Collection of problems for physics teaching

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Abstract. Problems are an important instrument for teachers to mediate physics content and for learners to adopt this content. This collection of problems is suited for traditional teaching and learning in lectures or student labs, but also for all kind of new ways of teaching and learning, such as self study, long distant teaching, project oriented learning and the use of of remote labs/web experiments. We focussed on Rutherford´s scattering experiment, electron diffraction, Millikan´s experiment and the use of pendulums to measure the dependency of gravitational acceleration on latitude. The collection contains about 50 problems with 160 subtasks and solutions, altogether 100 pages. Structure, content, range and added value of the problems are described. The whole material can be downloaded for free.

1. Introduction

Problems and tasks for physics teaching at school and at university level have a very long tradition. Certainly the scope, the aims, the pedagogical intentions, the methodological approaches etc. have varied between extremes from one generation of teachers to the next: problems to be answered by writing essays versus problems overloaded by maths; complex questions versus step by step problems; etc.. Even learning acquired by students in the lab was sometimes - because of large number of participants - examined by theoretical oriented problems. In recent years multiple choice and quick exams of a lecture show up in the internet.

Our aim is to set out a rich collection of problems concerning various topics for the interested teacher/professor at work. We offer a collection of problems on the following topics: Rutherford´s scattering experiment, electron diffraction, Millikan´s experiment and problems concerning a real pendulum to measure gravitational acceleration, especially the dependency on latitude. The collection of problems can be downloaded for free in German and English from the RCL-portal [1].

2. Structure of the collection of problems

Figure 1a shows the content of the problems about Rutherford´s scattering experiment to illustrate the structure of the collection: tasks about theoretical background (I), about experimental setup (II) and about measurement/data analysis (III). Especially for teachers we describe teaching applications (0), we present elaborate solutions (IV, V and VI) and we close with helpful references (VII).
Each problem concerns one aspect of the experiment – in Figure 1b the multi-particle scattering modelled in Rutherford´s atomic model – and may consist of up to seven subtasks.

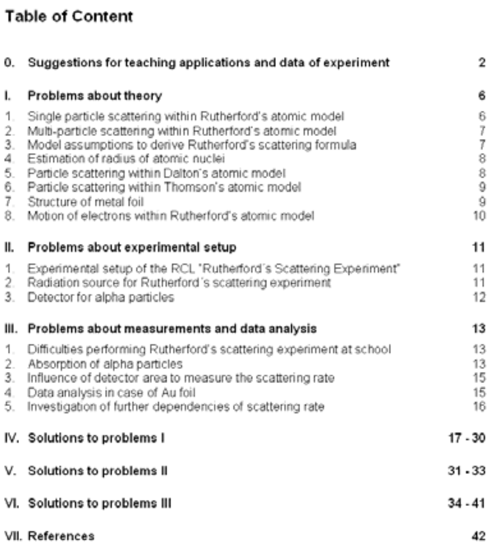
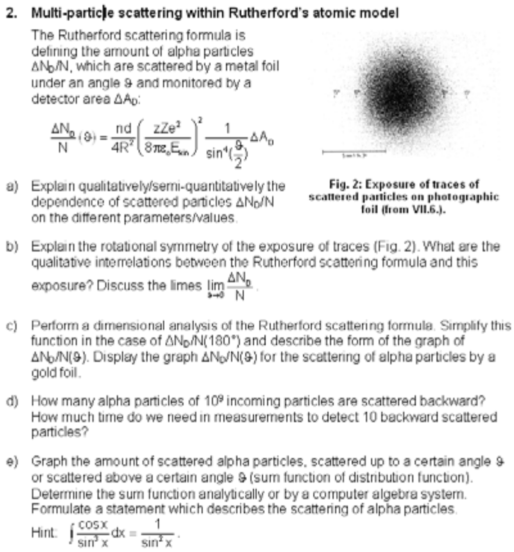


Table of Content

(a)



2. Multi-particle scattering within Rutherford's atomic model

The Rutherford scattering formula is defining the amount of alpha particles $\Delta N_D/N$, which are scattered by a metal foil under an angle ϑ and monitored by a detector area ΔA_D:

$$\frac{\Delta N_D}{N}(\vartheta) = \frac{nd}{4R^2}\left(\frac{zZe^2}{8\pi\varepsilon_0 E_{kin}}\right)^2 \frac{1}{\sin^4(\frac{\vartheta}{2})}\Delta A_D$$

Fig. 2: Exposure of traces of scattered particles on photographic foil (from VII.6.).

a) Explain qualitatively/semi-quantitatively the dependence of scattered particles $\Delta N_D/N$ on the different parameters/values.

b) Explain the rotational symmetry of the exposure of traces (Fig. 2). What are the qualitative interrelations between the Rutherford scattering formula and this exposure? Discuss the limes $\lim_{\vartheta \to 0} \frac{\Delta N_D}{N}$.

c) Perform a dimensional analysis of the Rutherford scattering formula. Simplify this function in the case of $\Delta N_D/N(180°)$ and describe the form of the graph of $\Delta N_D/N(\vartheta)$. Display the graph $\Delta N_D/N(\vartheta)$ for the scattering of alpha particles by a gold foil.

d) How many alpha particles of 10^9 incoming particles are scattered backward? How much time do we need in measurements to detect 10 backward scattered particles?

e) Graph the amount of scattered alpha particles, scattered up to a certain angle ϑ or scattered above a certain angle ϑ (sum function of distribution function). Determine the sum function analytically or by a computer algebra system. Formulate a statement which describes the scattering of alpha particles.

Hint: $\int \frac{\cos x}{\sin^3 x}dx = \frac{1}{\sin^2 x}$.

(b)

Figure 1. Collection of problems about RCL ‚Rutherford's Scattering Experiment'. (a) Table of content. (b) Problem I.2.

Table 1 gives information about the range of this collection: about 100 pages with 50 problems, 160 subtasks and solutions. About 60 % of the pages concern our elaborate solutions: the clearness of these solutions are guaranteed by extended texts, detailed derivations, step by step calculations and pictures.

Table 1. Collection of problems: number of problems (subtasks) for theory, setup and measurement/analysis. Number of pages for problems and solutions.

Experiment	Theory	Setup	Measurement/ analysis	Total	Problems + solutions
Rutherford's Scattering Experiment	8 (28)	3 (8)	5 (21)	16 (57)	11 + 25 = 36
Electron Diffraction	3 (8)	3 (7)	3 (9)	9 (24)	4 + 11 = 15
Millikan's Experiment	10 (31)	5 (16)	2 (7)	17 (54)	8 + 14 = 22
World Pendulum	4 (14)	3 (6)	3 (5)	10 (25)	5 + 15 = 20
Total	25 (81)	14 (37)	13 (42)	52 (160)	28 + 65 = 93

3. Added value of material

3.1. Problems concerning experimental setup

It is known that problems concerning experimental setup motivate learners more than abstract, theory oriented tasks. For example, lab-components must be addressed by their function or their sensitivity and limits discussed, standard error analysis in relation to used technology has to be performed and the resulting measured data has to be discussed with respect to the applied model and approximations used.

3.2. Suited for school and university level

In many countries one can observe a smooth transition from secondary to tertiary educational system: at school level we know of highly gifted pupils who already follow lectures. Very often school textbooks are modified versions of university textbooks. Table 2 shows the applicability of the collection for school and university level.

Table. 2. Number of subtasks for school, school/university and for university only.

Experiment	School	School/ university	University only	Total
Rutherford's Scattering Experiment	20	16	21	57
Electron Diffraction	14	8	2	24
Millikan's Experiment	21	20	13	54
World Pendulum	0	6	19	25
Total	55	50	55	160

3.3. Suited for self study

It is well known that a high percentage of learners, solving problems by themselves, drop their initiative when the first difficulties show up. Therefore we tried to organize the subtasks with increasing level of difficulty and complexity. In addition, the solutions can act as a tool for self study or distance learning. Our solutions are as good as model examples, which a tutor develops on blackboard for on-campus students.

3.4. Solving problems by digital tools

Several problems can be solved only by digital tools such as programs for modelling (e.g. Stella) or computer algebra systems (e.g. Math lab) or spreadsheet applications (e.g. Excel). These tools are essential to illustrate physical dependencies and to support physical considerations (e.g. to create, extend and proof models or to compare measured data and theory).

3.5. Multiple use of formulas/equations, graphs, tables, pictures and texts

All these methods are important elements to explore qualitative and quantitative relations for better understanding. Table 3 shows how elements are used as a methodological tool to solve problems.

Table 3. Methodological tools.

Element	Application
Formula/ equation	• to derive new or analogous formulas • to check if an answer is correct or wrong by special/limiting cases, by qualitative considerations and by dimensional analysis • to interpret physically or to generalize or specify • to indicate approximations or limiting cases • to reorganize to get the wanted value and to calculate the value
Graph	• to plot a graph qualitatively • to check it qualitatively and quantitatively • to explain the course of a graph and justify its scale • to recognize relations from a graph • to make physical statements about the course of a graph • to plot measured data in a graph • to recognize functional dependencies
Table	• to establish meaningful tables • to complete partially finished tables • to recognize qualitative or quantitative relations between measured data • to consider carefully if a diagram or a table is more predictive or evident
Picture	• to annotate the picture

	• to use a picture for better understanding • to recognize the relation to equations • to position several pictures in a meaningful way
Text	• to create a text for better understanding • to read the original text for deeper information • to use the internet to collect information • to read a textbook to understand details

4. Conclusion

Solving problems is an essential component in the teaching and learning of physics at school and university level. The advantage of this collection of problems is that they concern not only theoretical considerations but also experimental setup, measurements and data analysis. They can be used in traditional teaching and learning as well as in new types such as long distance education or remote labs. Elaborate extensive solutions support teachers and learners. We conclude with some remarks about their use in teaching environments:

These problems should be used in combination with performing real experiments to stress the value and position of experiments in comparison to theory. We have ensured this collection of problems is very flexible, comprehensive, and usable for different levels, i.e. not just for one scenario or application. The teacher should get an idea from the problems and then select, adopt and modify our proposal for his teaching situation: e.g. use in final exam, during class, as homework, as a repetition, for self study, for in-service training of physics teachers, as preparation for student labs, in long distance education courses.

Acknowledgements

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References

[1] http://rcl.physik.uni-kl.de, menu item ‘Material’ of RCLs ‘Rutherford´s Scattering Experiment’, ‘Electron Diffraction’, ‘Millikan´s Experiment’ and ‘World Pendulum’.