Learning of Atomic Physics and Quantum Mechanics: Which should Begin First

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Abstract

What are the differences and similarities between atomic-physics studies at different peoples (Han, Kazak and Uygur peoples in the same university) across Xinjiang (a far-west district in PR China which is a border for previous USSR and Kazak)? In this short report we focus on issues relating to the learning style of different-people students to pass the atomic physics course in physics department even the quantum mechanics course has not been taken before.

Keywords: Minority people, memorizing, bilingual

1 Introduction

Atomic physics is the academic subject that studies the inner workings of the atom as well as the interactions of the environment and atoms. It remains one of the most important testing grounds for quantum theory, and is therefore still an area of active research, both for its contribution to fundamental physics and to technology. Furthermore, many other branches of science rely heavily on atomic physics. The following gives a few examples: Astrophysics, plasma physics, atmospheric physics, solid state physics, chemical physics and radiation physics for physical science. Chemistry (analysis, reaction rates), biology (molecular structure, physiology), materials science, energy research, fusion studies are for other sciences. Lasers, X-ray technology, NMR, pollution detection, medical applications of devices (lasers, NMR etc.) are for direct applications.

Unfortunately the study of physics is not seen as a good option today in China (PR China). The worst holds for the far-west of PR China (PRC), like Xinjiang district now\textsuperscript{1−2}. The area of Xinjiang district is around 1/7 of the total area of PRC. The capital city of the Xinjiang district is Urumqi (where around 2.5 millions of Han, Uygur, Kazak peoples live therein) and there are limited educational resources like universities and academic institutes (the most important ones belong to the China Academy of Science or CAS) up to now\textsuperscript{1−2}. Most of those students studying in physics prefer choosing material, condensed matter and optical physics as their major. Nowadays even a few of the best (physics) postgraduates (holding MSc degrees) can only got teaching jobs in high schools in Urumqi.
The decrease of interest in the study of atomic physics (an undergraduate (UG) course in PR China’s university) has, as we have already surveyed, two important causes. The first reason is that the job market as well as the chances for postgraduate study in Xinjiang (PR China) actually requires few atomic-physicists. The second is that atomic physics, as an important field of knowledge, seems to have reached a plateau, and no immediate revolutionary developments in high technology are foreseen, at least for Xinjiang District in PR China.

Our paper is structured as follows: in Section 2 we give some data on the verification of atomic-physics teaching in Xinjiang Normal University; in Section 3 we describe the details of the comparative study between different-peoples UGs and in the last section we discuss the results. The presentations seem to us significant and interesting, not just in relation to the undergraduates that have been tested, but for the current system of atomic-physics teaching, and future reform.

2 Verification of Atomic-Physics Learning

We shall present an evaluation system for the primary learning of atomic physics (UG courses) in Xinjiang Normal University (XJNU). This course is offered for year-2 Han-people UGs but for Other-people UGs, they can only study this course at year-3. The latter is due to the poor listening as well as the writing of Mandarin (Putonghua or Han-language) and Chinese, not to mention the speaking of Mandarin. After entering the university (XJNU), all Other-people UGs should learn Mandarin (speaking and listening) and Chinese (writing) at year-1 academic year. The remaining parts of the time during year-1 all Other-people UGs should also try to catch up those prerequisites, like basic mathematics. Note that there exists a task of training ethnic bilingual teachers (mainly for high schools) in Xinjiang around 2004 for some universities and institutes therein at Urumqi. All UGs have the well-known (Chinese) textbook: Atomic Physics written and edited by Ch’u Sheng-Lin. We like to remind the readers that Dr. Ch’u S-L got PhD from Univ. Chicago in 1935 (under the thesis supervisor: Prof. Depmster, AJ: working in the high frequency spark field).

Most of the China universities adopt this textbook for UGs atomic-physics teaching. In average it is a 4-credits UG course for one academic semester and most of the universities in China urge the lecturer of this course to complete the teaching within 18 or 19 weeks with 4 or 5 (class) hours per week.

To be specific, the textbook contents are listed below:

Chapter 1. Introduction to Atoms
Chapter 2. Energy Levels and Radiation of Atoms
Chapter 3. Fundamentals of Quantum Mechanics
Chapter 4. Alkali-metal Atoms and Electron Spin
Chapter 5. Multi-Electron Atoms
Chapter 6. Atoms in Magnetic Field
Chapter 7. Shell Structure of Atoms
Chapter 8. X-ray
Chapter 9. Molecular Structure and Molecular (Optical) Spectra
Chapter 10. Atomic Nuclei
Chapter 11. Fundamental Particles

Due to the limitation of time and the knowledge of UGs for each semester, normally only around 8 chapters are covered during the teaching. Note that most of the contents of this textbook (up to Chapter 7) borrow those in Refs. 6-9 and relevant material from Russia. There are homework assignments for UGs of this course and the percentage is only 10% for the total score (as UGs will copy the solutions of the problems easily before submitting). The primary verification of the understanding as well as learning of atomic-physics for UGs from this course is through the final examination or (written) test.

Two groups of UGs from Xinjiang Normal University were tested on their knowledge acquired by having attended a course in atomic physics. Fig. 1 gives the exact distribution of questions on each chapter or main category for a (written) final examination (for year-2 Han-people UGs). There are 25 questions in total which are (i) single-choice problem : 10 sets (each of the problem is graded by points 2); (ii) filling-in problem : 7 sets (each of the problem is graded by points ranging from 2 to 4); (iii) simplified-answer problem : 4 sets (each of the problem is graded by points 5); (iv) calculation problem : 4 sets (each of the problem is graded by points 10).

There is limited percentage for Chapter 3 (related to quantum mechanics) because all UGs have trouble in rapid understanding the quantum-physics essentials before taking one semester quantum-mechanics course from a short chapter contents of the textbook. The latter situation is similar to other countries. This can be easily found out during the class teaching. For instance, students thought that the Heisenberg uncertainty relation is too abstract. The other difficult topic is related to the essence of spin!

As the prerequisite background (say, physical mathematics, electrodynamics, thermodynamics) is much more worse for Other-people (mainly Uygur- and Kazak-people) UGs, the detailed distribution of questions on each chapter or main category for a (written) final examination (for year-3 Other-people UGs) is slightly different from that in Fig. 1. This can be evidenced in Fig. 2. There are no (directly-linked) questions on Chapter 3 : Fundamentals of Quantum Mechanics. Please refer to Fig. 3 for similar details. Note that the maximal evaluation mark in China universities is 100/100. The difficulty characterization for both written examinations is only of medium difficulty. The 60-points grading means the passing an examination in China universities.
3 Comparative Study between Han- and Other-people UGs

We illustrate the distribution of (total) marks for the final (written) examination of atomic-physics course taken by year-2 Han-people and year-3 Other-people UGs, respectively in Figs. 4 and 5. The comparison could be directly figured out from these two figures. The number of Han-people UGs passing the final examination within the semester during which they attended the lectures is 27 (8 failed) reaches 77% (23% failed). Meanwhile around 92% (8%) Other-people (mainly Uygur- and Kazak-people) UGs passed (failed) the final examination within the semester during which they attended the atomic-physics lectures. The general trend was that the Mandarin (most of them are Han-people) UGs considered their theoretical background above and the practical comparable or below that of the Uygur and Kazak UGs. A trend was that to most of the year-2 Han-people UGs the focus is rather on understanding than on memorizing. However, as UGs still didn’t learn the course : Quantum Mechanics in details, their understanding (i.e., the ability to derive some of the simple formula in atomic physics) is limited. During the final examination, those who have better memorizing skill normally can get high scores! This is especially suitable to year-3 Other-people UGs since their Chinese as well as Mandarin are already poor enough (thus they try to keep in mind everything for the preparation of final (written) examination of atomic physics).

4 Discussion

We can further demonstrate some of the troubled details about the learning of atomic physics before attending the quantum mechanics course. For instance, consider this question : Try to obtain the rotating frequency, linear velocity of electron in the first Bohr orbit (orbiting a nucleus of hydrogen atom) (cf. Chapter 2 in Ref. 4). We can easily work out the solutions by noting the development of atomic physics.

Firstly in 1911 Rutherford discovered the nucleus. This then led to the idea of atoms consisting of electrons in certain orbits in which the central forces are provided by the Coulomb attraction to the positive nucleus. In 1913 Bohr produced his model for the atom. The key new elements of the model are:

(a) The angular momentum \( L \) of the electron is quantized in units of \( \hbar \) (\( \hbar = h/2\pi \)):
\[
L = n\hbar ; \text{ where } n \text{ is an integer.}
\]

(b) The atomic orbits are stable, and light is only emitted or absorbed when the electron jumps from one orbit to another.

When Bohr made these hypotheses in 1913, there was no justification for them other than they were spectacularly successful in predicting the energy spectrum of hydrogen. With the hindsight of quantum mechanics, we now know why they work. The first assumption is equivalent to
stating that the orbit must correspond to a fixed number of de Broglie wavelengths. For a circular orbit, this can be written:

\[ 2\pi r = n \times \frac{h}{p} = n \times \frac{h}{mv}, \]  

which can then be rearranged to give \( L = mvr = n \times h/2\pi \). With the final expression, we can directly calculate the linear velocity \( (v) \) and then the rotating frequency (set \( r = a_1, a_1 = 5.29 \times 10^{-11} \text{m} \) : the first Bohr orbit).

The second assumption is a consequence of the fact that the Schrödinger equation

\[ (H_0 + V)\psi = E\psi \]  

leads to time-independent solutions (eigenstates) where the simplest form of \( H_0 \) is

\[ H_0 \equiv -\frac{\hbar^2}{2m} \frac{d^2}{dx^2}, \]

and \( V \equiv V(x) \) is the possible potential. Furthermore, the derivation of the quantized energy levels proceeds as follows. Consider an electron orbiting a nucleus of mass \( m_N \) and charge \( +Ze \). The central force is provided by the Coulomb force:

\[ F = \frac{mv^2}{r} = \frac{Ze^2}{4\pi \varepsilon_0 r^2}. \]  

As with all two-body orbit systems, the mass \( m \) that enters the formula is the reduced mass :

\[ \frac{1}{m} = \frac{1}{m_e} + \frac{1}{m_N}. \]

The energy is given by the sum of kinetic energy and potential energy

\[ E_n = \frac{mv^2}{2} - \frac{Ze^2}{4\pi \varepsilon r} = \frac{mZ^2e^4}{8\varepsilon_0^2\hbar^2n^2} \]

where we have used \( v = (nh)/(mr2\pi) \) and Eq. (3). This can be written as

\[ E_n = -\frac{R'}{n^2} \]

with

\[ R' = \frac{m}{m_e} Z^2 R_\infty, \]

where \( R_\infty \) is the Rydberg energy.

All UGs should memorize some of the results (say, quantized energy levels, the Rydberg energy : \( m_e e^4/(8\varepsilon_0^2\hbar^2) = 2.18 \times 10^{-18} \text{J} = 13.6 \text{eV} \), the (effective) Rydberg constant) which can be derived after learning the quantum mechanics.

Above mentioned facts could explain why the year-3 Other-people UGs got better scores than the year-2 Han-people after the final examination of atomic physics. Other-people UGs prepared the test as well as doing exercises mostly by memorizing. Note that here the year-3 Other-people
UGs were selected after their year-1 studies according to their better gradings of those courses they have taken during the first year study at XJNU. The teaching of atomic physics is now plainly in a unstable state. The interest of undergraduates for this discipline is falling sharply, and the general level of achievement is poor, as it is for specific abilities also (say, earlier knowledge of quantum physics). The solutions that we, as lecturer or instructors, have to grasp in order to overcome these circumstances are\textsuperscript{13}:

(i) A flexible teaching system for different-people UGs.

(ii) The use while teaching of computer and communication technologies: liable in themselves to render courses much more attractive.

(iii) Introduction of up-to-date themes, the study of which would provide undergraduates with highly useful knowledge in the field for which they are training. It is not normal for courses in atomic physics taught in the late 2000s to stop the learning at the level of knowledge that was the current in the 1940s. \textit{Acknowledgements.} The first author thanks the support of Xinjiang Normal University.

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Fig. 1 Distribution of problems for the atomic-physics final examination for Han-people UGs.
Undergraduate (UG) Course: Atomic Physics

Proportions of Question on each Subtopic or Chapter
(Other-People UGs)

Fig. 2 Distribution of problems for the atomic-physics final examination for Other-people (like Uygur and Kazak) UGs.
### Undergraduate Course: Atomic Physics

| Chp. 1 | Introduction to Atoms         | Chp. 5 | Multi-Electron Atoms        |
|--------|--------------------------------|--------|----------------------------|
| Chp. 2 | Energy Levels and             | Chp. 6 | Atoms in Magnetic           |
|        | Radiation of Atoms            |        | Field                      |
| Chp. 3 | Fundamentals of              | Chp. 7 | Shell Structure of          |
|        | Quantum Mechanics             |        | Atoms                      |
| Chp. 4 | Alkali-metal Atoms and        | Chp. 8 | X-Ray                      |
|        | Electron Spin                 |        |                            |

**Contents of Chinese Textbook: Atomic Physics (written by Ch’u S-L) [4]**

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Fig. 3 Outline of contents of the textbook (in Chinese) for atomic physics⁴. Dr. Ch’u S-L got PhD from Univ. Chicago around 1935 and was an expert in high frequency spark then⁵.
Fig. 4 Distribution of marks for the atomic-physics final examination for Han-people UGs.
Fig. 5 Distribution of marks for the atomic-physics final examination for Other-people (like Uygur and Kazak) UGs.