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THE EHRENFEST MACHINE AND TEACHING OF THE SECOND LAW

We have on the programme of this IV Danube Seminar contributions concerning global concepts of school physics education and we have other ones dealing with more or less special areas which is the case of my short talk.

In one point, I guess, your experience from discussions on physics education in your countries does not differ from mine in Czechoslovakia:

Any general idea on the didactical system of school physics and any suggestion concerning a special topic, no matter how good and justified and how attractive they appear, are for the school praxis of nowadays or of the near future only as much useful as their realization is ripe also didactically.

In the above sense I would like to present a simple aid helping in understanding the concepts needed for the teaching of the second law of thermodynamics.

The role of the Second Law is certainly highly appreciated not only for the pure physics education, but also for the interface Physics-Biology and Physics-Sociology. However, we know how difficult and time-consuming it is to build up e.g. the concept of entropy in a physically full and correct way for the freshmen at the university. Therefore, it might seem to be little hope for successful teaching of the topic in the school. Not with standing, I would like to draw your attention to a possibly practicable approach when we want to prepare the way for understanding concepts like reversibility, fluctuations, disordering, macrostate, and microstate.

First I shall remind the machine described by Paul and Tatiana Ehrenfest in their paper on the Boltzmann H-Theorem /Ehrenfest P, Ehrenfest T.: Über zwei bekannte Einwände gegen das Boltzmannsche H-Theorem. Phys.Z.8 /1907/, 311-314/. Then I will give a modification of the procedure suitable for use in the school.

Paul and Tatiana Ehrenfest consider an example of the probability calculus:

"... Let us have N numbered balls, e.g. 100, divided between two boxes. The box A contains P_o /e.g. 90/, the box B consequently Q_o = /N-P_o/ balls. However, it is not known, which individual balls are lying in each box. Besides, there is a bag with N lottery-tickets numbered 1 to N. Every time unit a ticket is taken out and put back. Any time when a number is drawn, the ball with this number is jumping out of the box in which it is just lying into the other one where it rests till its number is drawn incidentally again.

It is at any time more probable that the actually called ball will be found in the fuller than in the emptier box. Thus, so far the box A is still much fuller than the box B, the box A will as a rule become emptier in favour of the box B and will get only exceptionally a ball from the box B... ."

The described Ehrenfest machine makes it possible to elucidate such features of the system which may be characterized by the actual distribution of the balls between the two boxes A and B in dependence on the time. Thus we can elucidate:

/1/ The tendency of the system to develop to a prominent state i.e. to the equipartition distribution of the balls between the two boxes.

/2/ The reversibility and the irreversibility on the macroscale.

/3/ Fluctuations.

A slight modification makes the Ehrenfest machine didactically both more telling in the above applications and still broader applicable:

/4/ The likelihood character of the group of the balls actually present in the box can be demonstrated directly.

/5/ Moreover, it is easy to get insight into the spontaneity of the disordering processes.

/6/ Another application is in making the first preparative steps towards understanding the concepts of macrostate and microstate.

All this is practicable in this way:

N objects numbered 1 to N, e.g. 40 tickets, are distributed between two fields A, B. Both the fields are divided in the same manner to N areas numbered 1 to N. The example with N=40 is given in Fig.1 /all objects in the field A/. Besides, we have a bag with N lottery-tickets numbered 1 to N. A ticket is taken out of the bag and its number determines the objects to be put from the field A /B/ into the field B /A/.

A

1	2	3	4	5	6	7	8
9	10	11	12	13	14	15	16
17	18	19	20	21	22	23	24
25	26	27	28	29	30	31	32
33	34	35	36	37	38	39	40

B

1	2	3	4	5	6	7	8
9	10	11	12	13	14	15	16
17	18	19	20	21	22	23	24
25	26	27	28	29	30	31	32
33	34	35	36	37	38	39	40

Fig.1. All objects in the field A. The field B is empty.

So far the field A is much fuller than the field B, the field A will become gradually emptier till the field A and the field B contain approximately the same number of objects.

The number of objects in the field corresponds to the macrostate of the system. The same macrostate may be realized by many microstates - in our case by configurations of the given number of tickets in the field /Fig.2/.

A

1	2	3	4	5	6	7	8
9	10	11	12	13	14	15	16
17	18	19	20	21	22	23	24
25	26	27	28	29	30	31	32
33	34	35	36	37	38	39	40

B

1	2	3	4	5	6	7	8
9	10	11	12	13	14	15	16
17	18	19	20	21	22	23	24
25	26	27	28	29	30	31	32
33	34	35	36	37	38	39	40

Fig.2. One macrostate /n=3/ realized by two different microstates /configurations/.

In the course of the lottery-ticket drawing and the corresponding transfer procedure one observes very clearly the spontaneity of the disordering of the system on the one side and the tendency to attain the prominent equilibrium state of the system on the other side.

Needless to say that many details of the procedure are worthy to be discussed in the class.

There is no doubt that teacning of the Second Law is one of the more difficult tasks in physics education. We are certainly very reserved in hopes to be successful with it in the school generally. However, in special schools or with groups of physically talented pupils the presented suggestions could be of interest.