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The explaining away of the arrow of time: a problem

I would like to begin with a quotation from Peter Bak, in his New Scientist's review of Ilya Prigogine's new book, « The end of certainty ». So doing, I wish to make clear, right from the beginning, two aspects of the situation I wish to describe.

First, that my interest for this situation is indeed linked with my interest for Prigogine's work. Second, that the peculiarity of the situation is that as a philosopher I feel able to intrude into a controversy among physicists. More precisely, to intrude at the level of the problem, obviously not at the level of the solution Prigogine is proposing. But as you will see it is at the very level of the problem Peter Bak is denying any scientific merit to Prigogine's enterprise, to Prigogine's claim that it is both crucial and possible to incorporate the « arrow of time » in the so-called « fundamental » physical description.

Here is the quote: « *I cannot help feeling that the confusion is due to a misunderstanding of the priorities of physical laws. The fundamental laws, such as Newton's laws and quantum mechanics, have the highest priority. Thermodynamics must conform with these laws... In any case any explanation of thermodynamics must be consistent with the dynamical laws, not vice versa* ». (New Scientist, 6 September 97, p. 43)

The conformity argument is part of the 20th's century physicist's common sense. It is what any physicist or chemist has learned in any textbook dealing with the probabilistic interpretation of entropy which is meant to link microscopic reversibility with macroscopic irreversibility. It is nearly an insult to use it against a specialist of statistical mechanics like Prigogine. But Peter Bak's « priority » argument makes clear that Prigogine's true crime is to challenge the hierarchy between fundamental laws and macroscopic description. Thus, this hierarchy is not only some kind of a « common sense », or « purely ideological » view of the world which could be nicely separated from physics. It can be used by a physicist in order to refute right away the proposition of an other physicist. Peter Bak does not even comment on Prigogine's theoretical construction. He does not need it. Prigogine, since he is claiming that the arrow of time, that is the

difference between past and future, should be part of the fundamental description, is wrong. Prigogine, since he is not satisfied with the way fundamental laws of physics explain away irreversibility by linking it with initial conditions and lack of accuracy, has misunderstood physics.

Here is where the philosophers and the historian may intrude, wondering when and how the hierarchy between so-called fundamental and phenomenological description acquired such an impressive authority. Historically speaking, we know that the probabilistic interpretation, or rather the « explaining away », of irreversibility, refers to Ludwig Boltzmann's work. And also that it was never something Boltzmann was proud of, but the result of his failure to have a kinetic model of elastically colliding particles reproducing an irreversible, entropy increasing evolution towards thermodynamic equilibrium. His claim was destroyed by the so-called Loschmidt's « velocity reversal objection ». It was through this objection that the consequence of the formal property of dynamical equations, the fact that they are time-symmetric came at full light. If we reverse at some instant the velocities of all particles in Boltzmann's population evolving towards equilibrium, we have prepared the initial state for an entropy decreasing evolution, going away from equilibrium.

It is worth recalling this famous clash between a kinetic model and its purely dynamical counterpart because, more than one century later, after relativity, quantum mechanics or the free lunch cosmology, it is still present.

First, it is worth emphasising that Loschmidt's objection implies a completely realistic definition of dynamics. To reverse the velocity of individual particles implies that even if you are quite unable to define the trajectories of billions of colliding molecules, their unknown dynamical description has the power to predict the result: the whole colliding system will go backwards towards its initial state. If it was on its way towards what is macroscopically described as its equilibrium state, it will, against the second law of thermodynamics, evolve further and further away from equilibrium.

A well known aspect of the situation is that the least inaccuracy of the description, which is the rule in any computer simulation physicists can now produce, will destroy this time symmetry: a simulation of the velocity reversal experiment will indeed show that after a time, the system starts again evolving towards equilibrium. Thus, as Peter Bak claims, molecular dynamics simulations, which work with approximate values, indeed show an evolution consistently agreeing with the second law of thermodynamics while obeying dynamics. The fact that the least approximation is sufficient to break dynamical time symmetry is a crucial aspect of our problem. For

physicists the situation is quite satisfactory since they can have the cake, that is the dynamical laws, and also eat it, that is quite easily derive the macroscopic description. But this position may have two meanings. Either physicists are happy with the idea that bridging the gap between the fundamental description and the macroscopically relevant one is such an easy operation, thus denying any kind of special authority to the so-called fundamental laws. In this case, they should accept being interested in Prigogine's work, wondering if maybe the reformulation he proposes could in some cases work still better, for instance include not only equilibrium but also non equilibrium descriptions in the bridging operation¹. Or they affirm the great divide between the trajectory, as it is really, and any approximate description we can produce, thus claiming that all descriptions, from chemistry to biology and maybe even human sciences, may be judged away as approximate versions of the only realistic descriptions of reality, the time-symmetric one. Laplace's demon could predict any state of the Universe, but the claim implied in this last position is still stronger. From the fundamental description, now, the point is no longer to predict what will happen but to deny that anything did or will happen. The sun is not burning away. It should be described as a static superposition of independent eigenvalues of some kind of a universal psi function.

Another way to describe the same situation is to address the probabilistic interpretation of entropy. Here, we can forget about any dynamical evolution whatsoever. The only thing we keep is the hypothesis that all dynamical states have the same a priori probability, and the only point of interest is to count the number of dynamical microstates which correspond to the same macrostate description. Then everything is all right: the equilibrium- state corresponds to the huge majority of the microstates, it is thus the most probable one. It seems that you may also conclude that microstates evolutions corresponding to a macroscopic evolution leading from a less probable state to a more probable state are themselves more numerous those leading from a more probable to a less probable macroscopic state. Irreversible evolution thus means the most probable evolution, towards the most probable state. However, if you recall that the probability interpretation did stem from the Loschmidt velocity reversal objection, and thus from the decision to take into account the full authority of dynamics when the definition of the microstate is concerned, strange

¹ Technical remark: when approximations are responsible for the irreversible evolution towards equilibrium, there is no way to give an « objective » meaning to experimentally well defined physical quantities such as relaxation times which depend on the rate of this evolution. This rate indeed depends on the degree of « coarse graining » which has been introduced.

consequences happen. Whatever the dynamic microstate you have, you can deduce from its description the description of an other microstate characterised by the reverse time-behaviour. You are thus bound to conclude that there are just as many microstates corresponding to an evolution towards equilibrium than away from equilibrium. Why do some of those microstates correspond to the usual initial conditions, those which we can prepare, and the others, never? There is no answer and this is normal since the probabilistic interpretation has in fact nothing to say about irreversible evolutions. It is timeless, and it should be since it starts with the equal probability hypothesis for all dynamical states. It gives to understand why a system at equilibrium will probably remain at equilibrium, that is why equilibrium is a stable state. Nothing else.

We have thus two complementary way to explain away the very notion of a broken time symmetry evolution, first through explaining it by the approximations we are bound to introduce in our description of trajectories, second through forgetting about any temporal evolution whatsoever and just defining equilibrium as the most probable macrostate. In both cases, the conclusion is clear: as soon as your descriptions are not time-symmetric you can say goodbye to reality, your approximations, or your decision to be interested in macrostates, are the responsible for any description of a system irreversibly evolving towards equilibrium.

How should I, as a philosopher, react to this situation ? Obviously I could ask the physicists how they came to be able to deny the arrow of time while experimental practices, which grounds the authority of physics, imply a difference between past and future. Without even speaking about human activity, I would thus recall that one cannot even describe a measurement process if one does not accept it produces a difference. But if I use this argument, it produces very violent reactions. It means war. It is as if I was putting into question the very vocation of physics, its freedom to reach a purified, intelligible reality beyond human interests and operations. The fact that theoretical physicists thus appear to entertain some kind of Platonist stance has often been emphasised. What I wish to bring to this problem through exploring the question of how the arrow of time came to be explained away is the hypothesis that the issue is not a « philosophical » conviction, even if it may be expressed in philosophical terms. And it is not a matter of « psychology of discovery », even if we find statements about the necessary character of the physicist's faith in the possibility of getting access to the one intelligible reality. It is first and foremost a « political » definition of physics, of its value and claims. And it is a « war » definition.

In order to construct the problem, let us start with the time when thermodynamics was a new, revolutionary science, the time when energy was discovered to be both conserved and irreversibly degraded, as William Thomson characterised it. As we know it, the idea of degradation of energy came to be superseded by the notion of the increase of a new quantity, entropy. Clausius won against Thomson and I want first to emphasise the significance of this victory.

Clausius' point was that energy, as it had been extended through the first law of thermodynamics - being now conserved not only in the ideal, frictionless pure dynamic motion, but also in any natural processes - had lost its special role in the understanding of physical change. In technical terms energy is no longer, as it was in dynamics, a state function, connecting the description of a state with that of its possibility of evolution. Processes we deem impossible do however conform to the thermodynamic energy conservation just as those we deem possible.

It is important to emphasise that the increase of entropy is not just an other name for the dissipation of energy. This was the point of the conflict between Clausius and British physicists such as Tait For Clausius, entropy is a new kind of physical function, spelling the irrelevance of both energy and work as far as irreversible processes are concerned Degradation of energy or irreversible loss of « available work » do not characterise natural processes as such They are relevant only when we deal with work-producing devices, that is when a process may be defined in terms of the expected work it can produce through heat exchanges at definite temperatures Contrastedly, entropy may stand as a general measure of the irreversibility of a process It is the subject of the second principle

However, entropy which takes the place of energy as the thermodynamic state function, takes it in a very peculiar way. Indeed it is well-defined in the case of reversible changes where it is both physically well-defined and conserved. But such changes never happen in nature, they correspond to a perfectly controlled and infinitely progressive displacement. Technically, along a reversible displacement, a system never leaves equilibrium. Which means that at each step, if it is left alone, it will remain as it is. Reversible displacements are thus entirely determined by external manipulation. As soon as any spontaneous process takes place, entropy increases. But this increase of entropy cannot be measured as energy is, that is using the variables which describe the spontaneous process. This is why in the general case, that is if you cannot use the ideal, reversible displacement as a standard, only the entropy increase sign is well-defined. You can surely say that natural processes entail an increase of entropy, but

nothing more. What you have not actively taken the means to determinate, you cannot determinate.

Thus the so-called second principle spells the irrelevance of the whole understanding of change through energy, work and conservation, an understanding which was the key for the triumph of dynamic. Yes we have conservation, universal conservation, but it leads to no understanding of change. In Hegelian terms, energy is now an external measure while entropy is an internal, intrinsic measure. But entropy (or an other thermodynamic potential as the free energy) do not replace energy without at the same time putting the very idea of measure in what we may well call a critical position. With thermodynamics, when we measure, we mimic the beautiful understanding dynamics realised, that is we define the transformational path conserving a new quantity, entropy. This is quite useful, because it draws the line between what is physically possible and impossible. It defines the limits of possibility under the most perfect control we can conceive, the perfection of the control, the conservation of entropy and the reversible character of the transition all being synonymous. However drawing this line does not lead to any understanding of physical changes themselves. The line drawn does not testify for nature but for the perfection of our control. About natural, spontaneous processes, all we can say is that they do not allow the kind of general power of definition which dynamic motion legitimates. Thermodynamics faces the physicist with a choice: either the relevance of the physical description or the power of definition, not both together.

Among the many physicists who dealt with thermodynamics, I choose now to follow Max Planck. It is well known that Planck devoted a lot of effort against Wilhelm Ostwald's energeticism, that is a proposed unification of physics around the two principles which for Planck obscured the crucial difference between a spontaneous entropy increasing process such as the propagation of heat, and a dynamical motion such as that of a frictionless pendulum body. Planck is still better known for his sad remark that a new scientific truth never triumphs because its adversaries at last get convinced, but only because they die away, while a new generation grows for which this truth is a familiar business. The truth Planck was talking about was the crucial difference between irreversible processes and dynamical motion. And this difference was indeed recognised only with the probabilistic interpretation of entropy, that is when entropy was judged away.

Planck stated in his well-known 1909 lecture on « The Unity of the physical World Picture »², that « the distinction between reversible and irreversible processes is a much more profound one than that between mechanical and electrical processes, and that this difference is therefore better entitled than any other to form the chief basis for the classification of all physical events, and should be allotted the principal role in the physical world-picture of the future » (p. 14). And Planck shows indeed why the very point that there is an entropy increase is sufficient to make a crucial distinction the subject of which is Nature itself, or more precisely Nature as the object of a physical world-picture. Entropy increase means that there is a distinction « in nature » among the states between which the entropy increasing transition happens. For Max Planck, the two thermodynamics' principles speak about Nature, testify that all possible states have not the same « value » as far as Nature's preferences are concerned. « Those natural processes are impossible for whose final state nature would have less 'preference' than she has for the initial state ».

It is very important to emphasise that Planck does not attempt to characterise Nature's preferences. The point is that Nature is not indifferent. This point bears on what I would call a practical issue. Indifference - it makes no difference to X that we have it doing this or that tells something about « Nature » but not about « Nature » independently of what we aim to get from it. Moreover irreversibility, as expressing that Nature is not indifferent, means that the singular power of definition state functions achieve in dynamics is relative to « borderline cases only ». When we try to extend this power, we can still mimic this power, but at the price of relevance: we come to artificial transformations such as the ideal Carnot cycle, which have nothing to do with Nature, and everything with the active, manipulative extension of the relation between description and power to define.

In a way, the probabilistic interpretation did confirm Planck's view: the difference between Nature being or not being indifferent is the crucial one. It is only an indifferent Nature that allows the hypothesis of a priori equal probabilities for all states. If any state can be indifferently realised, depending on the preparation, we may indeed postulate that each has the same probability to represent the system. In other terms the probabilistic « explaining away » of entropy is nothing but a way to affirm that Nature is indeed indifferent, that entropy and irreversibility do not testify about « Nature » but only about our own inability to actualise the freedom of definition which « Nature » authorises. Planck's classification dividing reversible from irreversible processes can then be replaced by the

² Quoted from *Physical Reality*, ed. S. Toulmin, Harper Torchbooks, New York, 1970

probabilistic opposition between the human physicist who deals with macrostates only and the ideal physicist for whom entropy does not exist.

I feel I have now the elements I need in order to begin constructing the problem, that is I have both the setting and the witness, Max Planck, who testifies that my construction is not a purely retroactive one. Something indeed did happen which produced a decision « against » the very possibility of conceiving Nature as not indifferent. The problem now is how to tell this story, of which we know the present-day conclusion: in Peter Bak' s word, « The fundamental laws, such as Newton's laws and quantum mechanics, have the highest priority. Thermodynamics must conform with these laws....»

Let us first tell what physicists would probably answer. At the end of the 19th century, physics did succeed in getting beyond phenomena, be they dynamical or thermodynamical. It may well be that there is a crucial practical difference between our description of a frictionless pendulum and of spontaneous heat propagation, but this is a phenomenological difference. Going beyond phenomena, to the hidden molecular motions and events, we face a single physical world which is the true subject of physical understanding.

However this single world was first of all a world of events, many events, and many kinds of events: chemical « reactive » collisions, radioactive decompositions, ionisation, collisions. Those were furthermore kinetic events, since they were, if we may say, « blackboxed »: in a kinetic description it is the relative frequencies of events and the consequences which their happening entail that matter. Finally, if we recall the case of the spontaneous radio-active decomposition, the least we can say is that it does not testify for an indifferent nature.

In fact, only one of these kinetic events could be pictured as following a dynamic law that is belonging to an indifferent nature: it was the elastic collision. This was indeed the way Boltzmann's kinetic interpretation has been defeated: he had used kinetic collisions and the discontinuous changes in velocities they produce, but his results were smoothed away as soon as his kinetic collisions were seen as just an approximate version of a dynamical interaction.

My question thus remains. The probabilistic interpretation of entropy was seen as dealing away with irreversibility in general, not just for elastically colliding particles models. As Einstein put it, « we physicists » know that from the fundamental point of view, there is no objective difference between past and future. This means that all kinetic events, even the spontaneous decomposition of unstable nuclei, were accepted as playing the same part as the collision, were seen as « approximate » versions of

some kind of a time symmetrical process (that is open to the velocity reversal objection). Why were the kinetic events which gave access to a hidden discrete reality beyond continuous phenomena reduced to the unique model of the elastic collision ?

Here the physicist will probably go right away to quantum mechanics. But only to face the same issue. In the first, Bohr's version of quantum mechanics, the spontaneous emission of a photon is a time-oriented event. In the classical 1927 formalism, events have disappeared. They have been incorporated in the measurement process. The spontaneous emission is no longer part of an eventful world, it is but an indirect way to characterise a static quantum state, that, for instance, of the stationary atom. But the measurement process is an irreducible, time oriented event.

Furthermore, we can take Planck as our witness again, in order to show that going beyond phenomena towards a revolutionary hidden reality is not in itself a sufficient explanation. My point is that, in 1909, that is after he had achieved his own revolutionary results about the black body radiation, Planck had not accepted that irreversibility had actually been dealt away through probability. For him the possibility that « special configurations and velocities of atoms » could well lead to heat being propagated from a cold body to a hot one was not to be taken as an objection against irreversibility. « For a nature in which such things happened (..) would not be nature as we know it. As long as we are dealing only with the latter, we shall do better not to admit such singular occurrences as possible, but on the contrary to seek, and accept as realised in nature, that general conditions which exclude phenomena running counter to all experience. Boltzmann himself formulated that condition for the theory of the gases, it is generally speaking, the 'hypothesis of elementary disorder' - in short the assumption that the individual elements with which the statistical method operates remain completely independent of one another. With the introduction of this condition, the necessity of all natural events is restored ». (UPWP, 17-18)

In other words, Planck proposes to take into account irreversibility as a constraint which cannot be put into question in the name of microscopic models. We must use this constraint in order to derive conditions bearing on the microscopic world which cannot be deduced from pure dynamics. As for the black-body radiation problem, Planck also came to a condition which cannot be deduced from the theory of radiation he used: in order to exclude the possibility of « advanced waves » we must introduce the hypothesis of natural radiation. For Planck probabilistic models did not obliterate Nature's « preferences ». First picturing Nature as indifferent was a way to find the adequate expression of Nature's non-

indifference, through the model-dependent condition to be added in order for the model to exclude the possibility of spontaneous entropy-decreasing changes. Against Peter Bak, dynamical laws had to conform with thermodynamics.

An interesting point is that in a way, physics indeed did follow the road indicated by Planck. Physicists have never stopped identifying the relevant «approximations» which successfully bridge what they call «fundamental» and what they actually deal with. The difference is that they do not speak about conditions but about approximations. It is not clear which difference it would have made for the working physicist to follow Planck's proposal. To identify such differences is a challenge for Prigogine's proposal. What is clear, however, is the contrast between the way physicists present themselves in our story and how they would do it in that other possible story.

Another interesting point is that Planck's analysis was indeed accepted by many. For instance, the influential Ehrenfest's 1912 paper clarified the relation between the hypothesis of molecular chaos and the foundation of statistical mechanism, and concluded from the necessity of the molecular disorder hypothesis that the « postulate of determinism » did hold for observable evolution only. However, and it is here, I believe, that the generational analysis of truth Planck proposed may be used, for the physicists of the new generation, the loss of determinism came to be accepted as part of the revolutionary consequences of going « beyond phenomena », not because of the macroscopic 19th century increase of entropy. The great theme of quantum indeterminism was played with revolutionary tunes, celebrating the discovery of a new surprising reality not as part of the negotiation between the irreversibility evidence and a microscopic dynamical representation. From the quite legitimate idea that the question of indeterminacy in quantum physics cannot be identified with the question of the validity of the second law in a kinetic world of events, to the less legitimate idea that this last question is not allowed to add constraints to the already convoluted questions of quantum physics, the step is not logical but it is short. The more short if we recall that whatever the hypothesis needed in order to ensure the relevance of kinetic laws, they can always be presented as the result of approximations.

As we all know, the fate of the deterministic/indeterministic problem came to be a part of the question of the interpretation of the 1927 quantum formalism, with the Heisenberg famous uncertainty relation and the also famous measurement problem. For Planck, irreversibility had been a crucial part of the “physical world picture” and the conditions to add to

the dynamical microscopic models objectively identified what thermodynamics had first anthropomorphously expressed, « Nature's preferences ». Very curiously, for the new generation, « man » was again at the center of the picture, no longer man the engineer, judging « nature » from a utility standpoint but man « the observer », unable to attribute a precise value to both the position and the momentum of a quantum being. The generational analysis is useful but it must be complicated. Indeed, what I learned from Ilya Prigogine's story, and the reactions it provoked, is that we have also to understand the « vocation » aspect of this problem, the way the question of irreversibility came to be linked with the question of the identity of physics as a quest for an objective description of reality.

The damped motion of a pendulum or the levelling of temperature described by Fourier's law can be objectively described if by objective we mean quantitative, instrumentally well-defined and even predictive description. They are determinist, causal phenomena. Friction can be said to be the cause for the damping and the temperature difference the cause for the levelling. However, they are not ruled by the equivalency between causes and effects and for the physicist, at least since the « irreversibility crisis », it makes all the difference. Their quantitative description may be as precise as we may wish, it is only a description. The physicist will never be able to state that temperature is not relative to our possibilities of measurement, that it corresponds to an « objective » definition, independent of human choice. In contrast if you describe a dynamical motion in terms of variables such that you may state that once state B is reached, a complete return to state A can be accomplished in any way, you have the power to objectively identify cause and effect. A description that exhibits the possibility of its reverse entails the operational identification of cause and effect, the reverse meaning that what has been identified as the « effect » produces back what has been identified as the « cause ». In other words, the respective identity of cause and effect is objectively warranted by the fact that they can indifferently produce each other. In still other words, the objectivity physicists are interested in corresponds to what Planck characterised as Nature's indifference.

The idea that knowing all causes we would be able to grasp the determinist character of a change is an old idea. The novel point is that starting from Galileo, what we call dynamical phenomena have the power to identify what, for them, counts as cause and as effect. Reversibility, in this context, is not related to time, but to the operational identification of the equivalence which articulates cause and effect. I wish to emphasise that, so defined, the relation between cause and effect has nothing to do here with

what philosophers would call « common sense causality » and still less with the many kinds of causes we can distinguish (a forest is burning, a man has been arrested: count the number of « causes » which may be mobilised from the chemistry of oxydo-reduction to psychoanalysis or economic speculation). In fact the great interest of the operational identification of causes and effects is precisely that it closes any argument about what counts as a cause and how to take it into account. Physicists will say that the description is « objective » in the strongest meaning of the term: the transformation itself dictates how it should be described. This ideal is what thermodynamical reversible displacements did mimic.

I suggest to understand equivalency, or the reversible conservation of cause into its effects, as a key to a double singularity of physics: its division between what is called « fundamental laws » and phenomenological description », on the one hand, the strangely metaphysical questions physicists seem to be prone to deal with, on the other. When physicists speak about « reality in itself » as opposed to «reality as we know it », they do not confuse physics and metaphysics, they do not commit the Kantian capital crime, confusing phenomenon with «thing in itself ». They are just going on with the possibility to state that, whatever philosophers have to say, when you get a time symmetric description, it is a complete, perfect one, owing nothing to human intervention. Which may well mean, the step is not logic but it is short, that if your description is not time-symmetric, as it is the case in phenomenological physics, it can, and maybe must, be judged as relative to a purely instrumental, that is human, choice of variables.

In other words, I suggest not to look for « deep », cultural or philosophical reasons associated to the explaining away of the irreversibility issue. At least not before considering reasons which specifically belong to physics. The « probabilistic only » interpretation of entropy as opposed to the probabilistic-cum-molecular-chaos-hypothesis interpretation is, from a philosophical point of view, a gigantic decision, since it implies the denial of the difference between past and future. From the practical point of view of the physicist, it is both technically easy and of great value since it extends the power and relevance of the « objective », perfect description to the corresponding phenomenological domain. So doing, it stabilises the division between « phenomenological only » and « fundamental ». . . and also the claims of physics to be different from all other sciences.

With this last statement, I obviously open the game again. From my experience with physics and physicist's argumentation, I would say that

the connection between the great pseudo-philosophical theme inhabiting physics and « philosophical influences » are weak. Explicit connections obviously exist but I would say that they explain less than have to be explained: first comes, I suggest, the problem the physicist has to face, then the resource such or such philosophical argument can produce. Contrastedly, what I would call the « territorial », or « political » question - what can we claim as physicists ?, how is physics different? - is, I suggest, a much more reliable Ariadne's thread.

Again, this political definition of physics and of objectivity is a matter of story. In this case however, the story should not take physicists as its main actors. Indeed the questions of science and disinterested knowledge, of science and truth, of science and human value had many actors one century ago. And the stakes were many. The main one, all over Europe, was the question of the autonomy of science at a time when industrial enterprises were indeed very interested in scientific research, when the utility of science was no longer a matter of harmonious convergence between human progress and the progress of knowledge but had become a menace: see Liebig's « Lord Bacon », attacking British utilitarian, enslaved science and defending the vital right for scientist to choose their own problems - the very condition. Thomas Kuhn put to the possibility and fecundity of normal science. But we should also recall the French « bankruptcy of science » controversy about the ability of scientific rationality to replace religion as a source for human values. And we should not forget that Lenin found it urgent to attack the defenders of Mach's instrumentalist position, claiming that a true materialist should address matter, any deviation from this realist aim being idealist. Atoms and revolution were also linked.

The story to be told would thus be an involved one, implying many sub-stories, different from one country to the other. I will not follow it. I just wanted to recall that sorry time in order to recall that the physicists' claim to « realism » and « objectivity » took its contemporary formulation as a rallying, mobilising watchword. A watchword against adversaries who were indeed ready to identify any qualification as an admission that indeed physics was only a useful fiction. The only « truth » which could resist the suspicion to be a man-made one was indeed the « realist » one, with the access to a « pure » reality, beyond both interest and manipulation, as its only goal. Poor Henri Poincaré did not know it when he wrote « La science et l'hypothèse » in 1906. His « conventionalist » position was immediately enlisted in order to argue that indeed physics was human convention only, cut from any « truth ». The first sentence of the 1913 « La valeur de la

science » is « Searching for truth must be the goal of our activity. It is the only aim worthy of it ».

In times of war there is no place for any kind of a balanced position. Thinking is dangerous, it means betrayal. I am not claiming that the fate of irreversibility can be « explained » with such a « political » narrative. But I claim that it is connected with it and that the history of 20th century physics is still connected with it. When contemporary physicists today mobilise to wage a war against what they see as « relativistic irrationality », they do not remember the past. But the past is what fabricates them. Their inheritance of the way physics defined its own vocation one century ago makes it obvious for them that whoever does not accept physicist's realism at its face value means war.

This last narrative, however, opens the way for still another one, which is also a political one. Indeed till now I have admitted as « natural » that physicists were the ones who discussed the practical consequences of this great scientific event which was the « discovery of the conservation of energy ». Correlatively, I have mainly emphasised the loss of definitional power of energy as it is defined not by Joule or Mayer but by the first principle. Indeed, the actors I have followed were all, one way or another, inheritors not of the event of the discovery of the conservation of energy but of thermodynamics and its two principles. And this makes a great difference. Indeed, I would dare to speculate that with thermodynamics' two principles, a great part of the story has already been decided. While the conservation of energy as such did unite not only all natural processes but also all natural scientists, energy as the subject of the « first » of the two principles, belongs to the physicists and to the physicists only.

Indeed, as I have tried to show, the two principles construct between themselves the contrast between the dynamical definition of motion (energy being the state function) and the definition of an ideal thermodynamic displacement (entropy being the state function). Which means that the two principles define the wide variety of energy conserving processes through their common contrast with dynamics, as necessitating something else (entropy) in order to recover, or mimic, what dynamics achieved. And this has two consequences: nobody but physicists is interested in this contrast (there is no state function in chemistry or biology), once the issue is set, the physicist has the power position. All others have first to learn from them how to forget their own questions. Mistakes are very easy, the least « intuition » and you are lost because you have forgotten that the description of energy conserving processes is not the point

Here, for a last time, we can come back to Planck's thesis about Nature not being indifferent. But this time it is to emphasise the « hold up » aspect of this conclusion. What a great point to make ! Who but a physicist would even think to make it ! Indeed Planck's crucial division between dissipative and conservative (that is, indifferent) processes puts on one side the frictionless pendulum and other idealised dynamical motions, and on the other side everything else, from the propagation of heat to whatever you may think of. For the physicist, and the physicist only, the crucial issue is that Nature is not indifferent.

Thermodynamic energy, as distinct from conserved energy, has two main historical features. It came very quickly after the official « discovery » of the conservation, so that the physicists « hold up » is nearly invisible. It was very slow to be accepted. More precisely, many accepted the two principles without understanding what they did indeed accept. Had they understood, maybe the story would have been different. Physicists would have had a much harder time explaining away irreversibility if already the way thermodynamics deals with « dissipative processes » had been seen as a «for physicists only » matter.

I cannot resist the pleasure of emphasising one of those who understood what was happening: Friedrich Engels. Engels' (and Marx's) interest for the conservation of energy was a philosophical interest, but also an active interest. They were convinced that at this point, philosophy should intervene. Physicists do not understand what they are doing, wrote Engels in his *Dialectic of Nature*. They go on with their tradition without understanding that the conservation of energy has changed everything. The tradition of physics achieved the possibility of successfully ignoring quality but physicists did not understand the meaning of their own achievement. They have not even understood that the concept of work they have constructed was a tool for defining a qualitative change from the quantity point of view. They have kept the definition of work as related to forces, which is the case in dynamics and in dynamics only. And now, they do not see that the conservation of energy is related to a quantitative measurement problem. They don't see it leaves completely open the understanding of what it measures.

The story Engels wanted, whose starting point would have been Hegel's polemic against the physics of forces never happened. I do not know what it could have been but it probably would have interconnected in a rather different way physics and speculation, and it could have made a difference for philosophy also. The interest of the definition of entropy could indeed have been read in an Engelsian way: if you want to construct a quantitative measure to change, this is the way to do it. But don't forget

measure is your concern, do not forget that in the science of forces only measure and objective definition converge. We inherited a story along which, one way or another, physicists were free, without being challenged, to first define irreversibility as a « deep » problem and then to revolutionarily explain it away. From Engels' point of view, we have got only what we deserved.

What did indeed happen? About the inverse of what Engels wished for. Many are the texts in the nineteenth century in which « work » gets identified as some kind of a universal category. « Nature works ». But so does also « society ». Putting people to work, having all obstacles against the definition of man as workers removed, avoiding all « wastes » appeared as a legitimate, rational enterprise since it achieved the convergence between the general law of nature and the progress of social order. It is well known that the increase of entropy, as interpreted as the irreversible loss of useful work, was seen as a prophetic utterance, the doom awaiting civilisation. This use of thermodynamics belongs to the same generalisation as the naturally working nature: the still naturally working world is doomed by its very functioning. Furthermore, we have all the energy-progress stories going on, with the same wide scope, bridging nature, including life, with society. Ostwald is a beautiful illustration: whatever the progress, it can be deciphered either as increasing the quantity of available energy or as improving the efficiency of the transformation of available energy into useful energy. Such « inventing » universes are still with us today. They are no longer concerned with efficiency, more with « complexification » or « self-organisation ». They achieve the same kind of beautiful unification. Nature is going on developing through society. Conversely, natural scientists have a wisdom which mere politicians lack as they don't see this overall trend and remain attached to dubious, obsolete categories.

The point with all those extrapolations, which can easily be seen as so many mistakes, is that what they extrapolate is the power of definition claimed by physics. And they are mistaken because physics gained this power, the power to speak about fundamental laws of nature, at the price I have tried to describe. All visions which present themselves as extrapolations from physics to nature, life or society and try so doing to define one way or another Nature's preferences forget or ignore this price. What physics calls the « fundamental laws of nature » cannot bear any conclusion about « what Nature prefers ». The definitional power which the notion of law expresses depends on the creativity with which physics selects situations where Nature can, with some adequate approximations, be described as “fundamentally indifferent”. So physicists were (and still are

when self-organisation, complexity or chaos « prophets » are concerned) in position to destroy, deride and disqualify them all as « ideological uses of physics ». And physicists are right: it is the very greatness of the history of physics, at least as I have tried to tell it, to have gone all the way with the quest for an objective standpoint which indeed is a power standpoint. Physics had the strange greatness to get what its definition of objectivity deserved: an indifferent nature. A nature which can interest nobody but a physicist, since nothing which makes a difference can abide its laws.

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