Principles of physical time directionality and fallacies of the conventional philosophy.

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Introduction

These are the first two chapters from a monograph (*The Time Flow Manifesto*, Holster, 2013-14; unpublished), defending the concepts of *time directionality* and *time flow* in physics and naturalistic metaphysics, against long-standing attacks from the 'conventional philosophy of physical time'. This monograph sets out to disprove twelve specific *"fallacies of the conventional philosophy",* stated in the first section below. These are the foundational principles of the conventional philosophy, which developed in the mid-C20th from positivist-inspired studies. The first two chapters reproduced here challenge the first eight fallacies. These claims have been widely claimed for decades as scientific facts, and it should be surprising that *any* of these could really be in doubt. Yet the reasons for their failure are seen to be quite simple.

The approach here is to start with a straightforward, direct introduction to the key points, illustrated with simple models using simple applied mathematics. Precise statements and demonstrations of claims are given, but presented with minimal formal technicality in the Chapters. The idea is to get an accurate *visualisation* of the concepts. The conventional theory is based on a false visualisation, and we have to avoid this pitfall by establishing a new one. Formal analyses and proofs of various points of detail are given in the second half of the book. It is central to the approach here that *formalised proofs of conceptual claims* should ultimately be given to settle these disputes. However these Chapters represent effective proofs of the claims.

The first chapter begins by re-presenting the basic analysis of *time reversal symmetry* in the context of probabilistic or non-deterministic processes, removing the first critical error in the conventional account. The second chapter argues for a *law-like* explanation of physical time asymmetry and irreversibility, and shows how the 'reversibility paradoxes' are explained. This removes a number of problems that modern philosophers have spent considerable energy on, and made many assumptions about, under the illusion that the physical explanation is well understood.

Only limited references are given here. The wider literature is surveyed in a separate chapter. The conclusions here contradict a paradigm widely popularised in accounts of physics, but there is a much deeper diversity of opinion on the subject since the 1950's among leading researchers, who come from a variety of backgrounds, including physics, mathematics, logic and philosophy of science. In fact a tremendous scholarly and creative literature, largely supporting the conventional paradigm, but of much wider interest, developed from the 1960's, particularly in conjunction with the discovery of modern cosmology.

In any case, the conventional paradigm has certainly been given every chance to succeed. But the same conceptual inconsistencies and explanatory problems keep reappearing every generation, and never get resolved. The reason asserted here is because the paradigm is based on fundamental errors, and it just can't be resolved, any more than we can resolve $\sqrt{2}$ into a fraction. The alternative realist view of time directionality and time flow, which has been excluded from consideration for so long, needs to be seriously considered as an alternative to this failed conventional paradigm.

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Fallacies of the Conventional Philosophy of Time.[i]

The following are rejected as false claims.

1. Principles of time symmetry and quantum reversibility.

*1** **False Analytic Principle 1.** The time reversal of a deterministic causal law like: $s_1(t) \rightarrow s_2\,(t+\Delta t)$ is a law like: $Ts_2(t) \rightarrow Ts_1(t+\Delta t)$.

2* **False Analytic Principle 2.** The time reversal of a probabilistic law like: $prob(s_2(t+\Delta t)|\, s_1(t)) = p$ is a law like: $prob(Ts_1(t+\Delta t)|\, Ts_2(t)) = p$

3* **False Analytic Principle 3.** The condition for time symmetry of a probabilistic theory is that: $prob(s_2(t+\Delta t)|s_1(t)) = prob(Ts_1(t+\Delta t)|Ts_2(t))$ for all state transition laws.

4* **False Analytic Claim About Physics.** Quantum mechanics is *time symmetric* (*reversible* or *symmetric under time reversal transformation.*)

2. Explanation of physical time directionality and thermodynamics.

5* **False Analytic Claim About Physics.** Thermodynamics is only *contingently time asymmetric*.

6* **False Claim About Laws of Nature.** The physical processes in the universe could run backwards in time, and *the time reversed universe* would be obey the laws of physics just as much as the real universe.

7* **False Explanatory Claim About Time Asymmetry.** The observed (thermodynamic) time asymmetry of the universe is not law-like, but merely contingent. Its explanation must postulate a contingent initial state (boundary condition), in additional to the dynamic laws.

8* **False Claim about Physical Time.** There is no intrinsic asymmetry of time itself reflected in the laws of physics. Any asymmetric feature of time is derived merely from contingent processes.

3. Metaphysics of static time and time flow.

(These are not deal with here).

9* **False Claim about Concepts.** Time flow is meaningless in physics because physical time is intrinsically symmetric. No direction can be identified by the laws of nature as the 'past' and 'future' directions of time.

10* **False Claim about Concepts.** Time flow is meaningless in physics because physicists never need to refer to time flow in their textbooks.

11* **False Conceptual Paradoxes.** Time flow is a meaningless or paradoxical metaphysical concept, because it cannot be reduced to more basic physical concepts, it can only be explained by an infinite regress, etc.

12* **False Scientific Claim about Metaphysics.** Relativity theory shows that that time is just another space-like dimension, in which events exist, without any objective quality of being 'past', 'present' or 'future', and with no intrinsic directionality. Time flow is scientifically meaningless because no rate of time flow can be specified. Time flow is scientifically irrelevant to modern physics.

Tally Ho!

Chapter 1. The Analysis of Time Symmetry.

Defining Time Symmetry

To begin with we consider what *time symmetry* means. An abstract 'mathematical' answer is:

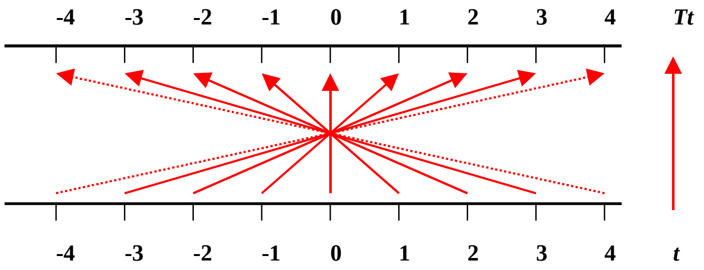
- *Time symmetry* means *invariance under the time reversal transformation*, a symmetry transformation based on the mapping: $\boldsymbol{T}: t \rightarrow -t$.
- A *symmetry transformation* is based on a 1-1 mapping of a fundamental variable (like time, space, charge, etc) back onto itself. This must logically induce transformations on all other complex constructions involving this quantity. E.g. the mapping $t \rightarrow -t$ determines that $d\mathbf{r}/dt \rightarrow d\mathbf{r}/d(-t)$ (velocity reversal follows from time reversal).
- Any kind of well-defined object or logical construction (e.g. variables, states, processes, laws, worlds) for which *the time reversal transformation* is defined may have the property of *time symmetry,* meaning that the object or construction is identical to its time-reversed image.
- The laws of physics are *time symmetric (reversible) just in case they are identical to their image under the time reversal transformation.*

This assumes that we have a theory defined as a *mathematical construction*, in which all references to *time* are fully interpreted.[ii] It is essential to refer back to this definition, but it is too abstract to begin with, and I will start with a simple conventional presentation of the view of time reversal in physics, and then return to show it is wrong when analysed correctly.[iii]

Before going on to that, however, I clarify why *time reversal symmetry* is intimately and uniquely related to the *directional properties of time.* This is important, but somewhat technical to start with, and the reader should skip over the next section and return to it later if they are more interested in the physical arguments first.

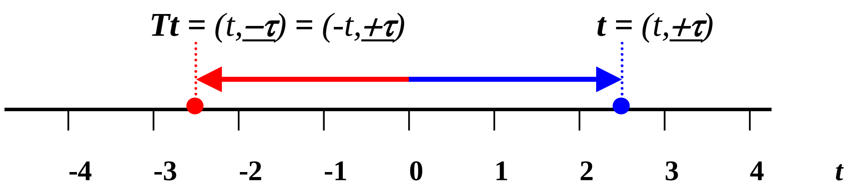
Time Reversal and Directional Properties of Time.

The *time reversal mapping* is a reflection, which reverses the *order* of moments.



Point-to-point reflection mapping of moments. T: t → -t.

The *moments of time* is a linear continuum of points. But we can think of the time line as a *vector space,* with points indicated by vectors from a conventional origin. Then we have 1-dimensional *time-like vectors* defined by: $\boldsymbol{t} = (t,\underline{+\tau})$, where: $\underline{+\tau}$ is the *basis vector* (or unit vector) for time, and *t* is the magnitude.



Vector reflection mapping. $T: (t,\underline{+\tau}) \rightarrow (t,\underline{-\tau})$

Being one dimensional, there are only two directions: $\underline{+\tau}$ and $\underline{-\tau}$, which we will identify with the *future* and *past* directions of real time. One direction (or basis vector), say the future (or positive) direction, is taken as fundamental. The past (or negative) direction is defined from the future direction, by:

Definition of the negative time direction.

- $(t,\underline{+\tau}) = (-t,\underline{-\tau})$

I.e. if we exchange the *coordinate t for the negative coordinate, -t, and the direction* $\underline{+\tau}$ *for the negative direction,* $\underline{-\tau}$, the vector is left unchanged. In other words, there is only one *independently definable direction,* and a second inter-definable direction.

To see this clearly, note that directions are properties of *pairs of temporal points*, say *(t,t')*. The proposition that: *the direction from t to t' is future,* can be written as: $\underline{+\tau}(t,t')$. It is true just in case, in vector form: $t \equiv (t,\underline{+\tau})$, $t' \equiv (t',\underline{+\tau})$, and: $t < t'$. Then by the definition: $\underline{+\tau}(t,t') \Leftrightarrow \underline{-\tau}(t',t)$. I.e the *direction from t to t' is future* *__just in case__* the *direction from t' to t is past.* So there not two independent facts about the temporal direction between two moments, just one relation.

The vector representation lets us identify the *directions of time* explicitly in the formal construction. The philosophical or metaphysical questions are whether or what sort of *directional properties* time has. This means: *does the* $\underline{+\tau}$ *direction have different properties to the* $\underline{-\tau}$ *direction?* The directional properties of interest are conferred by some *object of interest,* which may be processes, laws, theories, states, or anything that has an *explicit time construction* specified in the theory. For instance, if we define a velocity as usual: $\boldsymbol{v} = d\boldsymbol{r}/dt$, in time-vector form it looks like: $\boldsymbol{v} = d\boldsymbol{r}(\mathbf{t})/d(t,\underline{+\tau})$, and *the direction of time is transparent in the construction.* We can define the *time reversal of the velocity,* written: $T\boldsymbol{v}$, by substituting the negative time direction:

$T\boldsymbol{v} = d\boldsymbol{r}(\mathbf{t})/d(t,\underline{-\tau})$	[Exchange: $\underline{+\tau} \rightarrow \underline{-\tau}$ in the definition of $\boldsymbol{v}$]
$= d\boldsymbol{r}(\mathbf{t})/d(-t,\underline{+\tau})$	[Substitute definition of $\underline{-\tau}$]
$= -d\boldsymbol{r}(\mathbf{t})/d(t,\underline{+\tau})$	[Move negative sign to the front]
$= -\boldsymbol{v}$	[Substitute definition of $\boldsymbol{v}$]

As we know, the time reversal of a *velocity* is the negative velocity.

If the object of interest is a *proposition,* e.g. a *law of physics,* call it *L,* then it is a more complex construction, but as long as we can identify the term: $\underline{+\tau}$ in it, we can write is as: $\boldsymbol{L}(\underline{+\tau})$, i.e. first make the term $\underline{+\tau}$ in *L* into a *variable,* abstracting $\underline{+\tau}$ so that *L* becomes a function: $\boldsymbol{L}(.)$. This is applied to $\underline{+\tau}$, generating the original: $\boldsymbol{L}(\underline{+\tau}) = L$. The function: $\boldsymbol{L}(.)$ explicitly casts the proposition in terms of what it says *__about__* the *property of the time direction* $\underline{+\tau}$.

We can then ask whether this is also a property of the *negative time direction*, i.e. ***L(+τ)*** is true, but is: ***L(−τ)*** true? If this is also true, then ***L(.)*** is a common property of the two directions of time: ***L(+τ)*** & ***L(−τ)***.

We now define the *time reversal*, *TZ*, of any entity, *Z*, as:

Definition of time reversal transformation

- $TZ(-\tau) = Z(+\tau)$
- I.e. whatever *Z* says about $+\tau$, the time-reversal: *TZ* says about $-\tau$.

The concept of *invariance (i.e. symmetry) under time reversal* means simply that the time reversal image of an object is identical to the original:

Definition of invariance under time reversal

- *Z is invariant under time reversal* ⇔ $TZ(+\tau) = Z(+\tau)$ *[Definition]*
- *Z is invariant under time reversal* ⇔ $Z(-\tau) = Z(+\tau)$ *[Equivalent]*
- I.e. *time reversal invariance of* Z means that *Z says exactly the same things about both directions of time.*

This is a general interpretation of *time reversal* that shows how the *mathematical symmetry transformation, T,* relates precisely to *the properties conferred on the directions of time,* when we apply it to processes, propositions, laws, etc.

Contingent Process Reversal

- If the entity is a *process, P,* then *TP* is the time-reversed process (which is like the 'movie running backwards…' almost).
- It is unusual that: $P = TP$ for actual processes, i.e. they are usually directed in time, so that: $P \neq TP$.
- This means that for most actual processes: $P(+\tau)$, but *not-*$P(-\tau)$.
- Hence almost any specific process confers a *contingent* directionality on time.
- Some common *types of processes* are called *irreversible processes,* or *physical arrows of time,* e.g. thermodynamic processes are structurally time-directed.

- The conventional paradigm is that these are still only *contingently irreversible process types,* even though they appear to be governed by strictly irreversible laws of applied physics.

While the laws of applied sciences treat irreversible processes, universal laws of fundamental physics exhibit powerful symmetries, and *time reversal symmetry* is key.

- The 'laws of physics' here means laws or theories physics has actually found.
- The 'Laws of Nature', below, refers to idealised 'real laws', that physics is ostensibly trying to discover by proposing 'laws of physics'.

Reversibility of Laws of Physics.

- The law is represented by a *proposition, L,* and *TL* is the time-reversed law.
- We are normally interested in *universal laws of physics*, or *theories of physics.*
- We primarily want to know if: $L = TL$, i.e. if the law if identical to its time reversed image. In this case it is *reversible.*
- (Note that this is an *analytic exercise:* it follows from the definition of the law, not from experimental tests.)
- If $L = TL$, *then:* $L(\underline{+\tau}) = L(\underline{-\tau})$, i.e. the law L confers exactly the same property, $L(.)$, on both directions of time.
- A general theory (or law) that entails many laws is reversible just in case *if it entails a law, L, it also entails TL.*
- Note all theories and laws logically entail 'irreversible propositions', L, where: $L \neq TL$. All you have to do is restrict the time quantification of a universal law, and it is still true, but it becomes asymmetric w.r.t. time reversal.

We do not think of universal laws of physics as simply universally true *contingent* propositions however, but rather as identifying '*natural* (or *nomic*) *necessity'*.

Reversibility of Laws of Nature.

- Discovered laws of physics, *L,* are variously interpreted (in different ages, by different scientists) as *laws of nature.*
- This means that the properties of time directions that the laws *L* confer are taken as having a special significance, being 'nomically necessary' properties, or 'intrinsic properties', not merely reflecting contingent happenings *in time*.
- The interpretation of this is about the *significance* of reversibility or otherwise of *specific laws of physics proposed as laws of nature.* It is separate to the question of the time reversal of *L,* or whether *L = TL,* i.e. *L* is reversible. It is dependant on the 'metaphysical' or 'modal' status that laws and theories are interpreted to have.
- If a *modal statement* like: *L is a law of nature* is true, and it is also analytically true that: *L ≠ TL,* then we expect the modal statement: *A law of nature is irreversible,* and subsequently: *the time directions are distinguished by at least one law of nature.* I.e. modal claims about *L* are reflected in modal claims about its implications. But this has not much o do with time reversal.

The conclusion to emphasise is that:

- *Time reversal invariance or symmetry is the only relevant property of laws of physics with respect to identifying directional properties of time.*

A great deal of debate has revolved around identifying different '*kinds of time asymmetry',* classifying them into types, e.g. 'intrinsic directionality' versus 'contingent directionality'. However, there is really just one concept of time asymmetry (*asymmetry w.r.t. the time directions*), with many different types of modal claims that can be made about any particular example of a time asymmetry. Similarly, there is a common concept of time asymmetry across the different theories of physics – we do not have a *special concept of time symmetry for quantum mechanics*, and another concept for classical physics, and so on, as some writers suggest.[iv] And time directionality properties are uniquely related to the time reversal transformation.

- *If L = TL then L can confer no directional properties on time*
- *If L ≠ TL then L must confer directional properties on time*

Conventional Presentation of Time Reversal.

There are two common ways of explaining time symmetry in physics. The first is to make a concrete visualization: imagine first a (normal) physical process that obeys the laws of physics. Then imagine the same process running in reversed temporal sequence – what we would see if we ran a film of it backwards. This is the *time reversed process.* The laws of physics are time symmetric just in case any time-reversed process also obeys the same laws of physics as the normal process. If this is true for the general laws of physics, then the laws do not support an 'intrinsic' (or law-like) directionality of time, or a 'preferred direction' for physical processes.

The processes we see in real life of course do not *appear* to be reversible – we cannot make a river run uphill, or make a broken egg fall upwards from the floor and reassemble on the bench. These reversed processes do not appear to be physically possible. But this, we are told by the physicists, is an illusion. It is merely the result of the peculiar 'low entropy' state in which our universe began – not a matter of any intrinsic asymmetry in the fundamental laws of physics themselves. And this, we are told, is one of the most profound results in the history of science. It shows there is no scientific foundation for what we intuitively believe, viz. that there is an 'intrinsic flow of time', from past to future. The whole process of the universe could have happened in time-reversed order, as far as the laws of nature are concerned. And then we would all identify the opposite directions of time as 'past' and 'future'. This conclusion is the starting point for most modern writing on the naturalistic philosophy of time for the last 50 years or so.

But how do the physicists *prove* this result? Well of course we can't examine every possible process individually and check if it is 'reversible'. There are infinitely many possible processes. Instead, *we check the general laws of physics for the property of time symmetry*. These laws tell us what processes are possible at a fundamental level (according to present physics). These laws are written as equations ('fundamental equations'), and by doing some formal transformations on the equations, we can check whether they are time symmetric. This gives the second common method for explaining the meaning of time symmetry in physics.

The *time reversal transformation*, we are told, is simple and straightforward. It simply consists in *replacing the time variable, t, with its negative image, -t, throughout the equations of physics.* Oh, and replacing any state description, *s*, with its time-reversed image, *T(S).* If the laws are time symmetric, then the time reversal *TL* of any law *L* is also a law of physics. This seems easy enough to understand with examples. The simplest example of a process is a particle travelling in a straight line at a constant velocity:

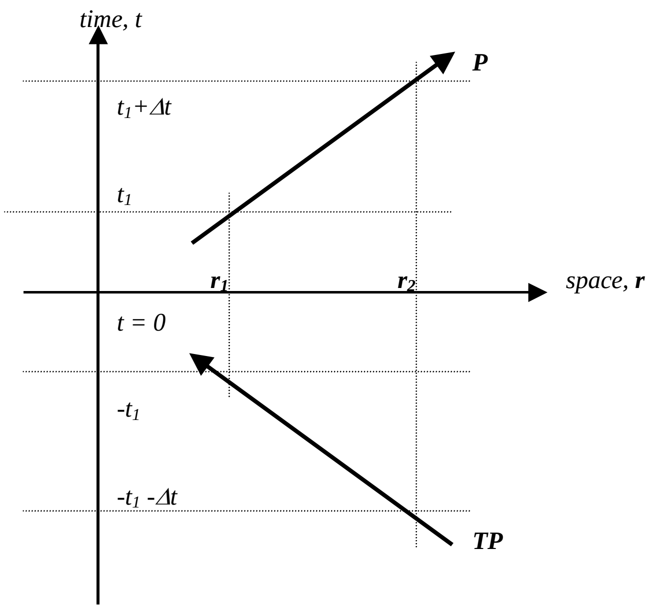


Figure 1. Space-time diagram illustrating a simple process (*P*) and its time reversal *(TP)*. *TP* is the reflection of *P* through $t = 0$. In *P*, a particle moves from $\mathbf{r}_1$ *to* $\mathbf{r}_2$ in a period Δt. In *TP*, the particle moves from $\mathbf{r}_2$ back to $\mathbf{r}_1$ in a period Δt. But in *TP*, the *velocity* is reversed, because it is moving 'backwards'. Both of these are possible processes for an isolated particle according to most theories of physics.

The intuitive line of thought goes like this. We take this first of all to be a deterministic process. For the process *P* to be physically possible (as in classical physics), there must be a law like:

L_D $\quad\quad\quad s_1(t) \rightarrow s_2\,(t+\Delta t)$

meaning that *an (isolated) system in a state* s_1 *at time t will develop, according to the laws of physics, into a later state* s_2 *at time* $t+\Delta t$*.* Note that laws are assumed to be *time translation invariant* - where we choose to assign the coordinate value: $t = 0$ is merely conventional - so this law applies to any time *t*. Logicians would say that the general laws have an implicit universal quantifier on *t*, meaning that “for all moments *t*, …”.

We are interested in whether the reversed process *TP* is possible given that *P* is possible. Since *P* starts in state s_1 and ends in state s_2, the reversed process must start with Ts_2 and end with Ts_1. Given the law L_D that governs the process *P*, it seems that we then need a *time reversed* law like the following to allow the reversed process:

TL_D* $\quad\quad Ts_2(t) \rightarrow Ts_1(t+\Delta t)$

I.e. *an (isolated) system in a state* Ts_2 *at time t will develop, according to the laws of physics, into a later state* Ts_1 *at time* $t+\Delta t$*.* This is assumed to be the *time reversal of the law* L_D in the conventional analysis. I have labelled it with an asterix, TL_D*, however, because actually it is not the time reversal of L_D at all! I will let the reader puzzle over this for a few moments, and see if they work out what the real time reversal of L_D is – it is obvious enough when you see it, but the conventional presentation, as above, conceals the correct answer under false intuition. Before revealing the answer I consider probabilistic laws.

Probabilistic Laws

The serious problems arise when we move on to *probabilistic laws.* Quantum mechanics is widely believed to be the fundamental theory of particle physics, and to require irreducibly probabilistic laws, and these laws are claimed to be time symmetric. Physicists take the time reversal of a *probabilistic transition law* of the following form:

L $\quad Prob(s_1(t) \rightarrow s_2\,(t+\Delta t)\,) = p$

(The probability of a transition from s_1 *to* s_2 *after a period* Δt *equals* p, *with* p *a real number from 0 to 1*.)

to be a corresponding law of the form:

*TL** $\quad Prob(Ts_2\,(t) \rightarrow Ts_1(t+\Delta t)) = p$

(The probability of a transition from Ts_2 *to* Ts_1 *after a period of* Δt *equals* p)

Again I have labelled *TL** with an asterix because it is not really the time reversal of *L*. The proof that quantum mechanics is time symmetric in its probabilistic laws then amounts to the claim that the following symmetry principle holds:

[QM cause-effect exchange symmetry]

$$Prob(s_1(t) \rightarrow s_2\,(t+\Delta t)\,) = Prob(Ts_2\,(t) \rightarrow Ts_1(t+\Delta t))$$

for all quantum state transitions – since this assures us that for every law *L* of the theory there is a corresponding law *TL**. Note also that if we take the transition probability to be p=1, then this reduces to the deterministic case above. However although this principle is generally true in quantum mechanics (with the exception of some meson decay processes), we will see that it *does not represent time symmetry at all.* This is why I have called it *QM cause-effect exchange symmetry,* instead of QM time reversal symmetry as stated in all the textbooks.

To illustrate let us consider another very simple example, of a clearly *time symmetric probabilistic process.* Imagine a system with just three possible states, call them s_0, s_1, s_2, which 'jumps' from state to state after every interval of time, Δt, like this:

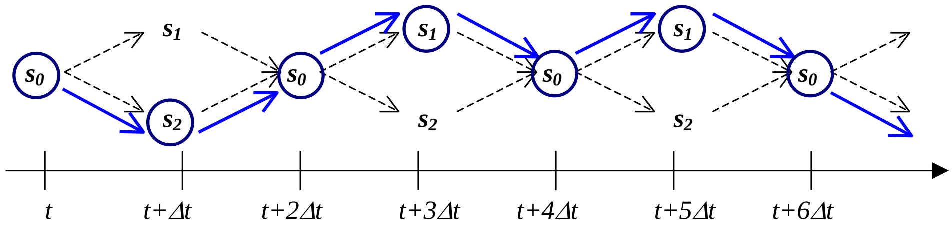


Figure 2. A simple probabilistic process. From state s_0 the system jumps randomly to either s_1 *or* s_2 , i.e. with probability 0.5 in each case. From state s_1 *or* s_2 the system always jumps back to s_0, i.e. with probability 1 in each case. The underlying probabilities are indicated in black, a series of actual events (actualised probabilities) is indicated in blue: …0201010…

There are four simple laws for the dynamics of this system:

L_{01} $\qquad prob(s_1(t+\Delta t)|s_0(t)) = 0.5$

L_{02} $\qquad prob(s_2(t+\Delta t)|s_0(t)) = 0.5$

L_{10} $\qquad prob(s_0(t+\Delta t)|s_1(t)) = 1$

L_{20} $\qquad prob(s_0(t+\Delta t)|s_2(t)) = 1$

To ensure the theory of this process as a whole is *time symmetric*, we also ensure that *there is no start or end to the process*, with an extra law that:

L_+ $\qquad prob(s_0(t) \text{ or } s_1(t) \text{ or } s_2(t)) = 1$, *for all times, t.*

L_{01} means that *the probability of the state* s_1 *at time* $t+\Delta t$ *given the state* s_0 *at time t equals 0.5*, and so on. L_+ entails that system at any time always has an earlier and a later state. We could imagine this for example as an infinite coin-tossing process, where s_0 is the randomised state before each toss, s_1 is the outcome state *heads*, s_2 is the outcome state *tails*, and after each toss the coin is returned to its randomised state. (In quantum physics, this could be modelled as a series of spin-1/2 experiments, with 'up' and 'down' as outcomes, and the system returned to the superposition after each event.)

To keep the example simple, we define the states to be their own time reversals, i.e. $Ts_0 = s_0$, $Ts_1 = s_1$, $Ts_2 = s_2$. Hence when we play a sequence of states backwards, we see a sequence of the same kind of states again. E.g. suppose a process has a sub-sequence:

P *…020101010201020201020201020201010102010202010…*

Then the time reversed process has the sub-sequence:

TP *…010202010201010102020102020102020102010101020…*

Now it seems patently obvious that this process is *time symmetric*, and that the set of laws L_{01}, L_{02}, L_{10}, L_{20}, that govern it forms a *time symmetric set of laws*. It is impossible to tell a sequence and its time reversal apart statistically. Of course a directional pattern could occur, e.g.: …0101010101010202020202020… But any directional pattern in an actual sequence is merely the result of coincidence, with the same probability of the reversed directional pattern occurring by coincidence, and this still doesn't help us determine any direction of time for the process from the stochastic laws.

The Physicists Reversal Fails

Let us now examine this set of laws using the physicist's criterion for finding the time reversal of probabilistic laws. According to that, the reversals of the laws for this system are:

Original Theory		***Physicists' Time Reversal***	
L_{01}	$prob(s_1(t+\Delta t)\|s_0(t)) = 0.5$	$TL_{01}*$	$prob(s_0(t+\Delta t)\|s_1(t)) = 0.5$
L_{02}	$prob(s_2(t+\Delta t)\|s_0(t)) = 0.5$	$TL_{02}*$	$prob(s_0(t+\Delta t)\|s_2(t)) = 0.5$
L_{10}	$prob(s_0(t+\Delta t)\|s_1(t)) = 1$	$TL_{10}*$	$prob(s_1(t+\Delta t)\|s_0(t)) = 1$
L_{20}	$prob(s_0(t+\Delta t)\|s_2(t)) = 1$	$TL_{20}*$	$prob(s_2(t+\Delta t)\|s_0(t)) = 1$

But there is something wrong here - the *physicists' time reversal of the theory contradicts the original theory!* E.g. in the original theory, $prob(s_1(t+\Delta t)|s_0(t)) = 0.5$, but in the *physicists' time reversal,* $prob(s_1(t+\Delta t)|s_0(t)) = 1$. In fact the physicists' time reversal of the theory gives a self-contradictory theory, stating that both: $prob(s_1(t+\Delta t)|s_0(t)) = 1$ and $prob(s_2(t+\Delta t)|s_0(t)) = 1$. This requires that the state $s_0(t)$ develops deterministically to the state $s_1(t+\Delta t)$ and to the state $s_2(t+\Delta t)$.

So this analysis using the physicist's principles would tell us that the theory is not time symmetric! But we know intuitively that the theory is perfectly time symmetric. The time reversal of the theory, if derived correctly, must be identical to the original theory. There is a fallacy in the physicists' derivation of time reversal.

The Correct Principle for Time Reversal

I now state the correct principle for deriving time reversal. First, for our original example of a deterministic law like:

L_D $\quad s_1(t) \rightarrow s_2\,(t+\Delta t)$

The time reversal is actually:

TL_D $\quad Ts_1(t) \rightarrow Ts_2\,(t-\Delta t)$

This means that the state Ts_1 *at t determines the earlier state,* Ts_2 *at* t-Δt. That is to say, the *future-directed deterministic law,* L_D, becomes a *past-directed deterministic law,* TL_D, when the law L_D is reversed.

More generally, the time reversal of a probabilistic law like:

L $\quad prob(s_2(t+\Delta t)|\, s_1(t)) = p$

Is actually:

TL $\quad prob(Ts_2(t-\Delta t)|\, Ts_1(t)) = p$

Again this is a *past directed law*. The requirement for time symmetry of a probabilistic theory, **T**, is then that:

[**T** is time symmetric] **T** entails that: $prob(s_2(t+\Delta t)|\, s_1(t)) = prob(Ts_2(t-\Delta t)|\, Ts_1(t))$, for all state transition laws of the theory.

Applying this to our example:

Original Theory		***True Time Reversal***	
L_{01}	$prob(s_1(t+\Delta t)\|s_0(t)) = 0.5$	TL_{01}	$prob(s_1(t-\Delta t)\|s_0(t)) = 0.5$
L_{02}	$prob(s_2(t+\Delta t)\|s_0(t)) = 0.5$	TL_{02}	$prob(s_2(t-\Delta t)\|s_0(t)) = 0.5$
L_{10}	$prob(s_0(t+\Delta t)\|s_1(t)) = 1$	TL_{10}	$prob(s_0(t-\Delta t)\|s_1(t)) = 1$
L_{20}	$prob(s_0(t+\Delta t)\|s_2(t)) = 1$	TL_{20}	$prob(s_0(t-\Delta t)\|s_2(t)) = 1$

L_+ $\quad prob(s_0(t) \text{ or } s_1(t) \text{ or } s_2(t)) = 1$, *for all times, t, is identical in both.*

And the time reversed theory indeed turns out to be exactly the same as the original theory. E.g. the original theory requires that the state s_1 *is always followed by* s_0 – and it equally entails that the state s_1 *is always preceded by* s_0. Similarly, the original theory requires that the state s_0 *is followed by* s_1 with 0.5 chance – and it equally entails that the state s_0 *is preceded by* s_1 with 0.5 chance. Without this symmetry between *future-directed transition statistics* and *past-directed transition statistics* the theory clearly could not be time symmetric, and this example matches all our intuitions.

The simplest way to assure yourself that *TL* is the time reversed image of *L* is simply to follow the 'formal recipe' recommended by physicists, and *substitute all time variables for their negatives in L (including substitution of Ts for each state s)*. This first gives us: $prob(Ts_2(-t-\Delta t)|\ Ts_1(-t)) = p$. Because t is universally quantified but $-\Delta t$ is a specific constant, this is logically equivalent to: $prob(Ts_2(t-\Delta t)|\ Ts_1(t)) = p$, which is *TL* as stated. Not that hard!?

The Fallacy in the Physicists Principle.

How did the physicists make this error? I think by using unanalysed intuition to formulate their ‘reversal’ principle, and then failing to check it. To obtain the physicists’ *TL** we have to perform the substitution of *–t* for *t,* and *then also exchange the causal order of states.* This does not give the time reversed image of *L* at all – it sneaks in a ‘double reversal’, to satisfy our normal intuition that causal laws must go forward in time. In fact, this does not represent a symmetry transformation at all.

A *symmetry transformation* is based on a 1-1 mapping of a fundamental variable (like time, space, charge) back onto itself. This must logically induce transformations on all other complex constructions involving this quantity. But *TL** does not have any possible underlying transformation! A full proof of this is given in Holster 2003, where it is proved that the conventional criterion is neither a necessary nor sufficient condition for time symmetry. The physicists’ time reversal principle is actually logically irrelevant to time symmetry!

What physicist have called *time reversal* is best called *cause-and-effect-reversal,* or *causal exchange* for short, because it involves exchanging the order of cause and effect, along with the time reversal of states. This is already seen in the deterministic case. The law L_D states that s_1 *at t will cause* s_2 *at* $t+\Delta t$. The physicists’ reversal of this, *TL**, states that Ts_2 *at t will cause* Ts_1 *at* $t+\Delta t$. It may seem intuitive that this is time reversal, but that is a fallacy of intuition: it does not represent the *time reversal transformation,* as induced by the mapping: $t \rightarrow -t$, and it does not have any of the implications of time reversal that are critical to the philosopher’s interpretation of what this means. Equally, what is called *time symmetry (or reversibility) of quantum mechanics* in textbooks should be called ‘*causal exchange symmetry of quantum mechanics’.*

I note that there is another problem with time reversal in both quantum theory and even classical electromagnetic theory, viz. the choice of the time reversal operator on states, i.e. the transformation: $s \rightarrow Ts$. The literature on this reveals great confusion.[v]

Quantum Mechanics is Time Asymmetric.

The famous result that quantum mechanics is time symmetric is based on the fallacious principle we have just seen, and it is completely wrong. It is wrong in its method: it uses the wrong principle to analyse time symmetry, identifying *TL** instead of *TL* as the reversal of *L*. And it is wrong in its conclusion: when the analysis is done correctly, it is clear that quantum mechanics is *time asymmetric (irreversible).* The probabilistic laws of quantum mechanics *simply do not hold of time-reversed quantum processes.* This can be seen from a simple theorem to the effect that:

Theorem of QM Equilibrium. *Time symmetry* and *cause-effect exchange symmetry* jointly entail *thermodynamic equilibrium*, where absolute probabilities of all micro-states are equally likely.

This of course contradicts the observation of disequilibrium in our universe:

Observation of Disequilibrium. The real universe is in a state of disequilibrium.

A simple derivation of the previous theorem follows.

Derivation of the Theorem of QM Equilibrium.

The easiest way to demonstrate this is by combining the quantum principle of causal exchange:

$$prob(s_2(t+\Delta t)|\ s_1(t)) = prob(Ts_1(t+\Delta t)|\ Ts_2(t))$$

With the requirement for true time symmetry:

$$prob(s_2(t+\Delta t)|\ s_1(t)) = prob(Ts_2(t-\Delta t)|\ Ts_1(t))$$

If these both held generally, then equating the right hand sides:

$$prob(Ts_1(t+\Delta t)|\ Ts_2(t))= prob(Ts_2(t-\Delta t)|\ Ts_1(t))$$

By substitution of Ts_1 and Ts_2 for s_1 and s_2 and using the identities: $TTs_1 = s_1$ and $TTs_2 = s_2$ and the general quantification of t, we then obtain:

$$prob(s_1(t+\Delta t)|\ s_2(t))= prob(s_2(t-\Delta t)|\ s_1(t)) = prob(s_2(t)|\ s_1(t+\Delta t))$$

But this can only hold if the absolute probabilities for the two states, $s_2(t)$ and $s_1(t+\Delta t)$ are equal. This is seen by expanding into conditional probabilities:

$$prob(s_1(t+\Delta t)|\ s_2(t))= prob(s_1(t+\Delta t))/\ prob(s_1(t+\Delta t) \text{ and } s_2(t))$$

$= prob(s_2(t)| \, s_1(t+\Delta t)) = prob(s_2(t)) / \, prob(s_2(t)$ and $s_1(t+\Delta t))$

Hence equating the right hand sides:

$prob(s_2(t)) = prob(s_1(t+\Delta t))$ (absolute probability law).

And since the laws are universalised w.r.t. time, this requires that:

$prob(s_2(t)) = prob(s_1(t))$

This states that *the absolute probabilities of any two micro-states, $s_1(t)$ and $s_2(t)$, are equal.* But this is a condition for *thermodynamic equilibrium.* It is absolutely not a condition that is met by the real universe. See Holster (2003) for more detailed proofs. In summary:

- Time symmetry and cause-effect exchange symmetry can both hold only in a thermodynamic equilibrium. Our universe is not in equilibrium. Hence at least one symmetry must fail. Since cause-effect exchange symmetry holds in quantum mechanics, time symmetry must fail in quantum mechanics.

This shows that it is quite impossible for quantum theory to be time symmetric. As a result, quantum mechanics implies an intrinsic time direction. This is *the direction of actualisation of quantum probabilities.* In Holster, 1990 [PhD Thesis], I adapted McCall 1976 [9], in interpreting this as *the direction of time flow.*

The Error in Quantum Mechanics Textbooks.

This shows that the claims *1** to *4** are fallacies. This fallacy is perpetuated in philosophical accounts in a deeply misleading way, but also advanced in textbooks on quantum mechanics, in a relatively more harmless way, but needing correction. E.g.

> *"A system is said to exhibit symmetry under time reversal if, at least in principle, its time development may be reversed and all physical processes run backwards, with initial and final states interchanged. Symmetry between the two directions of motion in time implies that to every state Ψ there corresponds a time-reversed state $\Theta\Psi$ and that the transformation Θ preserves the values of all probabilities, thus leaving invariant the absolute value of any scalar product between the two states." Merzbacher, 1970, p.406-407.* [10].

To correct the fallacy, this might be modified to read (with alterations underlined):

> "A system is said to exhibit symmetry under *causal exchange* if, at least in principle, its time development may be reversed and all physical processes run backwards, with initial and final states interchanged. This symmetry implies that to every state Ψ there corresponds a time-reversed state *T* Ψ and that the transformation *T* preserves the values of all probabilities, thus leaving invariant the absolute value of any scalar product between the two states. In quantum mechanics we normally identify the time reversal transformation, *T*, with the antiunitary operator, Θ.
>
> Note that this *causal exchange symmetry* is identified in older texts as *time reversal symmetry*, but it has been shown that it does not represent time reversal symmetry. True time reversal symmetry is not physically valid in quantum mechanics, and consequently of no interest in the technical development of the theory here. Implications of true time reversal symmetry cannot be inferred from the *causal exchange symmetry* which is explained here. There are currently no reliable textbooks treating time symmetry in quantum mechanics."

Along with similar replacement of the term *time reversal symmetry* with *causal exchange symmetry* at a few other places, this corrects the error represented in general physics textbooks. Of course this now leaves the concept of *time symmetry* unexplained, and leaves the rationale for choosing Θ instead of *T* unclear, and leaves the implications of *CPT* theorems for *time symmetry* unclear, but that goes beyond correcting the explicit error. The subsequent *mathematical derivations* in physics textbooks are usually reliable, the initial interpretation of what it *means* is incorrect. We can correct this by calling the symmetries by their proper names.

To forestall a common objection, I *insist* that this is not just a ‘semantic issue’ or ‘playing with definitions’. The meaning of the term ‘time reversal symmetry’ is not being conventionally defined or changed to our convenience – on the contrary *we are insisting on using it with its correct meaning*. The term has an objective meaning in physics. It means *symmetry under the time reversal transformation.* What is being corrected is a false identification, viz. of *causal exchange symmetry* as *time reversal symmetry*.

Conclusion. Fallacies 1* - 4*.

The fallacies of 1*- 4* have been demonstrated.

This removes the present case for the conventional conclusion that *the conventional reversibility of physics means time has no intrinsic temporal direction.*

Chapter 2. The Explanation of Physical Time Directionality.

We now turn to the claims *5* to 8**. These are the main explanatory consequences supported by claims: *1** - *4**. The claims and concepts of *5** - *8** are modelled on the classical theory of thermodynamics – i.e. thermodynamics based on a fully deterministic micro-theory, developed in the time of Boltzmann, Loschmidt and Gibbs in the late C19th. The classical theory has well-known 'reversibility paradoxes' when applied to the universe as a whole. But the introduction of *intrinsic probabilities* in quantum mechanics, and its consequent *time asymmetry,* fundamentally changes the picture. However we begin with the situation in a deterministic 'classical' thermodynamics.

The Reversibility Problem in Deterministic Classical Physics

We suppose first of all that the laws of physics are fully deterministic and time symmetric. Physical systems (and our universe as a whole) evidently evolve from low-entropy states (highly ordered) to higher entropy states (randomised). For a simple model, to engage our intuitions, imagine that we start with a set of particles that start in a state where they are forced together in a tight ball, and then released. They will expand outwards, filling space more homogenously.

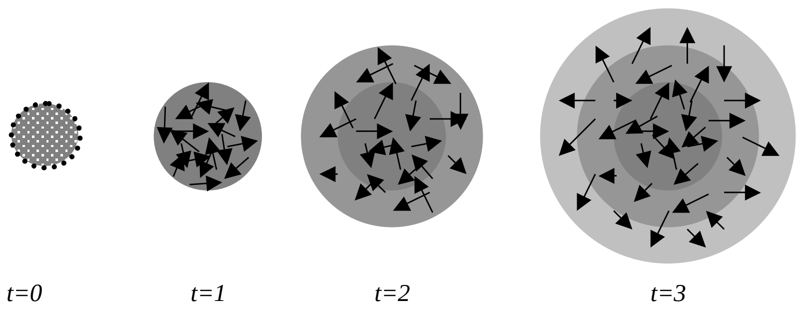


Figure 3. A ball of particles is released at *t=0*, and expands outwards due to 'random' particle motion and collisions. The entropy steadily increases with time, until the space is uniformly filled.

Of course this process looks ‘irreversible’ – in real life, we can’t actually produce the reversed process, involving a large cluster of particles spontaneously ‘shrinking’ into a ball through multiple collisions. But in a *time symmetric deterministic theory,* the reversed process is just as possible as the normal process – at least for a completely isolated system, or for the universe as a whole considered as a closed system. (It is not possible if there is even a very weak coupling of the system with random influences from the outside world.)

The reason is because of the *time symmetry of the classical laws,* or *classical reversibility*. The original process goes through a sequence of complete micro-states like: $s_0 \rightarrow s_1 \rightarrow s_2 \rightarrow s_3$. Each micro-state at time *t* fully determines the following state at *t+1* (on the assumption that the system is completely isolated – or that it comprises the entire universe). *Reversibility* is then said to mean that there is an equally deterministic process: $Ts_3 \rightarrow Ts_2 \rightarrow Ts_1 \rightarrow Ts_0$, starting with the reversed final state, and returning to the reversed initial state. Time-reversed states have the same appearance of order (or thermodynamic entropy) as their originals, since particles have the same spatial distribution, and precisely reversed velocity distributions. Hence the reversed process winds entropy back down.

(We should stress that this is a little inaccurate to start with, because as we have just seen, time symmetry means that for the time-reversed sequence, each later state fully determines each earlier state, like: $Ts_3 \leftarrow Ts_2 \leftarrow Ts_1 \leftarrow Ts_0$. Time direction is still from left to right, but law-like determinism is from right to left, i.e. backwards in time. However given a theory is *fully deterministic*, all causal chains are unique, and there must be a law-like causal chain forward in time as well, which must be like: $Ts_3 \rightarrow Ts_2 \rightarrow Ts_1 \rightarrow Ts_0$. Then the classical argument can proceed).

This classical analysis is the standard visualisation found in the literature. The lesson drawn is that *in a reversible theory, the time reversal of any ordinary thermodynamic universe is just as physically possible as the original universe, hence reversible laws cannot determine that the second law of thermodynamics is law-like. The second law, that entropy increases, cannot be dictated by reversible micro-physical laws alone.*

It is then inferred that *the only explanation for thermodynamic directionality in the context of a reversible micro-theory is a contingent one. I.e. it must appeal to a contingent fact (or boundary condition), stating that the universe started in a low-entropy state.* Thus the paradigm for explanation of physical time asymmetry: it must appeal to *time symmetric laws plus time asymmetric facts.*

The Solution in Probabilistic Quantum Mechanics.

But this classical logic (assuming it is correct) cannot be transferred to quantum physics, because *quantum mechanics is not time symmetric*. The picture of thermodynamic asymmetry has to be rethought. What happens if we try to generate the time reversal of a thermodynamic process in this case? The reason the deterministic process can (theoretically) be reversed is because we imagine taking the *precise reversal of a final state,* and this is so precisely defined that it can unfold in perfect reverse order – something that seems miraculous from our ordinary point of view, because the states (positions and velocities) of all the particles must be coordinated with each other to an incredible degree of accuracy to ensure the highly improbable anti-thermodynamic process unfolds. But this is indeed possible in a fully deterministic universe.

However it is absolutely impossible in a process with intrinsically probabilistic events that can spread their influence – because probabilistic events will inevitably disrupt any degree of 'implicate order' encoded in the reversed state. This is quite simple to demonstrate in general principle. The conclusion will be that *quantum processes are not reversible. The time reversal of an ordinary quantum thermodynamic process is not really physically possible. The time reversal of the real universe, leading back to the 'big bang', is not physically possible. Quantum thermodynamics ensures that the time asymmetry of processes is law-like, not contingent, or 'fact-like'.* I will first sketch the general idea behind the proof of this, and then illustrate it using phase space or configuration space diagrams.

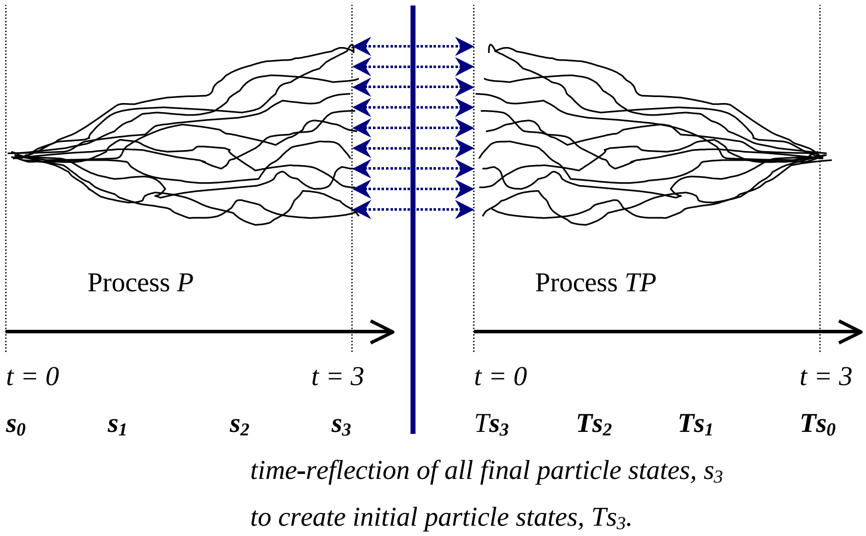


Figure 4. Classical time reversal of the process in Figure 3. If a deterministic state is precisely reversed, and the micro-laws are reversible, the system will retrace exactly the same path followed by the original. The time reversed state, Ts_0, has an 'implicate order' where all the individual particle states are precisely coordinated with each other to reverse the process.

But what happens if there are *intrinsically probabilistic or random or wilful events* involved in the reversed process? It takes only a tiny disruption of the 'implicate order' in the reversed states to completely wreck the reversed process.

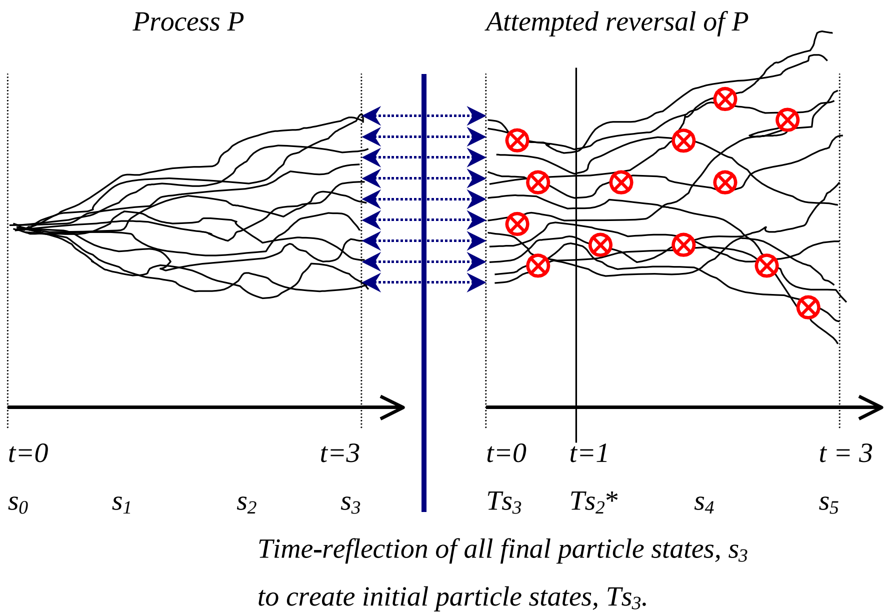


Figure 5. Time reversal in a probabilistic system.

A system is started in the time reversed state, Ts_3, hoping to cause it to retrace the original process back to Ts_0. But there are random probabilistic events (red crosses) that upset the 'implicate order'. The process 'reverses entropy' for a short period, but by t=1, the reversed process has reached Ts_2*, diverging significantly from Ts_2. From then on, the particles become completely unsynchronised from the reversed states, and ordinary thermodynamic behaviour takes over again. The probability of retracing the original path is infinitesimally small. The system will quickly revert to ordinary thermodynamic behaviour again.

A Statistical Model Demonstration.

How can we prove this? I start by clarifying the statistical picture with a simple example, and then making it more precise. Suppose that the initial state, s_0, in the example above, has a low entropy. Then it belongs to a small local volume in phase space, call this $\boldsymbol{S_0}$. A local volume in phase space is a set of similar micro-states. For simplicity, imagine that $\boldsymbol{S_0}$ contains just the one state, s_0. The later higher-entropy state, say s_3, belongs to a much larger local volume in phase space, $\boldsymbol{S_3}$, lets say

1,000,000 times larger than $\boldsymbol{S_0}$, or with 1,000,000 states. Corresponding to these are their time reversed images: $\boldsymbol{TS_0}$ has one state Ts_0, and $\boldsymbol{TS_3}$ has 1,000,000 time-reversed states from $\boldsymbol{S_3}$, including Ts_3. Note that $\boldsymbol{TS_0}$ and $\boldsymbol{TS_3}$ have the same entropies as $\boldsymbol{S_0}$ and $\boldsymbol{S_3}$ respectively.

The probability that s_0 makes the transition to exactly the state s_3 is very small - only about 1/1,000,000 (slightly smaller when we allow for thermodynamic randomness). But there are 1,000,000 states similar to s_3 in phase space $\boldsymbol{S_3}$, with the same probability that s_0 makes the transition to each of these. So the probability that s_0 transitions to $\boldsymbol{S_3}$ is roughly: 1,000,000 x 1/1,000,000, or very close to 1. We have:

$Prob(s_3|\ s_0) \approx 1/1{,}000{,}000$

$Prob(s_3|\ \boldsymbol{S_0}) \approx 1/1{,}000{,}000$

$Prob(\boldsymbol{S_3}|\ s_0) \approx 1$ *entropy almost always increases from* s_0 *to* $\boldsymbol{S_3}$

$Prob(\boldsymbol{S_3}|\ \boldsymbol{S_0}) \approx 1$ *entropy almost always increases from* $\boldsymbol{S_0}$ *to* $\boldsymbol{S_3}$

(With all probabilities going forwards in time from *t=0 to t=3*.) Now the 'reversibility' of quantum mechanics (i.e. *cause-effect exchange symmetry)* means that:

$Prob(Ts_0|Ts_3) \approx 1/1{,}000{,}000$

$Prob(\boldsymbol{TS_0}|Ts_3) \approx 1/1{,}000{,}000$

And this holds equally for each state in $\boldsymbol{TS_3}$, so:

$Prob(Ts_0|\boldsymbol{TS_3}) \approx 1/1{,}000{,}000$

$Prob(\boldsymbol{TS_0}|\boldsymbol{TS_3}) \approx 1/1{,}000{,}000$

(With all probabilities going forwards in time from *t=0 to t=3*.) This means that:

- *The system will almost never make the transition from* Ts_3 *(or any other state in* $\boldsymbol{TS_3}$ *) back to* Ts_0 *(or any other state in* $\boldsymbol{TS_0}$*).*

- *Entropy will almost never decrease from the high entropy of* Ts_3 *(or any other state in* $T\boldsymbol{S}_3$ *) back to the low entropy of* $T\boldsymbol{S}_0$

The behaviour is completely different to the classical behaviour. Quantum thermodynamics has a law-like time asymmetry: entropy increases with overwhelming probability and there is no way to stop it in normal physics. It doesn't matter if we take the perfect time-reversal of a probabilistic system, its entropy is still overwhelmingly likely to increase after a short period. The quantum system will not retrace a process like a classical system.

Phase Space Visualisation of Quantum Irreversibility.

The best way to visualise what is happening is with a phase state diagram. Each point in phase space represents the complete state of a system (or the universe). Dynamic processes are paths through phase space.

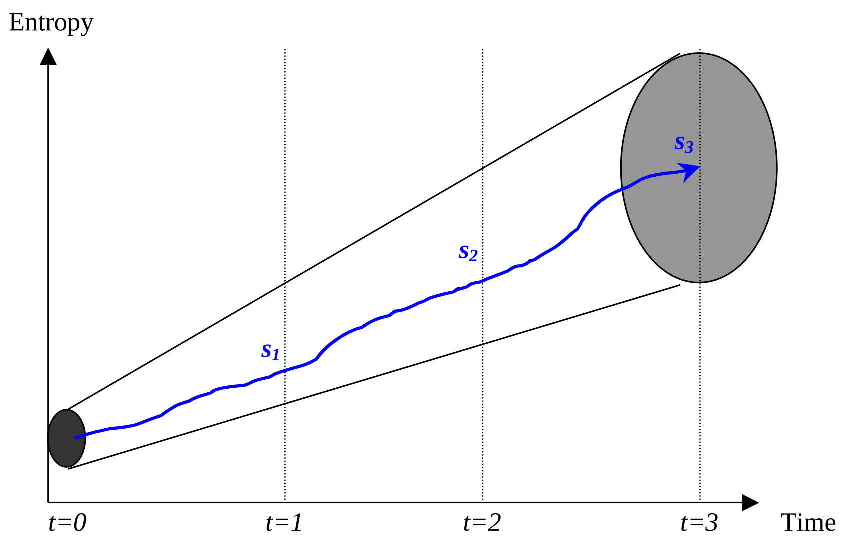


Figure 6. Development of the classical process in phase space. The initial state, s_0, belongs to a dense ball of similar low-entropy states, $\boldsymbol{S}_0$. The future paths from $\boldsymbol{S}_0$ go to a distended ball of states, $\boldsymbol{S}_3$, at t_3. Almost all the future paths lead to higher-entropy states like s_3.

The critical thing however is that *the total volume of states in* $\boldsymbol{S}_0$ *is exactly the same as the volume of their future states in* $\boldsymbol{S}_3$ - but $\boldsymbol{S}_3$ is distended across a much greater volume of phase space. The reason is that the states in $\boldsymbol{S_3}$ that come from s_0 are highly 'filamented'.

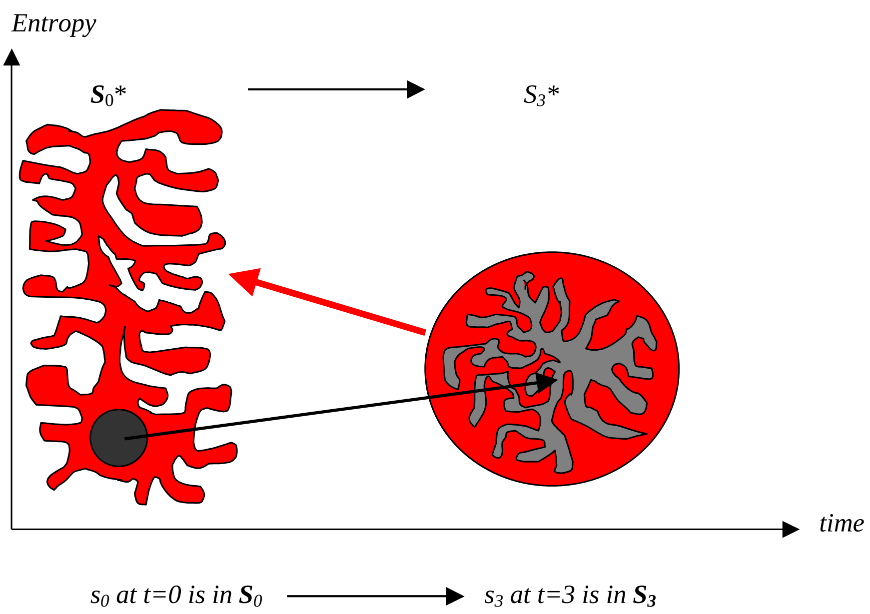


Figure 7. The filamented structure of $\boldsymbol{S_3}$ in classical physics. $\boldsymbol{S}_0$ is the grey ball at *t=0* containing the state s_0, and $\boldsymbol{S_3}$ is the grey filamented volume at *t=3* containing the state s_3. $\boldsymbol{S_3}$* is the red ball at *t=3* (enclosing and including $\boldsymbol{S_3}$) and $\boldsymbol{S}_0$* is the red filamented volume at *t=0* (enclosing and including $\boldsymbol{S}_0$).

States that start off very close together in $\boldsymbol{S}_0$ become far apart in $\boldsymbol{S_3}$ – hence its filamentation. This is the 'butterfly effect': small differences in initial conditions lead to large fluctuations in final states.

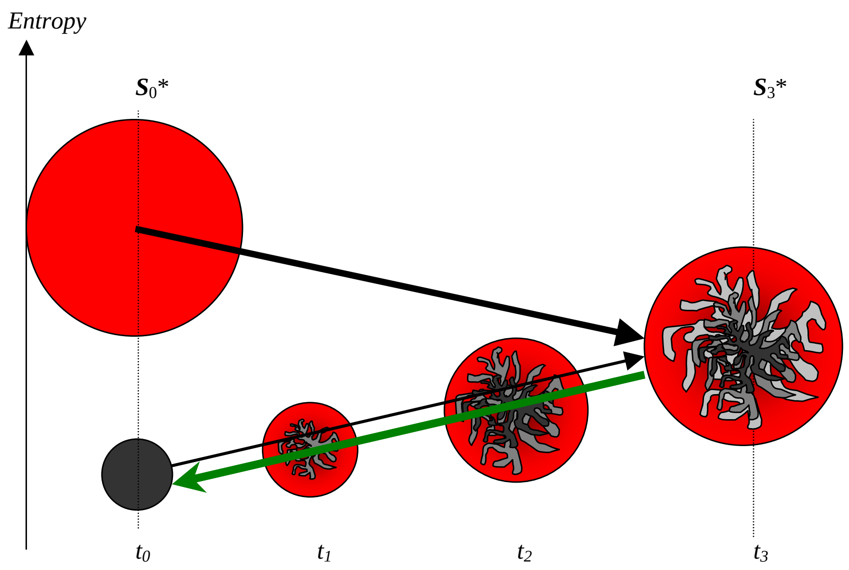
Because of this filamentation, many states very close to s_3 in phase space *are not in* $\boldsymbol{S_3}$ *– they have not developed from the low-entropy* $\boldsymbol{S}_0$. Instead they have developed from $\boldsymbol{S}_0$*, a larger volume of phase space at t=0 that encloses $\boldsymbol{S}_0$. $\boldsymbol{S}_0$* is filamented just like $\boldsymbol{S_3}$ is – the 'butterfly effect' backwards in time means that small differences in final conditions lead back to large fluctuations in initial states. Most of $\boldsymbol{S}_0$* will be from higher-entropy states than $\boldsymbol{S_3}$.

This structure illustrates the fact that, when we consider reversing the states $\boldsymbol{S_3}$ *and* $\boldsymbol{S_3}$*, *very small changes from the final reversed state* Ts_3 *will usually result in states in* $\boldsymbol{TS_3}$*, and these lead to *large fluctuations away from* Ts_0, and almost always to *increased entropy*. This is why it is so critical to set the reversed state, Ts_3, with extreme precision if we want the time reversed process to occur.

But for a process of any complexity in quantum mechanics, with intrinsically probabilistic events, no matter how precisely we set the reversed state, Ts_3, somewhere along the reversed process the state is almost certain to jump out of the desired path, e.g. at $T\boldsymbol{S}_2$, and move into $T\boldsymbol{S}_2*$ instead, and subsequently develop into a higher entropy state. The probabilistic nature of quantum mechanics make this an intrinsic, physically necessary, law-like feature of quantum processes.

The Reversibility Paradox.

It is worth mentioning the 'reversibility paradox' here as well, although it is not intended to deal with this in detail. This paradox comes about primarily because *our normal inferences from future to past (retrodiction; interpretation of physical systems as carrying information about the past)* conflict with our picture of *causality from past to future* in the context of a time symmetric micro-theory.



Normal retrodiction, from t_3 to t_0, infers a chain back to a low-entropy origin.

Figure 8. In real life, we normally infer that a system in $\boldsymbol{S}_3$* *(medium entropy)* has actually evolved from $\boldsymbol{S}_0$ *(low entropy),* not from $\boldsymbol{S}_0$* *(higher entropy).* Yet most possible micro-states in $\boldsymbol{S}_3$* evolve from $\boldsymbol{S}_0$*, so it is puzzling how we can justify this inference.

In reality we make a 'fact-like' assumption that systems in our universe originated in a common low-entropy ancestor state of 'branch systems' (Reichenbach). But can we reconcile this with the laws of physics?

If we start with an observation that a system is in a state in $\boldsymbol{S_3}$*, without being able to distinguish whether it belongs to the special filamented structure $\boldsymbol{S_3}$, and consider its causal origin, we should conclude that it almost certainly started in from a higher entropy state in $\boldsymbol{S}_0$*, and not from a special lower entropy state in $\boldsymbol{S}_0$. This is because there are far more high-entropy states in $\boldsymbol{S_0}$* than low entropy states in $\boldsymbol{S}_0$. If we do not have some additional reason to believe that $\boldsymbol{S}_0$ is preferred over $\boldsymbol{S}_0$* as the origin of the thermodynamic state in $\boldsymbol{S_3}$*, then we can hardly avoid this inference. Since the states in $\boldsymbol{S_3}$* are very close together in phase-space, i.e. have very similar micro-states, it seems that we cannot tell directly whether the micro-state, s_3, really lies within $\boldsymbol{S_3}$, or in $\boldsymbol{S_3}$*.

In real life, however, we constantly infer that systems originate from *lower entropy states*, i.e. we infer from $\boldsymbol{S_3}$* back to $\boldsymbol{S}_0$, and not to $\boldsymbol{S}_0$*. Without this, we would simply not be able to make sense of physical structures as *carrying information about the past*. Physics would become a *reductio ad absurdum*, because the present state (that we observe directly) would no longer allow any normal inference to its past.

There are three main points to make about this paradox.

1. **Paradox is unavoidable in a time symmetric theory.** In the context of a truly time symmetric theory (such as either reversible classical physics, or quantum mechanics with the additional constraint of time symmetry), the paradox seems almost impossible to avoid! This is because, as we have seen earlier, time symmetry along with cause-effect exchange symmetry *implies thermodynamic equilibrium* as the expected micro-state for the universe. If this is taken as a fundamental law of nature, then the most probable cause of any low-entropy state of the universe (such as we actually observe) has to be as a chance fluctuation away from a long-term equilibrium – exactly as Boltzmann realised.

2. **QM solves the paradox**. Real-world quantum mechanics is probabilistic and time *asymmetric*, and we are not forced to the paradoxical conclusion. Instead we are free to propose our normal causal explanations, that thermodynamic systems have

been evolving for a long period of time from a low-entropy state of the early universe.

3. **Why is this a better explanation?** Why is this a better explanation than the conventional philosophy that the laws of nature are really time symmetric? What we observe in the universe are not simply ‘thermodynamic states’, like $\boldsymbol{S_3}$*, (e.g. hot water, cold water), we observe highly complex structures, repeated over and over again in similar forms. In terms of a theoretical solution, we need to show that we can observe or infer that micro-states like s_3 in our example *really do belong to the filamented structures like* $\boldsymbol{S_3}$*, and not just to* $\boldsymbol{S_3}$**.* To stress this in Figure 8, I have shown the filamented structure as building up a *depth of complexity (like a fractal pattern),* with layers of repeated structures, rather than just a ‘flat’ filamented structured.

The approach associated with Prigogine 1985 [22] which is closely related to chaos theory shows that far-from-equilibrium thermodynamic systems naturally evolve complex structures (Onsanger). We need such theories for the detailed scientific explanation of complex structures. Chaotic *deterministic* dynamics is often inferred to be sufficient to determine law-like irreversibility. I will not consider this here, but chaos theory and far-from-equilibrium thermodynamics is a leading attempt to explain the development of complex ordered structure from chaotic beginnings, and is mutually supportive of the view here.

Cosmological Time.

We have been considering micro-physics so far, but it is also important to see how this combines with modern cosmology. There are four general types of models considered (conventional models, without going into many-world theories, fractal universes, holographic universes, etc). But we will see these are all naturally *time asymmetric.* Cosmology does not support time symmetry either.

***C1. Steady State Universe*.**	*Continuous future generation of matter or order.*
C2. Open Universe.	*Origin from a singularity then eternal expansion*
C3. Closed Universe.	*Origin from a singularity, collapse back to singularity.*
C4. Cyclic Universe.	*Eternal cosmological cycle of expansion and collapse.*

- The main point here is that *all these models are time asymmetric.*

C1. Steady state models typically propose continuous regeneration of matter and order. Normal thermodynamics degrades entropy: special mechanisms peculiar to the steady state theory restores entropy. Such models are explicitly directed in time. But since there are no popular models for this any more I will not discuss it further here.

C2. The open universe is proposed to originate a finite time ago with an initial 'singularity' (or point of infinite energy density), to explode through the Big Bang, and continue expanding forever after. This requires asymmetric cosmological time. The universe 'appears from nothing' but continues expanding forever in the future. Micro-physical (thermodynamic) directionality also continues in the future, leading to 'heat death'.

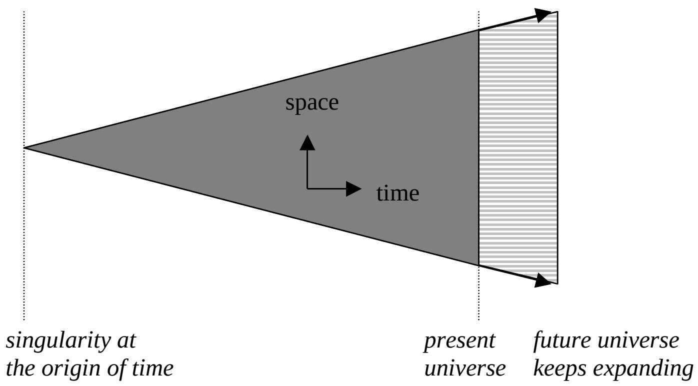


Figure 9. Open universe started at a point (singularity) and continues to expand forever in the future. Expansion could be slowing or accelerating – it is not likely to be constant as shown here – this diagram is purely schematic.

C3. The closed universe originates like the open universe from a singularity, but eventually collapses back into a singularity, and vanishes from existence. This has a finite start and finite end in time, so cosmological time is symmetric in that sense. The spatial expansion may even be symmetric around the mid-point. The point that will be made here however is that micro-processes in the universe must be *time asymmetric,* being driven by thermodynamics, with development of complex structures and information towards the future.

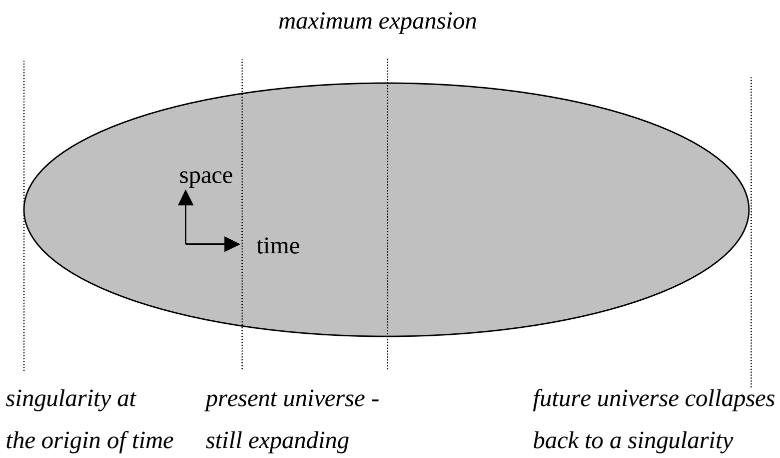


Figure 10. Closed universe starts at a point (singularity), expands, and collapses back to a point.

C4. The cyclic universe is the most interesting from the point of view of time directionality, and it illustrates a naturally occurring *time asymmetric cosmology*.

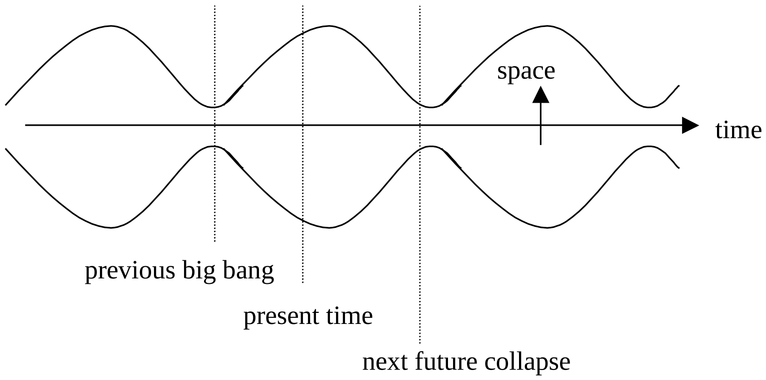


Figure 11. A cyclic universe expands and collapses through an infinite cycle.

This is discussed more in detail next, but a brief digression to consider which cosmology we actually live in.

The Incompleteness of Cosmology.

Most physicists would claim at present that the '*open universe'* is the most likely option, citing two theories: (i) the General Theory of Relativity applied to the earliest universe predicts an initial 'space-time singularity' (Hawking and Penrose), and (ii) the theory of dark energy indicates that the universe's expansion is accelerating and it will never collapse back into another singularity. But we should not take opinions on which kind of universe we are too seriously yet. Cosmology is too incomplete, and these are temporary guesses and hunches in the process of trying to work out a theory. Current models and current evidence are not decisive about such matters. Some reasons are worth emphasising.

On the first point, the theory of 'space-time singularities' used by Penrose and Hawking is a mathematical extrapolation from a theory of gravity (GTR) with no independent *evidence* I am aware of. It is obtained by taking GTR and extrapolating it to an extreme limit, where physical quantities are *literally taken to infinite values*. But there is no evidence that GTR is valid at such limits. In fact, although physicists talk of them all the time, there is no empirical evidence that I know of that singularities, naked or otherwise, really exist in nature! The only basis for belief in *physical singularities* is the theorist's metaphysical faith that GTR is a universal truth. But many theorists think GTR is incomplete at the fine scale where it meets QM, and a more complete theory will correct GTR in the extreme limits where it generates singularities. String theory is proposed partly as a way to fix singularities.[vi]

The existence of infinite quantities in nature (like infinite energy densities) contradicts our realist intuitions. The methodology of extrapolating theories like GTR to reach extreme consequences, inferring the physical possibility of circular time loops, reversed causation, worm-holes through space-time, etc, is speculative metaphysics if we cannot eventually confirm these things *independently*.

Note that infinite quantities appear in classical theories too if we take extreme limits – e.g. classical laws of gravitational and electric forces both involve the factor $1/r^2$, and as we limit $r \rightarrow 0$ (go infinitely close to the center of a point mass or electric charge), the forces theoretically become infinite. But we do not take this extrapolation as reflecting real physics. Instead we assume this is a *problem* for the theory - the classical theories break down at these limits. In GTR, extreme limits occur from the factor: $1/(1-2MG/c^2r)$ in the Schwarzschild solution. This goes to +/- infinity when $r \rightarrow 2MG/c^2$ (the black hole event horizon), and to zero when $r \rightarrow 0$ (the naked singularity), giving two singularities. But there is no reason to think these mathematical singularities are physically real in the final account.

"*But don't black holes exists? As predicted by GTR? Doesn't that prove the event horizon exists?*" Not quite. There is evidence for 'black holes' in a

> "Event Horizon Telescope".
>
> **MIT Haystack Observatory. 2012.**
> *"Project Summary: A long standing goal in astrophysics is to directly observe the immediate environment of a putative black hole with angular resolution comparable to the event horizon. Realizing this goal would open a new window on the study of General Relativity in the strong field regime, accretion and outflow processes at the edge of a black hole, the existence of an event horizon, and fundamental black hole physics. Steady long-term progress on improving the capability of Very Long Baseline Interferometry (VLBI) at short wavelengths has now made it extremely likely that this goal will be achieved within the next decade."*

generic sense – there are large conglomerations of matter in the centres of galaxies, and their gravity probably traps their light – but similar objects appear on many theories of gravity.[vii] The problem is that no one has observed the detailed features of a *GTR event horizon* yet, precisely enough to confirm it explicitly as a *GTR black hole.* This would be a new experimental confirmation of GTR if it was achieved. [See inset].

Similarly, dark matter and dark energy are recent hypotheses introduced to rescue theoretical consistency with GTR in the face of observational anomalies. But these now threaten to enter the realm of speculative metaphysics, because neither substance has been independently observed or detected, despite much trying, and no one seems to have any idea of what it could realistically be composed of.[viii] The observational evidence claimed for the *accelerating* expansion of the universe is very theory-dependant. This whole explanatory scenario is liable to collapse when a new unifying theory comes along. Dark matter and energy may be comparable to C17th theories of phlogiston.

We should not to take the *unconfirmed theoretical* hunches and extrapolatums of physicists too seriously as a source of metaphysical wisdom.

http://en.wikipedia.org/wiki/String_theory

Wikipedia, "String Theory"
"Many theoretical physicists (including Stephen Hawking, Edward Witten, and Juan Maldacena) believe that string theory is a step towards the correct fundamental description of nature. This is because string theory allows for the consistent combination of quantum field theory and general relativity, agrees with general insights in quantum gravity such as the holographic principle and black hole thermodynamics, and has passed many non-trivial checks of its internal consistency. According to Hawking, *"M-theory is the only candidate for a complete theory of the universe."* Other physicists, such as Richard Feynman, Roger Penrose, and Sheldon Lee Glashow, have criticized string theory for not providing novel experimental predictions at accessible energy scales and say that it is a failure as a theory of everything."

The Cyclic Universe Model is Naturally Asymmetric.

But we do not have to decide on any specific cosmological model to make the key point here, because all are time *asymmetric* in the same essential way as the *cyclic universe,* which illustrates time asymmetry most vividly. The cyclic universe expands and contracts in an endless cycle, swinging between states of high density ('Big Bangs') and low density (maximal expansion). Rather than contracting to a mathematical point and appearing/disappearing by magic, we assume that it 'bounces' after reaching a certain density. This cosmology operates through two sets of laws:

(i) the deterministic expansion-contraction cycle of space – we may assume this is time symmetric

(ii) the micro-physical laws of ordinary processes – assume this is like QM

The conventional assumption is that such a cyclic process *should have time symmetric laws.* However when we consider the thermodynamic cycle in such a model, we find it is naturally directed in time.

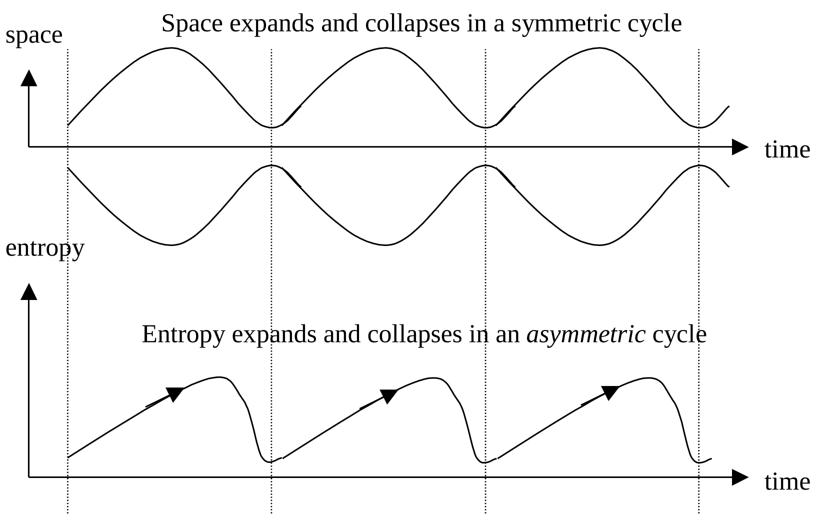


Figure 12. The entropy cycle for the cyclic universe is *asymmetric* – it points in the same direction as quantum mechanical probabilities. The entropy cycle has a 'saw-tooth' shape: it begins very low at the beginning of each cycle, increases steadily for most of the cycle, then rapidly falls back to a low value.

I will now try to show why this time asymmetry is inevitable, in the symmetrically expanding and collapsing cyclic universe. The first point is that given the universe has a cyclic state, *the entropy must fall back to the same low level by the beginning of every cycle. Yet ordinary thermodynamics tells us that it must also increase through much of the expansion cycle. So how does entropy fall? Isn't it supposed to always increase, according to thermodynamics?*

How Entropy Falls in the Cyclic Universe.

A popular speculation in the 1960's (due to Gold) was that entropy is related to the cosmological expansion – and it will start falling if the universe stops expanding and starts contracting, in a time symmetric fashion. But it was quickly pointed out that this does not make sense in terms of real physics. There is no known reason why ordinary processes (e.g. burning of suns; flowing of rivers; breaking of eggs…) should reverse if cosmological space begins to contract. There is no known reason we would even become aware that the expansion era has ended. Nonetheless the intuition remains with many writers that *the thermodynamic cycle for a cyclic universe may be time symmetric, because all the underlying laws of nature are time symmetric.* But this is simply a mistake – because the underlying micro-physical laws *are not time symmetric.* Once this mistake is dismissed (claims 1* - 4*), we can look at the mechanics with fresh eyes.

It is essential to realise that the reason entropy decreases in the collapse period is because *the configuration space itself is being compacted.* There are two components to a thermodynamic system: *the configuration space, which determines the freedom micro-states have to move in; and the micro-state itself.* When space expands in the cosmological model, *it expands the configuration space.* The micro-state responds by evolving into new states, and randomising itself in the new state-space – just as when we released the ball of particles in the earlier example, the particles had a larger space of possible states to inhabit. Conversely, when space contracts in the cosmological model, it forces the configuration space to contract – and eventually forces the entropy down. The entropy cycle lags behind the configuration space cycle, and it is not until the later stages of contraction that the entropy is forced down.

This is evident in the standard physics of the 'big bang'. In the early stages, when the universe was extremely compacted, it was impossible for ordinary particles to form – all the energy was forced into dense ball, with a small set of possible states. After the explosion, it became possible for the energy to crystallise into ordinary particles and atoms – allowing the highly complex states of the present universe.

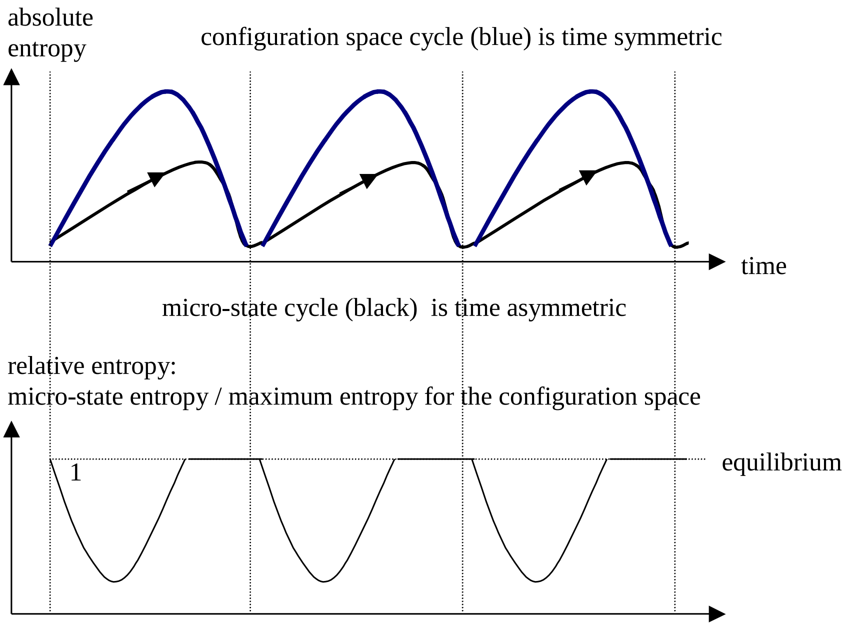


Figure 13. The top panel shows the configuration space cycle (maximum entropy allowed in the universe) in blue, and the micro-state entropy (actual entropy of the particle universe) following this in black. The latter is time asymmetric – a saw-tooth shape. The bottom panel shows the 'relative entropy' (or departure from *equilibrium*). Equilibrium occurs when the particle micro-state entropy is maximised relative to the entropy permitted by the configuration space, i.e. when: micro-state entropy/configuration space entropy = 1.

Even though the absolute entropy is very low at the most compacted points of the cycle, the universe is still in equilibrium. It is forced close to equilibrium through the later part of collapse cycle, because the configuration space cycle forces the absolute entropy down to the micro-state entropy.

I briefly note one peculiarity of this model. As the configuration space contracts, it should force probabilistic state transition laws of quantum mechanics to alter. More exactly, it seems that it should force the *cause-effect exchange symmetry to fail.* (The so-called 'reversibility symmetry' of ordinary quantum mechanics should fail). If it were absolutely impossible for this symmetry to fail, this cyclic model would probably not be possible. However, this quantum symmetry does indeed seem to mysteriously break for a certain interaction, viz. K-meson decay, so we know such an effect is physically possible. And as noted earlier, it is not a real *symmetry transformation* anyway.

The point is that this class of models – time symmetric cyclic collapse models – naturally generate a *time asymmetric entropy cycle* in the context of any micro-theory with intrinsic probabilities. Such models *must have time asymmetric fundamental laws*. Such models *explain the thermodynamic directionality without postulating any special initial states or boundary conditions.* In fact the same mechanism for generating time asymmetric thermodynamics applies in the open and closed models too. They also *have to have time asymmetric particle physics,* just like quantum mechanics.

Their main difference with the cyclic model lies in their lack of any explanation for the initial creation of the universe at a specific moment. In the cyclic model, the universe is taken as a physical entity persisting for all time – it has always existed and always will exist – it simply changes its present state as time passes. The existence of this universe is mysterious in the sense that the existence of *anything* is mysterious. But there are no 'creation miracles' *within* the natural history of the universe. Every physical state has an explanation in terms of preceding physical states. The open and closed universes seem to require 'miracles' to bring them into creation. They appear 'created from nothing', with no causal explanation for the original states of these universes. But the failure to explain ultimate causes does not undermine the explanation of irreversibility. Whatever the cosmology that produced our universe, the irreversibility of thermodynamic processes is a consequence of the parallel irreversibility of QM.

The Fallacy in the Conventional View.

The conventional defence will allow that our *asymmetric closed cyclic universe* may well be possible, but it will insist that if it is, then according to our best knowledge of the laws of nature, *the time reversed cycle must be equally possible.* E.g. they would insist that the kind of universe depicted below would be equally compatible with the laws of physics as the cyclic asymmetric universe I have depicted above. In this universe, there is a 'singularity' at the 'origin' of time, but with symmetric 'branches', going backwards and forwards in time respectively. The universe (thermodynamic behaviour) is symmetric around the singularity.

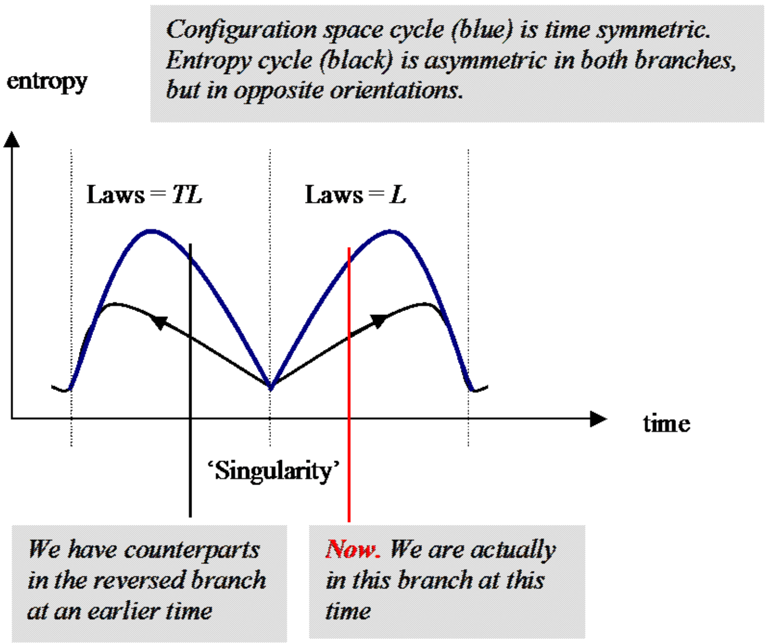


Figure 14. A 'time symmetric' universe with two branches. Note that this is physically impossible, according to our current knowledge of physics, because $TL \neq L$. This would contradict the notion that *the laws of physics are universal through time, or have time translation symmetry.*

The conventional philosophy insists that this universe must be just as physically possible as the cyclic universe depicted previously, because they believe that $TL = L$, i.e. that the laws of nature are time symmetric, and exactly the same time symmetric laws would hold in both branches. The only distinction between the two branches on their view must lie in the *boundary conditions,* at the ‘singularity’. If this were true, their claims 5* - 8* would be supported. We would not be able to tell which branch we are ‘really in’. We could have ‘counterparts’ in the reversed branch who think that ‘time flow’ occurs in the opposite direction to what we perceive.

However the whole discussion to this point proves that this is wrong, because *TL ≠ L!* The ‘time symmetric’ universe would contradict the assumption that *the laws of physics are universal through time,* i.e. have time translation symmetry. In a cyclic universe where the laws of physics are the same in each cycle, *the thermodynamic cycle must be time asymmetric in every branch.* There is no possible way to generate a consistent model of the type of universe above by manipulating boundary conditions, as the positivists believe.

Conclusion. Fallacies 5* - 8*.

The fallacies in 5* - 8* have been demonstrated sufficiently to show that known physics does *not* support the positivist explanation of process directionality as a merely ‘contingent fact’. Instead it supports the view that time is intrinsically directional, that this is reflected in the causal laws of nature, and process directionality or irreversibility in nature is a fundamental, law-like feature.

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Footnotes.

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i From *The Time Flow Manifesto (monograph; Holster, 2013-2014; unpublished).*

ii Spivak 1979 [17] is a classical modern mathematical treatment of the construction of differentiable manifolds, using tangent vector spaces. This is a very approachable text on advanced geometry, focussed on detailed application to GTR. It precisely defines the semantic interpretation of coordinate systems, tensor calculus, etc, giving a more complete interpretation than the usual introductions to STR or GTR, which present it as an applied tensor calculus, interpreted intuitively.

iii The key original source of this view is Watanabe 1955 [19], 1965 [20] (and other papers), who argued for the main point of Chapter 1, holding that this time asymmetry of QM makes a decisive difference to the problem of irreversibility, e.g.

> *"The reason (for the phenomenological one-way-ness of temporal developments) is, as we shall presently see, that quantum physics is basically irretrodictable, both microscopically and macroscopically, whether or not it obeys reversibility or any other similar invariance law. It is precisely irretrodictability which is related to phenomenological one-way-ness"* Watanabe, 1966 [20], section 8, p 156.

Holster 2003 [6] has proofs of claims in Chapter 1, confirming Watanabe's views:

> *"Watanabe's results show that the 'reversibility paradox' of classical thermodynamics is removed when we turn to QM thermodynamics."*

However Chapter 2 here overrides my earlier caution that:

> *"... until we have a convincing general cosmological theory I think it is premature to judge whether irreversibility has a contingent cause or is a fundamental law-like feature of the universe."* Holster, 2003 [6].

I now argue in Chapter 2 that the irreversibility of quantum mechanics explains thermodynamic irreversibility as a law-like feature, and it is not sensitive to choice of cosmological paradigm. This is consistent with Watanabe's larger view. A number of others have argued for non-conventional views, I note Schrodinger 1950 [14] and Healey 1981 [5] as two classic papers of special interest in this context.

Reichenbach 1957 [13] is the classic work that established the study of time directionality as a philosophical subject in its own right, and largely set the framework of concepts and problems that remains central to this day. He does not represent the conventional view however.

The classic statement of the *conventional view* is P.C.W. Davies' accomplished 1976 [2]. This is the first and best encapsulation of the conventional physics of time reversal, in one short systematic monograph, reviewing the major fundamental branches of physics, with simple statements of philosophical conclusions and inferences. Apart from my criticism of points of philosophy, which could easily be remedied in any case, this remains an excellent first introduction to the physics.

The most sophisticated development of the conventional view of *irreversibility* I think is given by Costa de Beauregard, 1987 [3]. This is one of the great scholarly and creative masterpieces of its kind. His close treatment of thermodynamics has many insights. He has probably the best version of the conventional view of the thermodynamic asymmetry, arguing at length that it is *contingent not law-like.*

From the 1970's, the conventional analysis of the *physics of time directionality* has advanced systematic expositions, with more book treatments such as Sachs 1987 [15], Zeh 1989 [21], along with accessible presentations of more general concepts and symmetries, such as Sklarr 1974 [16]. The development of relativity is brilliantly surveyed by Torretti 1983; 1996 [18]. Spivak 1979 [17] is a more complete mathematical treatment of differential manifolds. There are now many more popular and scholarly expositions. However *time reversal symmetry* is still a subject that continues to generate controversy and uncertainty. It is not understood transparently and clearly like other symmetries of physics.

Other paradigms appeared as well, notably from the confluence of chaos theory, Onsanger and far-from-equilibrium thermodynamics, Prigogine.

iv Some researchers try to 'redefine the concept of reversibility', or discover some new concept of 'time reversal in QM' that will let them render problematic laws 'reversible', and support their metaphysical preference for 'the intrinsic symmetry of physical time'. This reflects a fundamental misunderstanding.

v Physicists do not have a fully coherent account of the principles for time-reversal of states, any more than of laws. This point is pressed by Albert (2000) [1], which sparked outrage from many physicists and philosophers, with still no agreed outcome to the debate. The point about QM is considered by de Beauregard (1980) [4], referring to earlier interest by Racah (1937) [12]. Holster (2003) [7] examines this in more detail. The point to be made is that it is not the *definition of time reversal* that is open to question: the problem is that QM is simply ambiguous about the physical *interpretation of the wave function*, leaving the role of time ambiguous.

[vi] However string theory is still only a *mathematical* theory, as far as I know, because no physically realistic string theory has been identified yet. String theorists are *looking for ways to find a physical string theory.*

[vii] Michell and Laplace proposed the concept of a black hole in the C18th, see Michell, Laplace and the origin of the Black Hole Concept, Colin Montgomery, Wayne Orchiston and Ian Whittingham, Journal of Astronomical History and Heritage, 12(2), 90-96 (2009). Michell proposed the concept of a black hole in a paper of 1783, notable for its romantic title:

> "*On the means of Discovering the Distance, Magnitude, &c. of the Fixed Stars, in Consequence of the Diminution of the Velocity of Their Light, in Case Such a Diminution Should be Found to Take Place in any of Them, and Such Other Data Should be Procured from Observations, as Would be Further Necessary for That Purpose."*

[viii] *Decaying dark matter* has inevitably been proposed as the explanation of the latest new cosmological mystery, missing inter-galactic UV light.