PRESENTATION OF STRUCTURE OF ATOM IN CHEMISTRY TEXTBOOKS IN INDIA BASED ON A HISTORY AND PHILOSOPHY OF SCIENCE FRAMEWORK

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Background knowledge about the History and Philosophy of Science (HPS) will avoid questions like theories and models which have been proved false are useless. Rather students will appreciate the contribution of scientists whose theories/models have become the base for further progress of Science. The textbooks however fail to create this connection between the historical theories and contemporary theories. This discontinuity not just creates an incomplete picture of Science but also is a cause for increasing disinterest in science among students. Structure of Atom is one such topic which has tremendous scope to address HPS issue. The present paper is an attempt to study how Structure of Atom is dealt with in four commonly used Chemistry textbooks in Delhi.

Keywords: history and philosophy of science, structure of atom, textbook

INTRODUCTION

The 'Structure of Atom' is an important topic in school chemistry which lays the basis for further understanding of properties of matter. It is introduced in class IX Science textbooks and is discussed in detail in class XI. The chemistry textbooks of class XI deal with structure of atom in a historical manner discussing Thomson, Rutherford, Bohr and Quantum Mechanical model. This paper is an effort to analyze one of the chapters; 'Structure of Atom', of the textbooks used most frequently by teachers at senior secondary level, from a historical and philosophical perspective. The textbooks have been selected on the basis of discussion with teachers and students regarding the most widely used books by them. The framework developed by Niaz (1998) has been used for the analysis of textbooks. The same framework has been used by Niaz to analyse 53 chemistry textbooks in USA and by Niaz and Coştub (2009) to analyse 21 chemistry textbooks in Turkey, 41 physics textbooks by Maria Rodriguez and Niaz (2004).

NEED FOR STUDY

Historians and philosophers of science have recognized the importance of controversies in the progress of science. Research shows that there is a need to address questions related to philosophy/ nature of science and history of science. The notion often conveyed through the transaction of science curricula is that science has a neat, systematic process and old theory gives way to the new theory without contradictions. It appears as if all scientists work under the reigning paradigm and development of a new theory or novel discoveries occur overnight with a certain spark; EUREKA. The philosophical aspect of science is neglected in textbooks used throughout the world. The textbook contain inadequate information about the rival theories and tentative nature of scientific knowledge while more emphasis is on passing on information to the students.

During informal interviews with students of class XI and XII, it was found that students find the chapter 'Structure of Atom' difficult and fail to appreciate the need to study contribution of Thomson, Rutherford and Bohr models. Further, the manner in which, for example, the cathode ray experiment is described in the textbooks gives an impression that as soon as cathode rays were discovered, the electron was discovered, identified and named without any controversy or further probe. These observations created an interest to find out how the evolution in the model of atom is discussed in the textbooks.

Structure of atom is discussed in a chronological order in the textbooks which does point at the tentative nature of scientific theories but other important aspects of method of science like progress in science occurs through competition between rival and conflicting frameworks, importance of mathematical and philosophical issues are often ignored. Moreover, it develops scientific reasoning skills like creating models to explain experimental findings, making inferences from observations. The study of Rutherford or Bohr's model makes students understand through reasoning how based on few observations, new models are built and old models discarded (McKagan, Perkins & Wieman, 2008).

Various studies by Niaz on the controversies related to the developments in the structure of atom and his analysis of chemistry textbooks in USA to look into the philosophical and historical aspect represented in the textbooks created an interest to find out how the topic is dealt in India.

OBJECTIVE OF STUDY

The objective of the study is to evaluate general chemistry textbooks published in India based on the eight criteria developed by Niaz (1998).The textbooks widely used by chemistry teachers were analyzed.

METHODOLOGY

Using the framework of analysis used by Niaz to analyze the chemistry textbooks (From Cathode rays to alpha particles to quantum of action: A rational reconstruction of structure of the atom and its implications for chemistry textbooks) here I present the evaluation of 4 Indian general chemistry textbooks:

Textbook A: Chemistry Class XI Part 1, NCERT 2002

Textbook B: Chemistry Class XI Part 1, NCERT 2006

Textbook C: Saraswati Chemistry a textbook for class XI (2010)

Textbook D: Pradeep's New Course Chemistry for class XI (2010)

It is important to note that the criteria used in this study are precisely the same as used by Niaz (1998) to evaluate general chemistry textbooks published in U.S.A. To refer to the criteria based on the three models, the following symbols are used: T = Thomson; R = Rutherford; and B = Bohr.

ANALYSIS

Atomic structure chapter is introduced in class IX (All three models introduced), but not in a detailed manner. The description starts with Dalton's model, followed by Thomson's model. Thomson's plum pudding model is explained but the cathode ray experiment is not mentioned. The α- rays scattering experiment is explained with diagrams and satisfactory description of observations of the experiment. The limitation of Rutherford's model to explain stability thus formulation of Bohr's model is discussed in brief.

Class XI textbooks discuss the structure of atom in detail. The analysis of the three models (Thomson, Rutherford and Bohr) is as follows:

Thomson Model:

T1 – Cathode rays as charged particles or waves in the ether.
T2 – Determination of mass-to-charge ratio to decide whether cathode rays were ions or a universal charged particle

In all the books analyzed the discussion on structure of atom starts with Dalton and the mention that number of scientists like Faraday worked on cathode ray discharge tubes. The cathode ray experiment result is summarized and regarding the effect of magnetic and electric field it says, "In presence of electrical or magnetic field, the behaviour of cathode rays are similar to that expected from negatively charged particles suggesting that cathode rays consist of negatively charged particles called electrons" (p. 28, Textbook B)

However, the controversy related to Hertz (1883) experiment that showed cathode rays were not deflected by an electrostatic field, thus questioning the particle nature of the cathode rays is not mentioned. The existing ether theory and particle nature debate is nowhere mentioned. In fact, on basis of information informal interactions with students and teachers it is found that there existed ether theory, is not known to them.

The properties of cathode rays are summarized in the book. The text also mentions finding the e/m ratio by Thomson and the value is constant but there is no mention of the need to determine e/m ratio. The impression one gets from the text is that electron was known at that time and the experiment was to prove that electrons are constituent particles of all atoms. The fact that e/m ratio would help Thomson to identify cathode ray particles as ions or a universal charged particle, is not mentioned in the book.

The fact that other scientists like Schuster also had determined the e/m ratio, but lacked "Thomson's ability to speculate , elaborate alternative hypotheses and models, and perhaps most importantly formulate a theoretical framework for his experimental findings, led him to foresee and conceptualize what his contemporaries ignored" (Niaz, 1998). Thus along with experimental data bold novel ideas that help to explain the data are also important for the progress of science. This description is lacking in the book.

The textbook B mentions the experimental details but lacks on account of an overall interpretation of the event. The following two examples are presented to illustrate how some of these textbooks present scientific knowledge as 'rhetoric of conclusions':

"The results of these (cathode ray discharge tube) experiments are summarized below ------- in presence of electrical or magnetic field------ the characteristics of cathode rays (electrons) do not depend upon the material of electrodes and the nature of the gas present in the cathode ray tube. Thus, we conclude that the electrons are basic constituents of all atoms." (p. 28)

However in textbook A, there is no mention of the cathode ray discharge tube experiment, its results or nature of cathode rays which led to discovery of electron. The description appears to convey that scientists discovered the electron, proton and neutron and then different models were framed instead of looking into the aspect historically starting from cathode ray experiments.

The new edition of NCERT, textbook B, takes into account the importance of the historical aspect and there is discussion of how electron, proton and neutron were discovered.

Thomson's model is described in vacuum, i.e., in absence of any experimental or theoretical background that led to his proposed model.

Textbook C mentions that number of scientists like Goldstein, Plucker, Crookes and Hertz worked on cathode ray discharge tubes gives an idea of how different scientists work on the same problem and only few can explain the observations using a theoretical framework.

Textbook D mentions that number of scientists like Crookes, Thomson worked on cathode ray discharge tubes. The cathode ray experiment result is summarized and regarding the effect of magnetic and electric field it says, "They (cathode rays) are deflected in presence of electrical or magnetic field in such a manner which suggests they are negatively charged particles" (p.55)

Thus none of the books analyzed mentioned the historical background and philosophical aspect of Thomson model. There is no mention of criteria T1 and T2 in any of the 4 textbooks.

Rutherford model:

R1 – Nuclear atom.

Rutherford model discussion in all the analyzed textbooks starts with alpha ray scattering experiment. Thomson's model was unable to explain the alpha ray scattering experiment, so Rutherford proposed a model. The controversy about which model is correct continued. The textbooks give an impression that after the alpha ray experiment the Rutherford model was accepted overnight and Thomson's model was discarded.

However, textbook C mentions Rutherford designed an experiment to verify Thomson model but the experimental observations were to the contrary. The inability of Thomson model to explain the result of the α rays scattering experiment and the formulation of Rutherford's atomic model is dealt with satisfactorily, but the reader gets an impression that accepting the new model was a smooth transition (from Thomson to Rutherford model).

In all the four textbooks analyzed, satisfactory explanation of Thomson's plum pudding model and its limitation to explain experimental result of α- particle scattering experiment is given.

"The results of scattering experiment were quite unexpected (diagram given). According to Thomson model of atom, the mass of each gold atom in the foil should have been spread evenly over the entire atom, and α- particles had enough energy to pass directly through such a uniform distribution of mass. It was expected that the particles would slow down and change directions only by small angles as they passed through the foil." (p. 31, textbook B)

R2 – Probability of large deflections is exceedingly small, as the atom is the seat of an intense electric field.

There is a satisfactory explanation of observations and conclusions drawn from α- particle scattering experiment in all four textbooks analyzed.

"Rutherford and his students [Hans Geiger and Ernest Marsden] bombarded very thin gold foil with α- particles. …… a very few α- particles (~1 in 20,000) bounced back, that is were deflected back by nearly 180^{o}. ……The positive charge and most of the mass of the atom was densely concerted in extremely small region." (pp. 31-32, Textbook B)

R3 – Single/compound scattering of alpha particles.

There is no mention of the rivalry between two conflicting frameworks, namely Rutherford's hypothesis of single scattering and Thomson's hypothesis of compound scattering, put forward to explain Rutherford's alpha particle experiment in any of the textbooks.

Bohr's Model:

B1 – Paradoxical stability of the Rutherford model of the atom.

Formulation of Bohr's model in the textbooks is discussed in the backdrop of limitations of Rutherford's model being unable to explain stability of the atom and two major developments: Dual nature of electromagnetic radiations and atomic spectra. The model follows the description of work of Maxwell and Planck and the dilemma related to nature of matter. The paradox is satisfactorily discussed in all the textbooks.

"The motion of electrons around the nucleus contradicted the James Clark Maxwell's theory of electromagnetic radiations. According to this theory, when any charged particle moves under acceleration, it loses energy in the form of electromagnetic radiations. The electron is a charged particle and revolves around the nucleus. The circular motion being accelerated motion, the electrons will consciously lose energy in the form of electromagnetic radiation. So the electrons should move in a spiral and fall into the nucleus."(p.61, textbook C)

B2 – Explanation of the hydrogen line spectrum.

The book provides explanation of hydrogen spectra and considers dual behavior of electromagnetic radiation and experimental result of atomic spectra to have led to the formulation of Bohr's model. Thus there is an attempt to historically show the development of Bohr model, but a spectroscopic version of the model is discussed, though "the Rutherford Memorandum", shows he was not fully aware of the implications of spectroscopic research for his problem" (Niaz, 1998; Bohr, 1913; Bohr, 1922). The text mentions about fixed values of energy and angular momentum of the orbits mentions that it was the first model based on "quantization".

Textbook B, mentions about fixed values of energy and angular momentum of the orbits but does not mention the term "quantization". Quantization is explained in textbook D in detail (p. 2/34)

Textbook C deals satisfactorily with B2 and the text provides explanation of hydrogen spectra. The development of Bohr's model however is linked to the paradoxical stability of the Rutherford model of the atom, but does not link hydrogen spectra with formulation of Bohr's model, which most of the books do. (Niaz, 1998)

"It was a young Danish physicist Niels Bohr who, while working with Rutherford, made theoretical calculations and showed that according to the laws of classical physics, the electron in Rutherford model of an atom would not be stable and fall into the nucleus in about 10^{-8} second. In 1913, he proposed a most unconventional model of the atom. He argued that since classical physics leads to wrong conclusions about the behavior of electrons in an atom, these laws do not apply to them" (p. 69, textbook B)

Thus an idea that it is not just experimental data but also strong theoretical framework that leads to questioning of existing theories or models is put across to the readers.

B3 – Deep philosophical chasm.

All four textbooks satisfactorily discuss the deep philosophical chasm. There is a description of electromagnetic wave theory and quantum mechanical theory. The text mentions

observations like black body radiations, photoelectric effect (in detail) and line spectra of hydrogen (in detail) and also interference and diffraction leading to leading to bold assertion of dual nature of matter. Showing how scientists when faced with difficulties often resort to such contradictory "grafts".

Procedure for Implementing the Criteria

The following classifications used by Niaz (1998) were used to evaluate the textbooks:

Satisfactory (S): Treatment of the subject in the textbook is considered to be satisfactory if the role of conflicting frameworks based on competing models of the atom is briefly described.

Mention (M): A simple mention of the conflicting frameworks or controversy with no details.

No mention (N): No mention of the conflicting frameworks

Each textbook was awarded points on the following basis: Satisfactory (S) = 2 points; Mention (M) = 1 point; No mention (N) = 0 point.

S. No	Textbook	Criteria								Total
		T1	T2	R1	R2	R3	B1	B2	B3	
1.	NCERT (2006)	N	N	S	S	N	S	M	S	9
2.	NCERT (2002)	N	N	S	S	N	S	M	S	9
3.	Saraswati Chemistry (2010)	N	N	S	S	N	S	S	S	10
4.	Pradeep's New Course Chemistry	N	N	S	S	N	S	M	S	9

Table 1: Evaluation of chemistry textbooks based on a history and philosophy of science framework*

Result of analysis of all four textbooks on basis of Mathematical details to understand the atomic model, Illustrations of experimental apparatus and Illustrations of models:

1. Thomson and Rutherford model have no mathematical details. Bohr's model details of energy, radius and angular momentum expressions of orbits are given.
2. Illustrations of the experimental set up used are given for Thomson (except textbook A) and Rutherford model in each textbook. The diagram showing Lyman, Balmer and Paschen transitions (line spectra of hydrogen) is given.
3. Only Thomson's model is illustrated in textbooks A and B, both Thomson and Rutherford model in textbook C and all three models; Thomson, Rutherford and Bohr are illustrated in textbook D.

CONCLUSIONS AND EDUCATIONAL IMPLICATIONS

The appreciation of the work, creativity and insight of scientists and the importance of sound theoretical background for discoveries made in the past is lacking in the students as the textbooks fail to create an awareness of the same. Historical treatment will help students understand how revisions are made in pre-existing models and theories. The HPS treatment will help create an understanding of models in terms of usefulness, thus giving scope for

imaginative variations which will create deeper interest and understanding instead of rote learning. The progress of science is seen a sudden event of an apple falling and Newton formulating the law of gravitation, Kekule dreaming of snakes and coming up with the structure of benzene and not as a result of continued effort of scientists and their curiosity. Most of the textbooks deal with experimental details based on observations and generally ignore the "heuristic principles" (Schwab, 1974). The textbooks analyzed lacked a philosophy of science perspective; the developments in the formulation of structure of atom are not seen within a historical framework. The following observations are made on analyzing the textbooks:

(i) Thomson's experiment on cathode rays are mentioned in all books except the older edition of NCERT, but the emphasis is on experimental details and observation not on the controversy with regard to nature of cathode rays i.e. charged particles or waves in ether.

(ii) Thomson's determination of e/m ratio and the value of the ratio are mentioned but the need to find e/m ratio i.e. to identify cathode rays as ions or as universal charged particles is nor discussed neither mentioned.

(iii) The alpha particles scattering experiment is mentioned in all the textbooks along with the crucial finding that 1 in 20,000 particles deflected through large angles and how this observation was not in agreement with the Thomson model.

(iv) Rutherford model had to compete with rival framework of Thomson model and the acceptance of Rutherford model was not overnight event. Rutherford's hypothesis of single scattering and Thomson's hypothesis of compound scattering to explain the observations of alpha particle scattering experiment is not discussed in any book.

(v) All the books mention Bohr proposed a model to explain the paradoxical stability of Rutherford model but the Hydrogen spectra as a main contributing factor is also mentioned by most of the books.

(vi) The books discuss "quantization" of energy and angular momentum as the major contribution of Bohr.

All books take into account the historical events- Maxwell's electromagnetic waves theory; Planck's quantum theory and the inability of both to explain the nature of light alone thus dual nature of light being accepted to resolve the dilemma is discussed in detail.

Thus, the textbooks fail to look into the topic with a historical perspective, laying more emphasis on experimental details. The ignorance of textbooks to discuss the importance of competition between rival frameworks in progress of science gives an impression to the students that science follows a smooth transition from one theoretical framework to the other with help of experiments to show the limitations of existing theory (Many a times experiments are done to support the existing theory, the result might prove otherwise). The mathematical and theoretical means to point out the drawback of theories (mentioned in the books in case of limitations of Rutherford's model on basis of classical physics) shows the importance of thought experiments in science (the term is not mentioned in any of the textbooks).

The study of history of science is a neglected field. The importance of history and philosophy of science has been emphasized in various researches in science education. Not just the appreciation of the work of scientists but an understanding of nature of science is important

for creating and reviving the lost interest in science. Knowing about the way the theories are developed, understanding the importance of observation, hypothesis, control experiments and thought experiments will help in understanding the method of science.

The tentative nature of science has been taken up in the textbooks but the coexistence of rival theories needs to be discussed in textbooks so that an idea of a sudden overnight change (that exists among students) is replaced. I would once again emphasize on the need to create an understanding of history of science so that students do not carry wrong information about how science progresses. The paper was an attempt to show how the historical and philosophical aspects are overlooked or wrongly stated in the textbooks, leading to an understanding of nature of science which does not actually represent the nature of science.

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