuit may increase or decrease the total resistance. It depends on how you add them. If you add them in parallel, you give the current more pathways, so the total resistance is less. If you add them in series the resistance is more and current through the bulbs will be less and the brightness decreases.