

Atomic Physics for Pupils: A Hands-On Lab

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Introduction

We describe our work devoted to middle school teaching of the basic concepts of atomic physics. We developed materials and techniques, both formal and informal, to deal with this subject in an effective and beautiful way. Such an improvement is urged from teachers and physicists. We put together their perspectives, with the addition of a « science center » perspective that, as argued, is very important also in schools at this stage.

We focused on the core of such three perspectives and could therefore see clearly many different approaches and criteria that are needed in physics teaching. Here we review these approaches and criteria together with the new didactic material that we developed in this framework.

We specify the various phases of the work, of the interaction between faculty staff, school teachers and museum educators. The materials and techniques developed are used in an « interactive lab » at the museum. Their « export » in ordinary teaching in classrooms is on the way.

Perspectives: School Teachers, Faculty Staff and Science Centers Crew

Since this Panel Session is dedicated to “Science centers, schools and Universities”, it may be not considered inappropriate to briefly recall the respective specificities and concerns of the different kinds of educators. Basic points need to be spelled out again and again, otherwise they slowly slip out of sight.

School Teachers may say “... we do not only have to teach the fundamentals of physics...”. They are focused on pupils. Pupils need to... grow up. Teachers are thus concerned with their whole development. “Pupils need to learn... to pay attention, to speak, to discuss, to work with other pupils, to carry on with the daily duty...”

Faculty Staff i.e. physicists, the depositaries of the discipline of physics. They may underline that “The subject is physics, and it’s overall important...”. They have specific concerns about the goals of teaching. “Pupils must... learn the fundamentals (with rigor, not make banal), be able to do experiments, to handle formulas...”.

Science Centers Crew, the chief articulators of informal teaching, have an important word to say about both pupils and methods. “*Pupils need... to run, to play, to explore, to discover, to use hands, to marvel, to have fun...*”. Their remark that “*particularly in young age, learning has to pass through this*” has a little touch of irony towards self-appointed “experts” neglecting this.

So much, in a nutshell, about the three perspectives (Fig. 1), while each of them has reached a very deep level of systematization, with a broad set of different theories, as well as dedicated books, journals, conferences, and so forth.

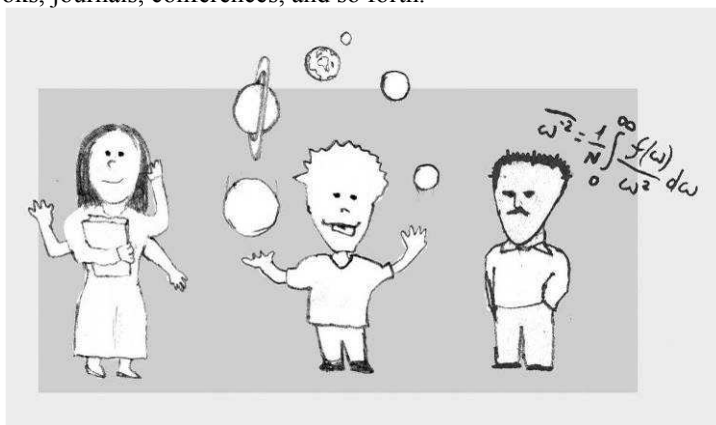


Figure 1: the three perspectives. From left to right, Teachers, Science Centers Crew, Faculty Staff

A huge amount of work has been done worldwide also in putting together the different perspectives. The interaction between School Teachers and Faculty Staff has been going on since the birth of mass education, and is at the root of most school textbooks. Mixed committees developed new courses, curricula, movies and materials [1]. Science Faculties and Departments started to act as places for teacher training and specialization.

It might have been that the coming on the scene of the third actor, Science Centers Crew, far from being just a fashion of the times, had been prompted by gaps swarming in programs, curricula, and praxis’s in the schools, especially at the earlier stages. As a result, Museums and Science Centers are increasingly becoming places for teacher meetings and teacher training [2].

Interweaving these three perspectives is the background of our work about the teaching of atomic physics for pupils. Let us discuss the approaches and criteria elaborated, and show how the materials we developed satisfy every and each perspective.

Criteria, Approaches and Materials

We developed an atomic model for the construction of molecules. The « **marble & spring** » model (Fig. 2). Its chief novelty and usefulness is the fact that the bonding is obtained via spring superposition, representing electron wavefunction superposition [3].

These objects (atomic models of hydrogen, oxygen, nitrogen, carbon) are the basis of activities about molecules. Pupils seat in pairs, and have a sheet with drawings and formulas

of molecules. The educators walk around, stop by, answer and ask questions, work together with each pair for a while. Pupils build molecules with simple, double, and triple bonds (Fig. 2a); they build little structures (radicals, rings), and they recognize these structures in more complex molecules (caffeine); a sort of chemical « synthesis »; they build polymers (Fig. 2b) and graphite planes.

Thus *the teacher* is satisfied, because these simple objects may help a great deal in introducing, explaining, deepening and recalling many topics. Objects have their own magic in communicating the content, in objecting to the mind and alerting it [4].

This model pleases *the physicist* more than the usual « ball & stick », because it is deeper. It features the representation of electron wavefunctions superposition, it easily allows double and triple bonds, it sketches bonding angles (water, benzene) and atomic shapes (« tetrahedral carbon »).

The science center educator is also satisfied. Pupils may memorize many chemical formulas, many molecular structures, many concepts... just playing. It is a game with simple rules. It is a hands-on activity. The little models, in their simplicity, are attractive.



Figure 2: « marble & spring » model. (a) H atoms, O₂ and N₂ molecules. (b) polyethylene.

These objects embed and allow many approaches and criteria (listed below, underlined), used also elsewhere in the laboratory. We now review them with some detail.

(1) Hands On philosophy may have become a shibboleth for every purpose, from the teaching of English to touristic guides and volunteer organizations. Still, in science teaching, the use of objects is unavoidable.

(2) The use of these little objects enhances Manuality. Pupils do not hold high hand-ability from birth. Hand-ability has to be exercised (Fig. 3a). There may also take place a « silent stimulus », a sound hunger for improving, when one sees others ahead in the construction.

(3) Improving of manuality goes hand in hand with performing the First « Little Experiments ». In high schools, students are supposed to do « serious lab work »: quantitative, data and linear regressions, repetition of landmark experiments, and so on. The soil for this has to be prepared. In middle school, performing of little experiments must be done, and in our opinion it shall consist in first place of: careful observation; description; use of scientific instruments (even if « scratch » they are scientific). In our interactive lab pupils also use **spectroscopes** and **monochords**.



Figure 3: « marble & spring » molecule construction gems (a) manuality (b) marvel.

(4) A most important criterion is that the activity must allow the springing of Marvel from pupil-side. Marvel is not made to gush by something external, artificially attached to an object or a phenomenon. But by the inner reason inscribed in the phenomenon itself.

This point has been splendidly clarified by Faraday. *«I hope you will now see that the perfection of a process - that is, its utility - is the better point of beauty about it. It is not the best looking thing, but the best acting thing, which is the most advantageous to us. This good-looking candle is a bad-burning one.»* [5]. What is true for a burning candle must be done also for a molecular model (e.g. Fig. 3b) or for a ball rolling down an inclined plane.

(5) As widely known, hands-on objects prompt a direct, active participation. The pupil is no longer a spectator. There is a Personal Engagement. He may also work and develop even further than what is requested, come up with really useful proposals, or good questions. And then he may feel rightly proud for the results he achieved.

(6) These activities also permit the pupils to take a Little Breath. There are moments when they are challenged up to some high standard, requiring all their efforts for concentration. Every teacher knows that it is important to punctuate these moments with other ones in which pupils may take a little breath. They relax the mind a bit, assemble what they have heard, prepare for the next topic.

(7) Objects are really helpful in preparing for the discussion. Because they raise questions, they call for an explanation. Two kinds of Explanations are possible in this laboratory. The first is seating side-by-side during the hands-on activity, a deep and targeted explanation. It may be given from the teacher as well as from the educator. And there is a kind of broad explanation, when the whole classroom is addressed. Many techniques and tools are important in this respect.

(8) A very important technique in « lecturing », and in physics lecturing nevertheless, is Narration or storytelling. The application of storytelling in science teaching has been often avoided, especially in high-schools. Strict formality has often been preferred.

It may be assumed that stories are neglected simply because they are not known, but this tells something about the lack of interest of the average physicist in the history of his subject. The difficult availability (and the scarce reading) of the writings of the scientists readily follows. Still, many scientists were masters in telling stories, and we use a few of them in the lab. The description of the cycle of *Plasmodium* is an example [6], and is very useful in describing the respective sizes and properties of humans, dapple-wing mosquitoes, plasmodium bacteria

and chloroquine molecules. It also vividly illustrates the interconnectedness of micro, meso and macro.

(9) Another very important technique is to call a pupil, putting him (or her) at the centre of the stage: welcoming him, asking him question, doing experiments together with him. He catalyzes the attention of his mates, he may also point out concepts. This Pupil Involvement takes place by an experiment – like ripple tank (Fig. 6a) and string « modes of vibration » – or drawing at the blackboard (Fig. 4), that we use in a peculiar way – see point (13) – projecting the computer over it.



Figure 4: discussing trajectory. A pupil is drawing the trajectory of a ball on « blackboard + PC »

(10) all these factors contribute to set the Discussion in a « Learning Atmosphere ». This atmosphere signals the interest of the pupil for the content of the lecture, and also that he is granting the lecturer with his confidence.

The construction of such an atmosphere is also important because it helps the pupil to put forward his own ideas. Discussion, confrontation, correction (if it is the case) and learning take place.

(11) it may be too early for formulas in middle-school, but it is surely not too early for Remarks on Physics Concepts. What physicists call « the physical meaning ». It calls for utmost clarity. The whole ensemble of hands-on, stories, questions... have this purpose, to convey the physical meaning. Its grasping by the pupil is in a sense a discovery, it enhances his creativity.

An example are the remarks on the inadequacy of the concept of trajectory in describing the motion of waves. First, together with the pupil, we focus on trajectory (Fig. 4), define it, and illustrate its broad applicability. Then we try to use the trajectory in the description of waves propagation (Fig. 6). Finally, we discuss its inapplicability. Wave motion needs other means of description.

It is not always possible to achieve this goal of « re-discovery » or « critical understanding », especially when the pupils have no other mean than relying on what the lecturer is saying. His remarks should in these cases form a seed of correct information.

The different models of the atom are an example. To underline the different quantitative properties of the atom (its combinatory power, the respective sizes of its parts, its shapes, the

properties of the electron) various analogies and models are used. Examples of different portraits of the atom are the « marble and spring » (combinatory power) and the « dandelion » (electronic orbital) (Fig 5).

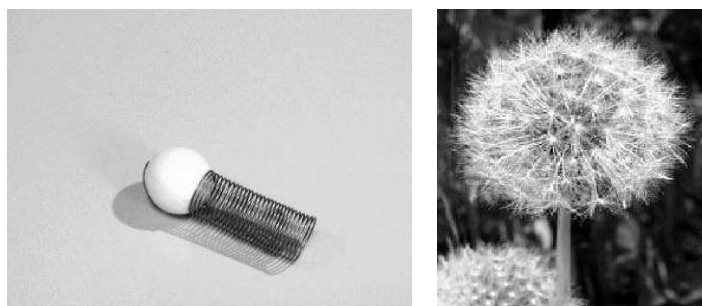


Figure 5: portraits of hydrogen emphasizing different properties.
(a) combinatory power (b) electronic orbital

(12) When possible, Experiments must be performed. In this lab analogies are drawn between processes at atomic scale and waves or harmonics. Experiments are needed to clarify the macroscopic part of the analogy. Every part of the experimental apparatus has to be presented, even if hidden. The question « what's going on here? » must be continuously answered and reformulated.

Most probably, these experiments (ripple tank, monochords, electron diffraction, spectroscopy) are among the first ones the pupils witness. The experimenter has therefore to take care of many things.

Questioning on the experimental setup and slight changes in the conditions are important. They lead to the recognition that the setup has been set up such and such so that a certain phenomenon was observable in the clearest way. Pupils may sometimes suggest modifications of the experimental conditions for the observation of correlated phenomena.

Anyway, they see that experiments need careful preparation. A lot of theory, of observations, goes therein. Caution and safety rules are also needed.

Even if « pre-quantitative » or « illustrative » experiments are more than hands-on. They require pupil concentration since these many things (what, why so, and if...) are simultaneously at work.

Experiments of atomic physics are performed: **electron diffraction** and **gas discharge spectra**. The sharp and precise lines of the latter are a forceful illustration of the fact that whatever the « mode of staying » of the electron around the nucleus, it must be characterized by some sharp and precise quantities.

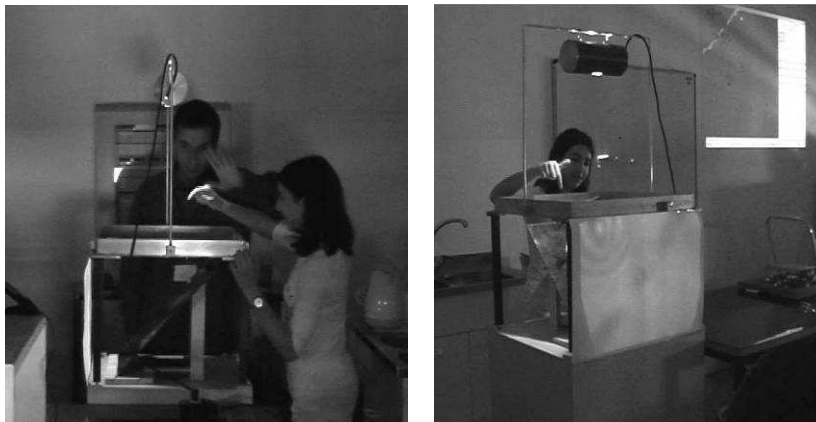


Figure 6: by the ripple tank. (a) pupil at the centre (b) experiment and computer

(13) The laboratory makes Use of the Computer again and again. It may be used for simulations, applets, physlets, animations, images and fancy dialogues between scientists to support storytelling, music and excerpts from movies.

A further use of the computer is the « **blackboard + computer** » approach (Fig. 4). We project on a white blackboard. And it is possible to draw on it (sometimes with the help of a ladder). Trajectories, rays, wavefronts, orbits... Pupils like this physical interaction with the computer.

How the interaction took place

This « interactive lab » has been first ideated in Dipartimento di Fisica and experimented in schools together with teachers. With the support of Museo Tridentino di Scienze Naturali it has been upgraded and (after another experimentation) adapted to this new context. It is part of the didactical offer of the Museo. In its 1st year it has been attended by 20 classes, more than 400 pupils.

At the moment there is « work in progress » to prepare booklets (on « marble & spring » model, and on spectrosopes) that make materials, ideas and resources easily available to the teacher, for everyday use in school activities.

References

- [1] The Physical Science Study Committee (PSSC) directed by Jerrold Zacharias dates back to 1956
- [2] The chief example is the Exploratorium Teacher Institute since 1984
- [3] a resource on physical molecular models is at <http://molvis.sdsc.edu/visres/sculpture/titles.jsp>
- [4] Jaki S 1999 Means to Message (Eerdmans) 13-23
- [5] Faraday M 1859-60 The Chemical History of a Candle (Dover 2003) (1st Ed Chautauqua Press)
- [6] Sherrington C 1937-38 Man On His Nature (Cambridge University Press, 2nd Ed 1963) 264-72