DISCUSSION ON TEMPORAL ASYMMETRY IN THERMODYNAMICS AND COSMOLOGY

Chairman: R. O. Davies
Reporter: O. Costa de Beauregard

The reporter has felt that, in a delicate subject where many arguments have already a long history and, moreover, can often have different shades of meaning, the best procedure was to produce a 'reader's digest' of the actual Cardiff discussion. So, after carefully listening to the tape recording and slightly rearranging the order, he has attempted to extract the essence of what each speaker had to say, and to preserve authenticity and flavour by using, whenever feasible, the acutal words spoken. He thus hopes that the discussion will unfold like a drama. He also apologizes if some contributors feel that what has, perforce, been left out was precisely what should have been included.

Chairman—A rough and ready test of the importance of any subject is the amount of nonsense that has been written about it (laughter). When applied to temporal asymmetry this test would place it as somewhat less important than religion and more important than information theory (laughter).

If we lay aside what elementary particle physicists are now telling us, all the elementary laws of physics are time reversible. The question then arises, why is it that for processes that can actually be seen there is in fact a greater variety of behaviour with respect to the time reversed transition? It seems that the central strands of the thing we are concerned with here are precisely how, and how firmly, the thermodynamic arrow may be associated with some other source of directiveness (perhaps a unique, perhaps not a unique, association). In an attempt to subdivide what is a very wide and perhaps indivisible field, I have entered on the board (Appendix A) a few categories which attempt to classify, among other things, the fascinating quotations prepared by Landsberg (See Appendix B).

Now I invite first those speakers who have, as it were, stuck their neck out by making statements they are willing to defend. Dr Collins, you have written that '*With a proper definition of a clock, the second law might be seen as a tautology*'.

R. Collins (Salford)—What prompted my statement was a remark by Zwanzig that, given long enough, any clock in a closed system will eventually wind itself up. It seems that at no point in the papers we have heard is there an analysis of what you require a clock to be. Statistical mechanicians would say it has to be larger than the system you are looking at, while cosmologists would say smaller (laughter). Do you have to suit the clock to the problem? And if not, why?

R. Zwanzig (Maryland, USA)—By international convention a clock is an atomic oscillator operating under the time reversible laws of quantum mechanics, so the time arrow is not built into it.

J. Lewis (Oxford)—Is it not possible that the time arrow is built into the clock through the process that counts the ticks?

P. T. Landsberg (Cardiff)—How would you know which tick is earlier and which later?

Lewis—By counting them.

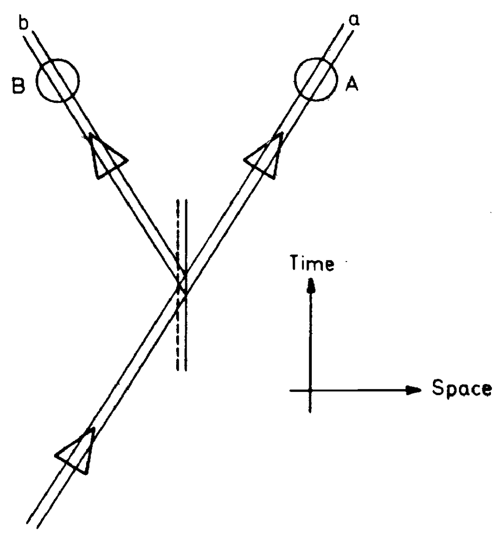
Landsberg—Ha! *Then* you are using the biological arrow of time.

K. G. Denbigh (London)—No, sir, you are doing more than that. Something *occurs* and, in the very definition of the word *occurs*, a time arrow is assumed. It was the same this morning with Narlikar's oscillating universe: in order to speak of a reversal occurring (note the word *occurring*) you have to assume some reference according to which that occurring occurs. In other words you would have to postulate a supertime.

A. Katz (Rehovoth, Israel)—I would refute that point. Time plays two distinct roles. The interval between two events can be measured by a reversible apparatus, while to know which is earlier or later is provided by the human sense of time.

Chairman—Let us pass on to a subject where attention is drawn to the essential aspect of measuring, implying perhaps those biological or psychological aspects just mentioned. Costa de Beauregard's statement was: '*To state the Einstein–Podolsky–Rosen "paradox" is to state that telegraphing into the past occurs on an elementary quantum level. And this happens in any quantum measurement.*'

O. Costa de Beauregard (Paris)—In Pittsburgh* I argued that the root of



* A symposium on 'A critical review of the foundations of relativistic and classical thermodynamics' was held in April 1969. The proceedings are in course of publication.

stochastic irreversibility lies in the nature of a boundary condition which states that *blind retrodiction is forbidden* and that, provided one uses a theory implying both statistics and waves (namely quantum mechanics), this boundary condition can be connected with the one stating that *advanced waves are forbidden*. My demonstration consisted in a mere rewording of von Neumann's irreversibility proof for the quantum process of measurement. To put it briefly, in quantum mechanics retarded and advanced waves respectively are used in prediction and retrodiction—whence my Pittsburgh statement.

It thus seems that Einstein's prohibition to telegraph into the past might well be of a macroscopic rather than of a microscopic character, so that, on the elementary quantum level, there would remain only a prohibition to telegraph outside the light cone. This I believe is shown by the so-called E–P–R 'paradox'. Suppose we have a wave which is split by a semi-transparent mirror and which we assume for simplicity to carry just one particle. If an observer A operating on beam *a* either finds the particle is present or absent in his beam, then he knows it is respectively absent or present in the other beam *b*, and an observer B operating on *b* is bound to find it so. The point is that the AB vector is spacelike and, moreover, that it can be quite large. Now, the calculation shows quite clearly that the logical inference from A to B (or from B to A) (or, if you prefer, the *telediction* along AB, because it is neither prediction nor retrodiction) is *not* telegraphed *directly* along AB, but along two timelike vectors, AS and SB, with S in the space-time domain where the separation occurs.

And I insist that this is a very general procedure occurring each time a quantum measurement is performed. Then *b* corresponds to the outgoing quantum object and *a* to the measuring device which observer A reads.

L. Tisza (Massachusetts, USA)—We are not really sending a message into the past. We get a message from the past, and what we project into the past is our information. As I said this morning, we make an inference from our present knowledge into the past. So, is it a good thing to call this 'telegraphing into the past'?

Costa de Beauregard—I had to make a provocative statement, you see (laughter).

D. Layzer (Massachusetts, USA)—This seems to me an attempt to discuss issues of information theory. When A gets the message he has all the information there is in this particular issue, so there is no transmission of information at all. My difficulty is that I do not see that the inference is drawn anywhere else than at the site of the measurement.

Costa de Beauregard—But it could be drawn at B just as well.

Katz—This type of telegraphing has nothing to do with causality. Causality (a rather shaky concept in general) would require that A or B could transfer (to B or A) a signal at will, and that he decides at some moment what to transfer. No such possibility exists.

Costa de Beauregard—I am glad you raise this question, which has been left pending since the Bohr–Einstein controversy. According to the accepted version of quantum theory, performing a measurement contributes producing the result of it. Thus it is definitely *not* at the surface of the mirror that the decision is made, but later.

Katz—Even so, the measurement does not produce an *arbitrary* result.

Costa de Beauregard—That is true, but either A or B *does* have control on the type of measurement he chooses to perform (spin or anything else). In *this* sense there is some kind of telegraphing between A and B.

R. J. Heaston (Germany)—In Pavlovian terms, a response is the result of a stimulation. So it is a matter of temporal ordering to know which event is stimulation and which response.

Costa de Beauregard—This simply won't work here, due to the spacelike character of the AB vector.

Chairman—Perhaps we ought to tackle this from another point of view. Would Landsberg like to add something to his nine-years old quotation '*This illustrates clearly how the entropy of a system or text depends not only on the system or text, but also on our knowledge of it, and the questions we ask about it*'.

Landsberg—In my opinion entropy is not an absolute quantity, but it depends on the available information. The Gibbs paradox (as I said this morning) is a good example of this, and the simplest.

J. A. Wilson (Cardiff)—I do not see why the entropy of a system should bear any relation to what you think it is. A system may well have an entropy defined by its own characteristics quite distinct from the one you assign to it by your theory, your calculations and (possibly) your measurements.

J. S. Rowlinson (London)—A short answer is to contemplate what happened before isotopes were known. All through the nineteenth century engineers and chemists were making perfectly accurate calculations with entropy, not knowing that there were isotopes. When these became known, then, as a matter of convention, all entropies could be redefined, and we now have them all larger than they were. And I can see no limit in such a process.

H. S. Robertson (Florida, USA)—My point of view also is that entropy really is our measure of the uncertainty regarding a system. When we describe a system thermodynamically we choose (or are forced) to give up our dynamical knowledge. That we say entropy increases as a system evolves to equilibrium, I regard as a statement of our knowledge. Also, my theory is time symmetric: we are just as unable to predict a (detailed) future as to retrodict a (detailed) past. Therefore the time arrow is not within the problems of thermodynamics or statistical mechanics.

Chairman—So, in your lecture, jiggling of the walls was not really the cause of irreversibility?

Robertson—I did use the outside world to bring in the uncertainty, but I can do it just as well by other means.

Chairman—It seems we have reached the end of this question. So I come back to another statement by Layzer: '*The phenomenon of irreversibility in isolated physical systems has its origin in the absence of microscopic information about initial states. The assumption that initial states have this property singles out a direction of time.*' Do you assign the time directiveness to the very form of the assumption pertaining to the initial state, or are you simply pointing to an initial state subject to previous remarks (in this discussion)?

Layzer—That's it. The time directiveness is away from that state [taken in itself].

Chairman—So 'initial' has to be understood by reference to something outside the system you are talking about.

Anon.*—Your statement specifies 'isolated systems'. How can you draw any information from a system without putting yourself in some kind of interaction with it? What can you say about time development in an isolated system of which you are not part?

Layzer—That is one idealization among many that one makes when analysing experiments. 'No interaction with the rest of the universe' is another one. I am free to leave out these interactions and see whether I am able to secure agreement with experiment.

Chairman—Perhaps the time has come to pass on to the cosmic question, with reference to another of Landsberg's statements: '*If entropy increase determines the direction of coarse grained time, then observers in an oscillating universe have their sense of time reversed during the contraction, and a new principle of impotence results: a contracting universe is unobservable.*' Would you like to defend that?

Landsberg—No. I have given the argument.

J. V. Narlikar (Cambridge)—In a model I discussed this morning, retarded and advanced potentials are respectively consistent with expansion and contraction of the universe. Thus, in an oscillating model, observers will always have their time arrow pointing towards expansion.

Costa de Beauregard—Boltzmann made an analogous statement in his well-known book. It may be, he says, that in the universe there are regions A where the entropy is going up and others, B, where it is going 'down' (with respect to some common time coordinate the direction of which is irrelevant, but which must be thought of as 'time extended'). He then feels that living beings are bound to experience increasing entropies in both the A and B regions.

D. Park (Massachusetts, USA)—It seems that we get our sense of time direction very much more from the radiation of the sun and the energy processes we take part in, than from anything the universe is doing. Why on earth should non-radiative living processes be bound up with the ultimate fate of radiation? This is not clear in Landsberg's statement, but Narlikar has his own answer. According to it, if suddenly the universe started to contract, then it would seem to us that, as a result of distant events, the sun would start re-absorbing radiation.

Landsberg—It would seem so to God, not to living things. God would say, ah, the universe is contracting and everybody is getting younger while I, God, am getting older.

Costa de Beauregard—No! Eternity is time-extended!

Landsberg—Mon Dieu (laughter)! I didn't really mean God.

Robertson—May I suggest that this being Landsberg requires for observing the oscillations of his Universe be hereafter called 'Landsberg's demon' (laughter)?

Katz—Statistics alone, as Zwanzig and others have stressed, will not produce a time arrow. Some other assumption is needed, which could be one of the many in Davies's list, or it could be Narlikar's, namely, retarded potentials.

* It was not possible to identify this contributor.

Retarded potentials, like the other things in the list, would have no effect on the immediate approach to equilibrium, but would have a great effect in the time range which obtains for the recurrences.

Zwanzig—It seems to me that retarded potentials are irrelevant here. Consider the decay of an excited hydrogen atom inside a closed box with perfectly reflecting walls. This is a closed quantum mechanical system with well-defined eigenvalues. Everything can be done in complete detail without any reference to retarded actions: it is straightforward quantum electrodynamics. Assuming that at some time the atom is in an excited state, the calculation shows that, provided the box is big enough, the probability goes down with the decay time appropriate for spontaneous emission of a photon. Eventually, when a photon bounces from the wall enough times, this curve may come up again. Nevertheless, as I have explained, for a long time everything looks like a standard decay process, which gives us the basis for our human direction of time.

[Katz and Zwanzig are reviving here the old Ritz–Einstein controversy where, the reporter believes, both were saying the same thing in *reciprocal* forms. Why they could not see it clearly was that, if photons were then known, matter waves were not. Today it is clear that particle scattering (in the sense of statistical mechanics) and wave scattering go hand in hand, so that the two *macroscopic* principles of 'blind retrodiction forbidden' and of 'advanced waves forbidden' are just two different wordings for one and the same statement. This being granted, it remains to understand why living beings are bound to follow the time arrow of increasing probabilities and retarded waves. Could it be, in the context of the generalized entropy principle of information theory, that they must gain information?]

Tisza—May I put a question to the cosmologists. Is it not conceivable that we notice a contracting universe by the violet shift as otherwise our biological feeling of time would remain unchanged?

Layzer—Not only is it conceivable, but it is what happens in the framework of accepted cosmological and physical theories. There is no reason why there should be any connection whatever between the expansion, and the direction of processes in the laboratory or in biological organisms. On these same grounds I would question Landsberg's assumption.

Narlikar—Of course I disagree with both Layzer and Zwanzig. And that is logical, because our basic assumptions are different. They are using a local field theory, while I am using a direct interaction theory which is non-local, and *does* bring in cosmology.

Tisza—I would say that the question of origin of irreversibility is biased by philosophical prejudice. I believe irreversibility is an inherent feature of Nature which need not be reduced to something else (laughter). I don't quite say there is no problem, because the very fact that it has been thought to be a problem is in itself a problem, and a problem that should be exorcised in some way.

As I understand it, in some future stage of the true quantum dynamics which we do not have yet, but which is already shaping up, the problem would appear as the rich interplay of dynamics and stochastic elements, both of which are inherent, but appear on very different grounds.

[Dr Tisza's wish looks extremely like a modernised form of what has been Boltzmann's and Gibbs's in their own days. What has become of it, Zwanzig, Robertson, Davies and others have told us today—not to mention Loschmidt, Zermelo and the Ehrenfests. So, exorcising the demon in irreversibility theory might be not an easy task.]

B. A. Pethica (Cheshire)—Thermodynamics is a first class science. Mechanics is only a second class science and we should stop pretending it comes prior to thermodynamics. Any attempt to provide an excuse for deriving from mechanics the arrow of time is faith. It is faith because the equations of mechanics are time symmetrical while mechanical events are irreversible. Thus thermodynamics is stronger than mechanics, and if mechanics will agree with thermodynamics, so much the better for it.

Rowlinson—I regard the fact that time has an asymmetry as a fact of Nature which does not worry me any more than does the fact that there are two kinds of electricity and not three (laughter). Where I think there is a problem, one that should be discussed and has at least been partially resolved, is of course between the time symmetric equations we use in certain parts of physics and the time asymmetric ones we use in others. This is a difficulty worthy of conferences of this kind. But the early problem I regard as a metaproblem.

Katz—I would express the view that the problem of the direction of time is outside the framework of either thermodynamics or statistical mechanics (as has been explained by Zwanzig and Robertson). But I would also submit that problems that are outside a certain science at a certain time should be studied nevertheless in a larger framework.

[Thus we have the 'agnostic minded', for whom temporal asymmetry is a natural fact needing no more explanation than Nature itself. 'Exorcism', 'faith', 'metaproblem' are the words they would use to qualify the 'religious-minded' who keep on asking 'why'? Why is it that we can at will enclose an excited atom inside a perfectly reflecting box, but we cannot *at will* open the box and pick out the atom in its excited state?]

APPENDIX A

Some of R. O. Davies's statements on the black board

Which reversed processes happen?—A Classification

Required		*Examples*
	Must happen	Fluctuations in isolated systems
	Does happen	Rolling balls; simple particle processes
	Does not happen	Emission of waves; cosmic evolution
	Must not happen	Thermodynamically irreversible processes
Forbidden		

APPENDIX B

This appendix reproduces the part of a paper, circulated to all participants, to which the Chairman referred in his opening remarks. It is based on Appendix A of the paper by P. T. Landsberg, 'Time in statistical physics and special relativity'. *Stadium Generale* (1970), to be published.

Quotations on irreversibility and entropy
(selected by P. T. Landsberg)

(i) *Irreversibility not yet understood*

It is not very difficult to show that the combination of the reversible laws of mechanics with Gibbsian statistics does not lead to irreversibility, but that the notion of irreversibility must be added as an extra ingredient . . . . the explanation of irreversibility in nature is to my mind still open.

P. G. BERGMANN, 1967 (ref. 1, p 11)

. . . causality plus statistics means irreversiblity. I think that is nonsense.

P. G. BERGMANN, 1967 (ref. 2, p 190)

(ii) *Entropy increase due to non-isolation of systems*

The failure of S to increase with time is due to the fact that we have overidealized an 'isolated' system . . . The momentum and energy transferred between outside molecules and the system proper then acts as a source of true randomness influencing the dynamical behaviour of the system inside the walls. We maintain that this is the origin of randomness and increasing entropy in statistical mechanics.

J. M. BLATT, 1959 (ref. 3, p 751)

(iii) *Time direction due to measurement*

In any observation process there must be a signal coming from the observed system to the recording apparatus, and since the propagation of any signal requires a finite time interval, this gives the possibility of defining the arrival of the signal to be 'later' than the time of emission. This specification of the sense of time is perfectly general.

L. ROSENFELD, 1967 (ref. 2, p 193; see also ref. 4, p 3)

(iv) *Irreversibility due to large systems*

. . . irreversible evolution towards equilibrium is an asymptotic property of large systems, for long times, derivable from mechanics alone.

R. BALESCU, 1967 (ref. 5, p 434)

. . . a necessary condition for a rigorous transition from statistical mechanics to thermodynamics consists in taking the so-called thermodynamic limit $N \to \infty$, $V + \infty$, N/V finite, where N represents the number of particles and V the volume of the system.

E. J. VERBOVEN, 1967 (ref. 6, p 49)

(v) *The need for coarse-graining and macro-observables*

Thus we have arrived at the crucial question of how to choose the set of macroscopic variables $A^{(v)}$. This seems to me the main problem in statistical mechanics of irreversible processes.

N. G. VAN KAMPEN, 1961 (ref. 7, p 183)

Any really satisfactory demonstration of the second law must therefore be based on a different approach than coarse graining.

E. T. JAYNES, 1965 (ref. 8, p 392)

(vi) *The importance of measurement and knowledge*

The increase of entropy comes where a *known* distribution goes over into an *unknown* distribution.

R. M. LEWIS, 1930 (ref. 9, p 573)

This illustrates clearly how the entropy of a system or text depends not only on the system or text, *but also on our knowledge of it, and on the questions we ask about it.*

P. T. LANDSBERG, 1961 (ref. 10, p 237)

For it (entropy) is a property, not of the physical system, but of the particular experiments you or I choose to perform on it.

E. T. JAYNES, 1965 (ref. 8, p 392)

..... the irreversibility exhibited by this system consists in the information becoming less relevant to the experiments which can be performed on the system.

A. HOBSON, 1966 (ref. 11, p 411)

(vii) *Irreversibility due to causality conditions*

... one may say that *irreversibility appears as a special aspect of the physical causality requirement,* which states that the distribution function at a given point is influenced only by the distribution function at points which correspond to earlier times on the trajectory.

I. PRIGOGINE, 1962 (ref. 12, p 296)

(viii) *Irreversibility due to ignorance concerning initial conditions*

The phenomenon of irreversibility in isolated physical systems has its origin in the absence of microscopic information about initial states. The assumption that *initial* states have this property singles out a direction of time.

D. LAYZER, 1967 (ref. 13, p 258)

... I presume that most of us would agree ... that the initial conditions generate thermodynamics ... The striking asymmetry of the dynamics originates from this asymmetry in the boundary conditions.

J. A. WHEELER, 1967 (ref. 2, p 233–234)

(ix) *Irreversibility due to smoothing*

Die Irreversibilität ist eine Folge der Reduktion der exakten mechanischen Gleichung (3) durch Mittelung auf die statistische Gleichung (8)... Diese Mittelung... stellt eine absichtliche 'Fälschung' der Mechanik dar, und angesichts dieses Umstandes ist es klar, dass kein Widerspruch zwischen Mechanik und Thermodynamik besteht; sie beruhen auf verschiedenen Grundannahmen.

M. BORN, 1948 (ref. 14, p 109)

The total probability density function W, even for a thermodynamically isolated system, does not obey the Liouville equation, $\partial W/\partial t = LW$, since small fluctuations due to its contact with the rest of the universe necessarily 'smoothe' W, by smoothing the direct many-body correlations in its logarithm. This smoothing is the cause of the entropy increase...

J. E. MAYER, 1961 (ref. 15, p 1207)

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