Ref.TH.2762-CERN

THE PHYSICIST'S ROLE IN PHYSICAL LAWS

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ABSTRACT

The physicist not only observes phenomena, but he also has an active rôle in the formulation of some laws. For instance, laws involving irreversibility refer explicitly to what can or cannot be done by physicists. As the abilities of the latter may vary, we obtain sequences of laws, the convergence of which is discussed.

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Ref.TH.2762-CERN
18 October 1979

The physicist's rôle as an observer has been discussed by many authors and sometimes its importance is even overstated. In this paper I discuss a different rôle for physicists. They do not appear at the level of individual events, but in the formulation of the physical laws themselves.

As a trivial example, instead of saying that no signal can travel faster than light, we could say that nobody can build an apparatus capable of sending signals faster than light (that is, signals intelligible to somebody else). The words added in parentheses are very important. As foreseen by Einstein 1) and formally proved by Bell 2), deliberate actions taken at one place are not without immediate influence on the outcome of events at arbitrarily distant places. However, this influence cannot be used to convey intelligible information 3),4).

A less trivial example is the problem of irreversibility : a time honoured paradox is that the behaviour of a few molecules in a vessel is reversible, but that of 10^{23} molecules is not. Where is the limit ? If it is fuzzy, then the whole concept of irreversibility is fuzzy and should be avoided in serious discussions. A similar paradox is the transition from quantum theory to classical theory : systems consisting of a few atoms must be described by quantum theory, but bodies made of 10^{23} atoms follow classical equations of motion. Where exactly is the transition point ?

The solution of these paradoxes is that the transition from quantitative to qualitative is found precisely in the eye of the beholder. Consider for simplicity the problem of classical molecules and, for additional clarity, allow me to use a slightly arrogant presentation. I decide that 100 molecules behave reversibly but 101 do not, because I can keep track of the positions, velocities, orientations, etc., of 100 molecules but I refuse (or am unable) to do so for more than 100. If the molecules are more numerous, I call them a gas and I use an incomplete description with fewer variables (density, pressure, etc.). It is well known that this coarse grained description is the root of irreversibility.

Now another, better equipped physicist may be able to track more molecules, say one million. For him, irreversibility will start at 1000001. Let us assume that every physicist is entitled to choose some "cut-off", i.e., specify the limits of his ability (and these cut-offs are finite). The consequences of this freedom of definition are staggering :

different physicists will find different laws. E.g., if I call a gas anything with more than 100 molecules and you call a gas anything with more than 10^6 molecules, we are using the word "gas" with different meanings and shall inevitably find different laws of gases. (The laws arising from a smaller cut-off will appear more complicated, e.g., imagine a law of gases remaining valid for just three molecules !)

These laws, however, form a sequence and the latter may converge. To illustrate the meaning of the word "converge", consider the various laws for the pressure $p(n,E)$, where n is the particle density and E the mean energy per particle. Because of fluctuations, p is not a constant in space and time. Now let ϵ and η be small but finite positive numbers. We require that, with due account of these fluctuations, the probability is more than $1-\eta$ to find

$$|(p_j/p_k) - 1 \; | < \epsilon,$$

where p_j and p_k refer to gas laws with cut-offs at N_j and N_k, respectively. A careful analysis will then show that this condition is fulfilled if both N_j and N_k are larger than some $N(\epsilon,\eta)$. Thus, if we agree on the required level of theoretical accuracy (ϵ and η) we can give a precise meaning to what <u>is</u> a gas, i.e., how many molecules are needed to make the evolution irreversible.

This procedure may look clumsy but it is similar to the numerical evaluation of $\int_0^\infty e^{-x}dx$. We never need (and cannot) go to infinity. Therefore we are satisfied by showing that the result lies between $1-\epsilon$ and 1, for arbitrarily small ϵ, provided that the upper limit of the integral is larger than some $N(\epsilon)$.

Once we have found a suitable definition for the convergence of a sequence of physical laws, the next question is whether this convergence is uniform. E.g., the cut-off required to obtain the van der Waals law with a given accuracy may be different from that required for the Navier-Stokes law, or the heat conductivity law, etc. Is there some cut-off large enough so that <u>all</u> laws converge ?

The answer is obviously negative, as the number of laws is limited only by our imagination. Thus, besides the choice of some cut-off for the total number of molecules which can be tracked individually, each physicist must set a limit to the number of interesting laws. This limit must, of course, be much smaller than the above cut-off, to ensure reasonable convergence properties of all these laws.

In conclusion, physics appears not to be an exact science, but rather a converging sequence of approximations. The theorist should not toy with the idea of a perfect calculation any more than the experimentalist can perform perfect measurements. To avoid any misunderstanding, I am not referring to the familiar "theoretical errors", like rounding off the last digit in the computer or neglecting a subset of Feynman diagrams. I am also not pointing at an ambiguity of the theory, but at the existence of a large number of competing theories, based on different "cut-offs", i.e., different descriptions of the same phenomenon.

Finally, what happens if we nevertheless want a perfect theory and if we push the cut-off to ridiculous figures, like 10^{50} molecules, more than we actually have to track ? Then, first of all, physics becomes less interesting. Imagine a physics library with no books on thermodynamics, statistical mechanics, etc. Moreover, there is now a serious problem of experimental verification. There is no longer any equipment producing permanent records (such as tracks on a photographic plate) to be studied by physicists, objectively, at some later time. The complete, reversible description of instruments is incompatible with their use for recording phenomena. Therefore, verification must actually be performed by physicists, who are macroscopic and behave irreversibly. If we try to escape from the physicist as a legislator, we meet him again as an observer.

ACKNOWLEDGEMENTS

I am grateful to CERN for hospitality, and to J.S. Bell for patiently listening to ideas with which he has little sympathy.

REFERENCES

1) A. Einstein - Philosopher-Scientist, ed. by P.A. Schilpp (Library of Living Philosophers, Evanston 1949) p. 85.

2) J.S. Bell - Physics 1, 195 (1964).

3) H.P. Stapp - Nuovo Cimento 40B, 191 (1977).

4) A. Peres - Amer.J.Phys. 46, 745 (1978).