The Arrow

A Brief Theory of Time

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11th October 2007

Contents

Part I

Dialogue

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The Cast

What time it is? So, you are one of these types who believe that Time exists? (The Devil in *The Dean* by LG)

Time is the substance of which I am made. Time is a river which sweeps me along, but I am the river; it is a tiger that mangles me, but I am the tiger; it is a fire that consumes me, but I am the fire. The world,unfortunately, is real; I, unfortunately, am Borges. (Jorge Luis Borges in *A New Refutation of Time*).

1.1 The Characters: Phil and Math

We give an introduction to the themes of the book in the form of a *Dialogue* between the two authors in the following two roles:

- **Phil**(ippe): philosopher, author of fiction and poetry,
- **Math**(ew): matematician, engineer and reform educator,

meeting regularly at **Atomic Clock Cafe** in Stockholm, see Fig. 1.1. Both **Phil** and **Math** primarily use common language and logic but occasionally resort to a more specialized discourse using tools from

- **Phil**: ontologi, semantics, rethoric, epistemologi,
- **Math**: Calculus, Newtonian and quantum mechanics.

The word Dialogue is a combination of the Greek words *diá* (through) and *logos* (word, speech) suggesting something like a *flowing-through meaning*.

The prefix diá is often confused with the prefix *di* (two) and then leads to the erronous conclusion that a dialogue only involves two parties. The Dialogue form was used extensively by Plato and Galileo (with three parties), and we will start following this great tradition, but then shift to instead a dialogue with the reader without separating the two authors.

FIGURE 1.1. The place for the Dialogue: Atomic Clock Cafe.

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Getting Started

> However deep the chasm that separates the intuitiv nature of space from that of time in our experience, nothing of this qualitative difference enters into the objective world which physics endeavors to crystalise out of different experience. It is a four-dimensional continuum, which is neither “time” nor “space”. (Hermann Weyl, 1949)

2.1 Math’s Declaration

Nice to meet you Phil. I have read many of your books with great pleasure, both fiction and poetry, with their charming mix of philosophy and life. You seem to have a special weakness for women, mathematics and science fiction?

2.2 Phil’s Declaration

Nice to meet you Math. Yes, it is true that I have nurtured a secret dream to be a mathematician. I like both its rigor with *axioms*, *lemmas*, *theorems* and *corollaries*, and its mind-boggling poetic terms like *transfinite numbers*, *non-enumerable set*, *continuum*, *Cauchy sequence*, *aleph*, *algebraic topology*, *Lipschitz continuity*, *Banach-Tarski paradox*, *Ljusternik-Schnirelman category*, *knot theory*, *homeomorphism*, *fiber bundles*, *differential geometry*, *Minkowski space-time*, *partial differential equation.*

And you Math, have you ever dreamed of becoming an author of fiction?

2.3 Math: A New Idea: Principe Perfeito

Yes, of course, we all have our dreams to be what we are not. A dream of change, one could say. I tried to write some fiction, but only tedious Calculus books came out.

In any case, your dream of mathematics is precisely what made me invite you to a coffee here at Atomic Clock Cafe and a discussion about aspects of *time*: You have direct contact with the worlds of poetry, fiction and philosophy, but you also like mathematics. A rare combination, indeed!

You see, in my work as an applied mathematician I have stumbled upon certain facts, or rather a certain principle, which I refer to as *Principe Perfeito*, which seems to offer an answer to the old problem of the *Arrow of Time*, that is the problem if time has a direction forward or is *irreversible.* I would like to present this principle to you and see if I can get you to embrace it and see its beauty. Of course, more generally I hope we can have good time together discussing various things, while we enjoy a good piece of cake and a café crème.

2.4 Phil: A Test?

OK, so you see our meetings here at Atomic Clock Cafe as a kind benchmark test of the functionality of Principe Perfeito. Well, that seems a bit limited and narrow to my taste, since I am used to think freely by myself and I hesitate to act like some kind of test rabbit in a laboratory. Nevertheless, following up on the idea of a laboratory, maybe we can use our meetings here at Atomic Clock Cafe as a case study of aspects of time, like

- *periodicity*,
- *repetition*,
- *duration*,
- *time flow*
- *irreversibility*,
- *memory*,
- *time travel.*

This is a neat idea; to study aspects of time by discussing it, in real time!

2.5 Math: Open Discussion

I fully understand your reservations. I suggest that we both try to have open minds willing to go wherever the discussion leads, and I promise to not insist on Principe Perfeito as the answer to just about anything, which would be tedious and single-minded. I just want to say that I believe I have a new angle of attack, on a very old problem. To just circle well known tracks without goal, would not be that interesting, I believe.

2.6 Phil: Independent Thinking

All right, I accept your declaration of intention, and take the liberty of not accepting anything you say without understanding it properly, and also to change the topic of discussion whenever you get lengthy and loose the track.

2.7 Math: Flow and Arrow of Time

Excellent. Please have another cake. Can I then suggest to organize our discussion into two main themes:

- Flow of Time.
- The Arrow of Time.

The Dialogue could then serve as a general introduction to the themes of the book allowing us to share ideas without going into details and technicalities. The rest of the book could then contain more careful analysis of various aspects, where we no longer separate our two roles.

2.8 Phil: Time Transfixed?

This seems like a possibly fruitful pie to me. But before taking on the main themes, let us see what the Masters have to say. By the way, I suggest we take a look at Magrittes *Time Transfixed* in Fig. 5.1 to get some inspiration: Is here time (trans)fixed? Or is time flowing?

Shall we agree to meet again *next week* at *3 pm* on Thursday? What do we have to think of to make this happen? I think a believe I know how. What about you? Do you have a calender and a watch?

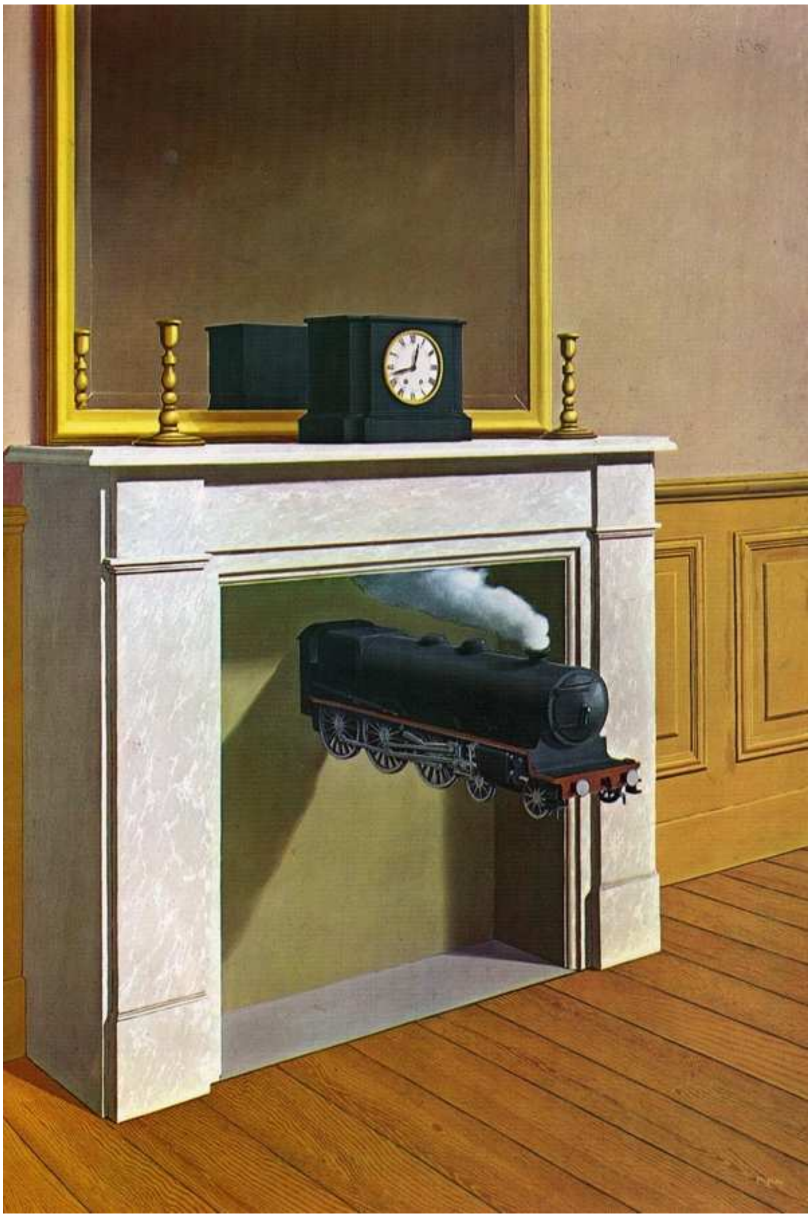


FIGURE 2.1. Time Transfixed by Magritte.

3
The Masters

> If everything when it occupies an equal space is at rest, and if that which is in locomotion is always occupying such a space at any moment, the flying arrow is therefore motionless. (Aristotle, Physics VI:9, 239b5)

3.1 Phil: Parmenides and Herakleitos

The debate on time goes back to early Greek philosophy, where you find two radically different views: *Heracleitos* argued for *perpetual change* including *time change*, while *Parmenides* maintained there was *no change* and thus neither time nor motion. You can connect Heracleitos perpetual change with a democratic attitude, where a poor man can get rich and vice versa, and Parmenides no-change with a aristocratic attitude with the noble family forever in control of their castle, land and servants without change.

We shall see below that Aristotle essentially took the position of Herakleitos, and it is logical that Aristotle carefully studied aspects of democracy.

3.2 Math: Growth

Yes, you are right. Parmenides no-change idea was abandoned with the scientific and industrial revolution starting with Leibniz' and Newton's *Calculus* in the 17th century, which is the *mathematics of change*.

In the industrial society new machines deliver increasing output every year offering ever increasing material wealth to the people, thereby opening to democracy. Democracy without change is impossible, and without (hope of) change to the better, democracy risks to collapse. If seems that the capitalistic system is based on growth of the economy, just like a life without growth is inconceivable.

On the other hand, and this is what we are facing today in the threat of *global warming*, anything that has the capability to grow also runs the risk of growing too much so that it suffocates. We know that today everybody sings the song of controled growth, not too much and not too little, but very few sing about no-growth.

3.3 Phil: Growth

I agree. What is also interesting is ....

3.4 Math: Relativity and Quantum Mechanics

What is contradictory is the development of the special and general *theory of relativity* by Einstein in the beginning of the 20th century, appearing as democratic Europe collapsed in the 1st World War. In relativity theory space and time are joined into *space-time* and in space-time there is no real change in time, only seemingly motionless space-time configurations

So, Parmenides has come back in our time in relativity theory viewed as one of the corner stones of modern physics. The other corner stone is *quantum mechanics*, which rather connects to Herakleitos perpetual change: The *wave functions* of quantum mechanics satisfying *Schrödinger's equation* describe the perpetual motion of clouds of electrons around atomic kernels.

The tragedy of modern physics is that relativity theory cannot be combined with quantum mechanics, and thus the basis of modern physics is shaky. Parmenides and Herakleitos seem incompatible without any possibility of synthesis, by many witnessed as a crisis.

3.5 Phil: Shocking!

This is shocking. I do not know what to say, or what to believe: Parmenides or Herakleitos? Artistocracy or democracy? Physics in crisis? Global warming? It is simply over-whelming.

3.6 Math: Unbelievable!

Yes, this is shocking and in a sense unbelievable. But there is only one possiblity: We have to go for democracy with perpetual change, and we must believe that physics can be given a rational foundation. This is our only chance in a hostile and cold Universe.

Anyway, let's take another cake and see what our discussion can lead to. Can I then suggest that you Phil take on the role of Parmenides to start with.

I have a vague feeling that we will be able to reach a form of synthesis, where in a sense the impossibility of motion of Parmenides can be acknowledged, without giving up the possibility of change. Change without motion, what about that?

3.7 Phil: OK I defend Parmenides

OK, I will try to defend the position of Parmenides, and we'll see how far that will carry. So I claim that motion is impossible, and therefore change is impossible. In the same spirit I volunteer to advocate that the flow of time is an illusion. Nothing changes, both motion and flow of time is an illusion.

To support my position I refer to McTaggart.....

3.8 Math: Zeno's Arrow

Fine, your position seems pretty clear, and you are not alone. I suggest we start with *Zeno's Arrow*, which is not the Arrow of Time, which we will come back to shortly. Zeno's Arrow is simply an arrow flying through space. The basic question is if *motion is possible?* Zeno asked:

- *How can an arrow move, when at each instant it stands still?*

This is referred to as *Zeno's Paradox*. It is a good paradox and not so easy to resolve. It is completely basic to our discussion: If the arrow moves or flies, then we may say that *time flows* or *time flies*, as we will understand more precisely below, and if the arrow stands still, so does must time.

3.9 Phil: Zeno's Paradox?

OK, so what is the resolution to the paradox: Does the arrow move or not? As far as I can see it stands still at each instant, and thus does cannot move. I think we need another coffee here. Waiter, please!

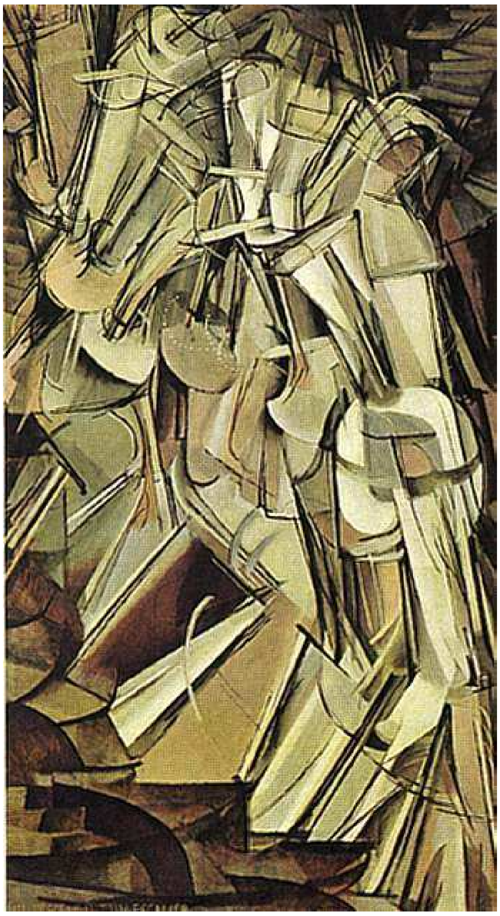


FIGURE 3.1. *Nude Descending a Staircase* by Marcel Duchamp caused a scandal when first shown in the Armory show in 1912: At each moment the nude is at a fixed position, yet she is descending the stairs.

4
Resolution of Zeno's Paradox

> But maybe that is our mistake: maybe there are no particle positions and velocities, but only waves. It is just that we try to fit the waves to our preconceived ideas of positions and velocities. The resulting mismatch is the cause of the apparent unpredictability (Stephen Hawking 1988)

4.1 Math: What Motion Is

To come to grips with the paradox, we have to understand what *motion* is. So what is it? Well, we can say that motion is *change in position* or *change in configuration*: Phil, when you lift your coffee cup from the table to your mouth, the cup changes position. You can only take a sip of coffee with the cup at your lips. But yet you say: At each instant the cup stands still, so how on Earth can it move from the table to my lips?

That is a tricky question, but it can be answered. To do so we have to go to quantum mechanics of course, since ultimately the question is how on Earth the atoms of the cup with coffee can move in space from the table to your lips?

Since quantum mechanics concerns wave functions, we have to understand what the characteristics of a *wave* are. Right Phil?

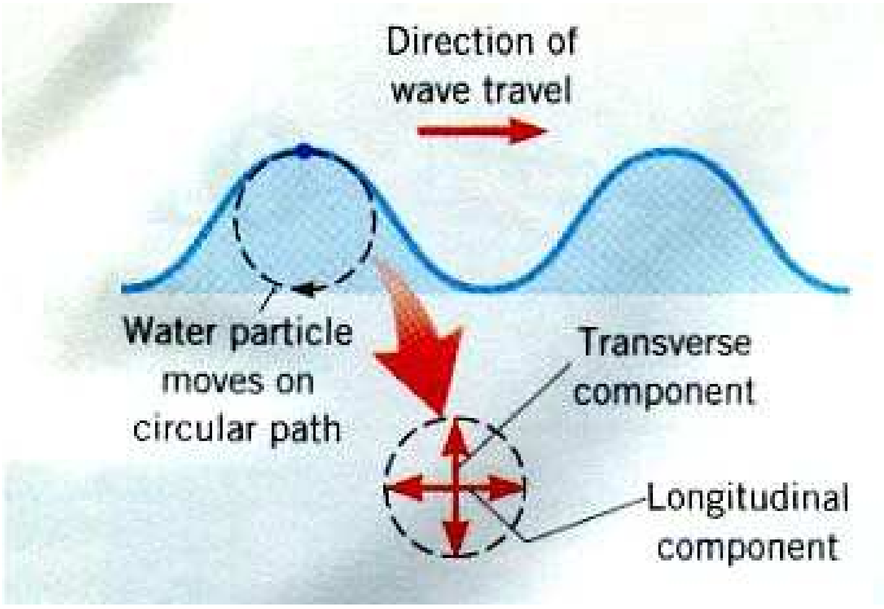


FIGURE 4.1. A water wave is generated by circular motion of the water molecules. The wave can propagate to right or left without loosing its form.

4.2 Phil: What is a Wave?

Yes Math, so what is then a wave? I am really curious!

4.3 Math: What a Wave Is

Well, you have certainly watched waves in the sea approaching a shore or you have felt waves approaching you when you are swimming or sailing. What is really intriguing about water waves, is that you see a wave moving horisontally, while the particles of water making the wave do not move with the wave. You may even know that each water particle moves in a small vertical circular motion, more or less on the spot, and thus does not move horisontally with the wave, see Fig. 47.1. The wave seems to be moving across the surface of the water, but the fluid particles are not moving with the wave. You see motion, essentially without any material particles moving.

4.4 Phil: Shake a Rope

Yes, I am familialr with this phenomen: If you fasten one end of a rope to a wall, stretch the rop and shake it quickly, you will see a wave progressing along the rope from your hand towards the wall, and of course no part of the rope itself moves along with that wave: The material of the rope moves up and down a little, more or less like the water particles in a water wave, but the wave moves horisontally. Physics is really quite fascinating, when you get that good feeling that you understand something!

4.5 Math: Wave Motion without Material Motion

If we now go back to the quantum mechanics of the atoms of a coffee cup, we can understand that if atoms with their electron clouds are described by a form of wave mechanics, and thus behave like waves, it is conceivable that the motion of an atom would be like the motion of a sea wave and thus not really require any motion of any material, whatever material is. With this perspective atoms would thus move like waves without any corresponding material motion. We thus get by without explaining what material motion is, and that is the beauty of a wave theory like quantum mechanics.

We could thus agree with Parmenides and say that material motion is maybe not possible, or rather that we do not need it and thus do not have to explain it, because a wave can move anyway and thus wave motion is possible.

4.6 Phil: Zeno's Arrow and Mushrooms

OK, I understand what you say, more or less, and of course this suggests a resolution of Zeno's Paradox: The arrow viewed as a wave is moving while the material of the arrow is not moving. It suggests that the arrow rather "appears" at different positions, just as the wave "appears" at different spots, without corresponding motion of material, whatever the meaning of that can be. In a sense the arrow thus "is born" anew at each spot, then dies away, and gets reborn at another spot. The impression we get is that the arrow moves.

As a metaphor one could think of an expanding ring of mushrooms above ground carried by an invisible *mycel* below ground. It could then appear as if the mushrooms were moving, but in reality they would not, because the apparent motion would come from new mushrooms appearing at some spots and dissapperaing at other spots.

I think this is a beautiful resolution of Zeno's paradox. Really neat!

4.7 Math: Back to Aristotle

Very good Phil, you seem to have a good intuition for quantum mechanics. If we now sum up, we agree that change of position is possible in the sense that the arrow can appear at different positions. To connect to the concept of time, we now recall that Aristotle claimed that time is change of position or configuration or rather

- *Time is an aspect of change which can be measured by numbers.*

Thus you can measure time by the change of position of the arms of a clock. A growing child can measure time by his/her length in centimeters, an old male philospher by the length of his beard, a farmer by the height of the corn in the fields. The time of the day by the height of the Sun et cet.

We are thus led to the following operational definition:

- *Time (flow) is what you measure with a clock.*

4.8 Phil:

OK, let's agree on that for the moment, but I am not finished yet. I think it is now time for a refreshing walk.

5 Questions and Answers

> Your memory is a monster; you forget - it doesn't. It simply files things away. It keeps things for you, or hides things from you - and summons them to your recall with a will of its own. You think you have a memory; but it has you! (John Irving)

5.1 Phil: Questions

There seems to be a fundamental difficulty to reconcile the intuitive experience of time flow with the physicalistic view of time as a topologically ordered set of points-in-time.This incompatibility gives raise to a number of profoundly connected puzzles. We find it already in early Greek philosophy as an incompatibility between the Eleatic school – time is unreal – and the Miletic – everything, even what seems stable , is in a state of continuous flow. In Kants Critique of Pure Reason Time is simply the way Human mind has to represent or arrange the external world in order to make it possible to deal with it in a rational way. Asked whether he really believed that the fact that our birth precedes our death is an arrangement of our reason and has no internal necessity in the nature of things, he would probably answer that time order is of a much more universal nature , as opposed to the taste of a vine or the pain from a needle, both sensations which o bviously presuppose an interaction between a stimulus and a sensory medium We cannot get out of it. For Mc Taggart the incompatibility between the objective, physical approach – time is a topological ,transitive and non-symmetric order of events – and the intuitive – there is a past a present which we are continuously loosing and there is a future, can only be solved by denying the objective existence of Time. In Henri Bergsons philosophy the flow of time or duration unlike its spatial representation in harmonic oscillators can only be grasped intuitively. It is a primitive fact not open to conceptual analysis. The fundamental ambiguity.

Time is normally treated as a dimension, e.g. in physics. What does that mean? How far can the analogy to the spatial dimensions be taken ? Does Time have a beginning, and if so, what would it mean for it to begin? What is a point in time? Could it be infinitely small or does time have a granular character?

5.2 Math: Answers

Following Aristotle, time is an aspect of change which you can measure by numbers. This means that time is one-dimensional and can be represented as a *line of numbers*. We can order the numbers in magnitude like the *natural numbers* $0, 1, 2, ...$, starting with 0 without end, or like the *integers* $..., -2, -1, 0, 1, 2, ...$ without beginning and end. We can fill in with the *rational numbers* as quotients of integers, or the *real numbers* as all (possibly infinite) decimal expansions. We can then measure time by anything which changes, like the height of the Sun for the time of the day, or the maximal height of the Sun over a day for the time of the year, length of your finger nails or hair if you let them grow without cutting, or the color of your hair as the years go by. Or you can simply watch the arms of your analog watch change position, or the change of the digits on your digital clock. You then understand that a digital clock shows granular time , where the smallest time unit may be a second, 1/10 or 1/100 of a second. For an analog clock there is theoretically no absolutely smallest time unit, but in practice there is, because you will not be able to distinguish two times if they are sufficiently close. This is a well-known difficulty of deciding who is the winner in a 100 meter sprint race.

With a clock at hand you would then say that an instant in time, or a point in time, is identified with a certain position of the arms of an analog clock and a certain number on a digital clock. You would also understand that the question if there is a first time has to be related to a specific event: For example your life has a certain first time, at the conception or at the birth, and it also has a certain final time. Likewise, it is believed that the Universe has a certain first time at the Big Bang, and the question what happened before Big Bang, or before the conception, in a sense has no meaning.

I recall that we agreed to give (the flow of) time an operational definition as what you measure with a clock. With this definition time is one-dimensional and ordered, because the readings of a clock are. What remains is then the question time has a direction or if there is an Arrow of Time. This is the most interesting and intriguing question about time, and accordingly I suggest we devote our main time to this question.

Let us meet again *next week* at the *same time*, if you understand what I mean?

5.3 Phil

I am sorry but I am not convinced: If Time is what we measure with clocks, why should its flow be one-directional ? Time has a property which sorts it out from the other three dimensions met with in everyday experience; it is one-directional. This elementary fact together with the questions of measurement and simultaneous events, which have given raise to statistical thermodynamics and the special theory of relativity,respectively, lead us to another, quite as interesting set of enigmas and seeming paradoxes. A few might be listed here, we shall return to them: Why should statistics influence physics?

We will start this introduction with the intuitive apprehension of time as a flea concept which has frequently been questioned by the philosophers as contradictory and generally problematic.

5.4 Math

You refer to special relativity with its mix of space and time, and denial of *simultaneity*. I suggest that we keep relativity theory out of the discussion, since nobody really understands it, and it causes so much confusion. In fact, I have written a whole book on this topic, showing that relativity theory is not a physical theory describing any physics of space and time. The special theory of relativity is based on an axiom stating that different observers moving with constant velosity with respect to each other, will measure the same speed of light. Today this is simply a definition of how to measure speed as distance per time unit, since by the commonly accepted 1983 SI standard the length unit is lightsecond, whohc is the distance traveled by light in one second. With this standard the speed of light is by definition one lightsecond per second. Thus Einstein's basic axiom for special relativity is simply a definition, and from a definition you cannot draw any conclusion about reality. It would be like believing that from the definition that there are 100 centimeters on a meter, you could draw any conclusion about e.g. your length or the distance to the Moon.

5.5 Phil:

I agree to stay away from relativity. In any case it is supposed to concern observations by people traveling at a speed close to speed of light, which will never be possible. Simultaneity, is then not a problem: We have identical clocks synchronized with the atomic clock at Atomic Clock Cafe, and we can be sure that if we agree to meet next Thursday a 3 pm, we will both be here at that time. No problem. Let's now start our real work.

By the way the Shakers seem to reach a state of mind of timelessness in their ecstatic dance, described in an old Shaker hymn as

Come life, Shaker life
Come life eternal;
Shake, shake out of me
All that is carnal.

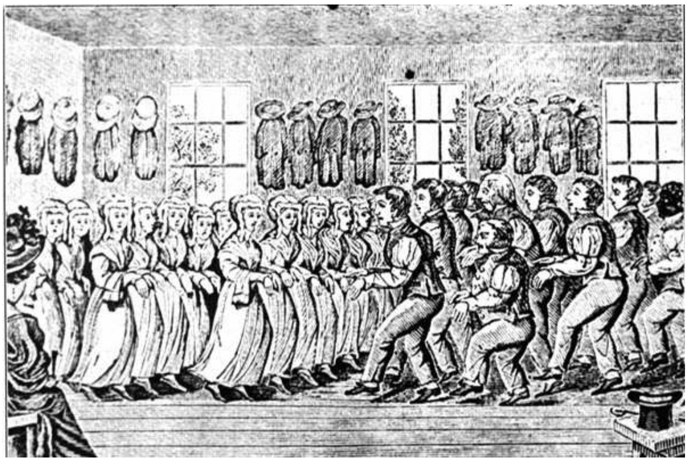


FIGURE 5.1. Ecstatic dancing giving shakers a feeling of timelessness.

6
The Arrow of Time

D. Joao II (Lisboa, 1452-1495), cognominado O Principe Perfeito pela forma como exerceu o Poder, dćimo-terceiro Rei de Portugal, nasceu no Paco das Alcácovas, no Castelo de Sao Jorge. Era filho do rei Afonso V de portugal e de Isabel de Coimbra, princesa de portugal. Joao II sucedeu ao seu pai após a sua abdicacao, em 1477; no entanto, Afonso V retornou e logo D. Joao lhe devolveu o poder, e só se tornou de novo rei após a sua morte em 1481.

6.1 Math: Principe Perfeito

Now we come to my baby *Principe Perfeito*, which I claim can solve the enigma of the Arrow of Time. Let me start with the following example, which you often meet in discussions about irreversibility: Take a new cup of coffe, pour in some milk, stir and watch the black coffee and the white milk mix into brownish café crème. This goes quick and you do not need very specific skills to succeed, right? Now, try to *reverse* the process, by reversing the stiring so that you separate the coffee and milk out of the mix. In principle, this should be possible, by simply reversing the stirring motion of the spoon and the pouring, right?

6.2 Phil: Impossible

But this is impossible. I know it without even trying: It is impossible to *un-stir* café crème and separate out black coffee and white milk! Simply impossible!

6.3 Math: Precision and Stability

I agree, this is impossible, but the question is, *why* it is impossible. Here Principe Perfeito comes in: It states that this is impossible because of a certain combination of the two basic aspects of

- *stability,*
- *precision.*

Both stirring and the reverse process of un-stirring are *unstable*, in the sense that nearby particles of coffee or milk get separated away from each other, and thus would come out differently by the slightest change in both stirring and unstirring. In practice, you have to accept that both stirring and unstirring cannot be realized with infinite precision: Your hand with the spoon will always shake a little bit, or a car will pass and the table will shake a bit, and since the process is unstable, the result will be that nearby particles get separated one way one day and another way another day? You cannot stir your coffee *exactly the same way* twice, Right?

The key is now what makes stirring possible but unstirring impossible? Both stirring and unstirring are pointwise unstable processes, so what is the difference?

6.4 Phil: The Objective or Process Output

I think I see what you are suggesting. We have to look at the objective of the process, or the result of the process. When stirring the result or *process output* is a brownish mix, while the output of unstirring would be black coffee and white milk. Clearly the output of stirring is stable under small perturbations as your hand is shaking: You always succeed in making a café crème even if your hands are shaking (it even improves the mixing).

But when the output is black coffee and white milk in the process of unstirring or unmixing, the slightest little error, will leave some milk in the coffee and visa versa.

6.5 Math: Turbulence

That's amazing Phil, that you get on track so easily. Clearly, you have captured a basic aspect of Principe Perfeito here in the setting of taking a café crème at Atomic Clock Cafe. So, we understand why a process of mixing may be *irreversible*.

But there is still a gap to irreversibility of time. Does the flow of time necessarily involve a process of mixing, which would make time irreversible? Is there some mixing going with the flow of time?

Yes, it turns out that there is, but this is a deeper aspect. Here, I can only say that it connects to a basic aspect of *turbulence*, which of course should not make you really happy, because it is common opinion that nobody knows what turbulence is. So referring to turbulence is like saying something which means nothing. The wonderful thing is now that Principe Perfeito in a way explains what turbulence is as a combination of a certain form of stability (which we refer to as *edge stability* below), and precision resulting in a form of mixing.

Principe Perfeito thus shows that turbulence necessarily appears in complex edge stable processes, like chemical reactions and life as a complex set of chemical reactions. Only simple processes without life can be without turbulence and thus be time reversible. The motion of a simple pendulum is an example of a simple stable process which is time reversible. Complex processes typically are edge stable as an expression of their complexity, and thus involve turbulent mixing and therefore are irreversible. Details are given below.

Let me here just say, that without turbulence, birds and airplanes would not be flying, you would not be able to speak and the blood in your veins would not carry enough of oxygene to support the life of the cells in your body. Without turbulence the World would be like a dull simple reversible pendulum, but the World is complex with effects of turbulence and thus time irreversible.

6.6 Phil: Sum Up

OK, I believe I get the main idea of Principe Perfeito as expressing that complex processes are turbulent, and turbulence causes mixing, and mixing is irreversible. Thus complex processes, typically life processes based on chemical reactions in water, are partly turbulent and thus are irreversible. The reason why you cannot reverse your life by pushing a rewind button, is thus that your life is complex and you are living on the edge. This is because your life is only edge stable and not more stable; a stable life would be a dull no-life. Thus you have to get your café créme to calm down, and then you have to stir milk into black coffee which is an irreversible process, and hence your life is irreversible.

The moral is that the interesting things in your life are irreversible, like falling in love, which you can finish but not undo or reverse.

7
More Debate

7.1 Phil: Intuitive Time, Neutral Time

There is an obvious difference between time such as we immediately perceive it – time flow; a unique present continuously escaping our hold and turning into a an unreachable past - and time as a non-subjective physical reality The firs question we shall deal with is: Can we describe time in a neutral way, i.e. abstracting from the essential feature of Time such as we experience it; the vaining moment? Is what remains after such a reduction still Time? Or, in that case might it be that we are handling an abstract model,based on spatial metaphors?

The confusion of the thing and its representation is a frequent source of confusion in philosophy. So why should it not be in what is probably its most difficult branch? A moment in Julius Caesar's time and the very moment when the last letter of this sentence is written can hardly be intrinsically different qua moments.It seems quite reasonable to see them all as existent elements in a series like books in a bookshelf and all having the same rights and privileges. Their existence as topologically ordered parts of the totality of time is then itself a timeless existence. There is no flow or movement here.

It is absurd to imagine that the totality of reality could change – writes the Swedish-Belgian philosopher Andries Mc Leod in Sur divers questions se presentant dans l'attitude du concept de realité, Leyden 1929. Why absurd? Because if it would change, it would thereby reveal that it is not the total reality.

So,reflecting on the nature of time we are confronted with two perspectives which seem to be unreconcilable. There is the immediate and as such, non rejectable experience of a flow of time and there is realization that the consecutive moments of history can not be different in an internal respect. They are all parts of the time flow and they are not present.

Only the present is present. It seems that something must have gone wrong here. It is not quite clear that everybody imagines the reality of Time and Time Flow in the same way. However there seems to be two standard models. Either Time itself is seen as flowing through the present or the present is seen as a sort of front line continuously gain territory from a future which is not really existent until it has reached the present. In both cases there is the idea of a flow or a motion. This seems absurd. If we assume that Time as a totality is flowing the obvious question is: moving through what? Through a supertime? Obviously an unacceptable regress is reached. If we assume on the other hand that the present is flowing forward through time we arrive at the same infinite regress when we ask for the speed of the flow. How many seconds pro second are we doing?

Confronted with the paradoxes of Time flow, an entire tradition in philosophy, from Zeno to Kant and McTaggart, has denied time an independent real existence. The idea of a flow of time, obviously leading to contradictions, is illusory or based on a fundamental misunderstanding. If so is the case there must be a way to restlessly translate the expression "now it is time to return the ball" to a tenseness expression "at t^n it is time to return the ball", where t^n is supposed to refer to an understandable coordinate system and a sufficient degree of precision

There is a rather radical division between those philosophers, e.g. Bertrand Russel and G.E Moore, who take the position that such a translation is possible and that it can be made complete, and those who, like Henri Bergson, claim that the flow of time, represented by the present is a primitive e xperience which can only be conceived by intuition. The intuitive representation of Time that has been described above could - accepting some minor variations - be called the Standard Model.

7.2 Math: Operational Definition

It seems to me that with an operational definition of time, as what you measure with an (atomic) clock, most of the difficulties you bring up, simply disappear, right?

Part II

Inventio

8
Aenigmae

> Quid est ergo tempus? Si nemo ex me quaerat, scio; si quaerenti explicare velim, nescio. (St. Augustine)
>
> Love is yesterday, it will be born today, and it was tomorrow. (Jan Skácel)
>
> Something is blowing through the dark space
> around the galaxies. It takes it's time.
> (L.G. Sonett XXXII 1977)

8.1 The Arrow

Space and *time* are fundamental concepts of human experience. The measurement of time has developed from the Sun dials of early civilizations over the mechanical clocks of the industrial society to the atomic clocks of our present information society. The accuracy has improved from hours over minutes to the nano-seconds of today.

Even if we all have an intuitive direct experience of time, and some intuitive idea of what time is and its qualities, there are many questions concerning this concept from philosophical, scientific and psychological point of view, which still are waiting for satisfactory answers.

The most fundamental question concerns if time has a *direction* from the *past* over the *present* towards the *future*? In other words, the basic question can be formulated as follows:

- Is there an *Arrow of Time*?

We can rephraze this question as

- Is it possible to *reverse* time?

Or more dramatically as

- Is *death* a necessary consequence of *life*?

Our direct experience tells us that for sure there is an Arrow of Time pointing forward, inevitably making us a bit older every second that passes, and that our life time is limited. We also know very well that time can be reversed in a movie by playing it backwards pushing the *rewind* button, but this is not possible in reality. But why? Why is there no rewind button in reality? Or is there?

Scientists have long struggled to answer this question without too much of success. The difficulty was well understood alread by St. Augustine in the 4th century AC as expressed in Fig. (8.1) below. The famous physicist Richard Feynman (1918-1988), Nobel Prize in Physics in 1965, expresses the same desperation in Fig. (8.2). Why have scientists not been able to come up with any convincing answers over all these more than 1600 years from St. Augustine to our time?

Of course, the educated reader now says that we have forgotten, apparently like Feynman, that the *2nd Law of Thermodynamics* presented in any book on *statistical mechanics*, defines forward time by increasing *entropy* or *disorder*. No, we have not forgotten that, but we do not, apparently just like Feynman, believe that statistics gives a good answer to the question about the Arrow. We believe that there is a better answer, and this what this book is about: An alternative to statistical mechanics as an explanation of *why* there is an Arrow of Time.

8.2 Variations

We shall see that the riddle of the Arrow of Time can be formulated in many different ways. Each of the following questions touches on a basic aspect of the riddle, as the book will show:

- How can there be *irreversibility* in a *formally reversible system*?
- How can there be *imperfection* in a *formally perfect world*?
- Why do not all people follow all laws?
- Why do you have to pay a fine for breaking the law?
- How can there be *friction* in a system *formally without friction*?
- How can there be *viscosity* in a system *formally without viscosity*?

FIGURE 8.1. S.t Augustine: *What is then time? If I am not asked, then I know; when asked to explain, then I don't know.* (Confessions, Chapter XIV, Book XI)

FIGURE 8.2. Richard Feynman: *Where does irreversibility come from? It does not come form Newton's laws. Obviously there must be some law, some obscure but fundamental equation. perhaps in electricty, maybe in neutrino physics, in which it* does *matter which way time goes.* (The Feynman Lectures on Physics 1963).

- Why is a *perpetuum mobile* impossible?
- Why is a *black-body* black?
- How can there be a *free will* in a *formally deterministic world*?
- Why do we have to pay interest on a loan?
- Why did the Soviet Union collapse in 1989?
- Why did the New York stock market collapse in 1929?
- Why does it take so long time to grow up?
- Why does writing take much longer time than reading?
- What makes a funny story funny?
- Is it necessary to forget to remember?
- What can and cannot be exact?
- What is precision?
- What makes the cause the cause and not the effect?

8.3 Principe Perfeito

In this book we explore a line of thought explaining *why* there is an Arrow of Time, which we refer to as,

- *Principe Perfeito,*

see Fig. 8.3. This principle can be given many names and can be formulated or described in several different ways. One way is illustrated in Fig. 8.4.

What do we see? Well, we see two devices where motion to the right is "easy", while motion to the left is "difficult". The top devise can be used to secure the motion of a lift in upward motion preventing it from falling down. The bottom device is a fish trap based on the principle that it is easy for a fish to get into the trap, but difficult to get out. We could say that it is a matter of *precision.* To get in does not require much of precision, becaue the fish is guided into the net. But to get out requires a very high precision, and fish aren't smart enough to sneak out by pure intelligence and cannot find the way by trial and error before they die. So the trap works.

Evidently, both devices are *directed* and Principe Perfeito says that time is similarly directed for a similar reason: It is "easy" for time to move forward, but "difficult" to move backwards, because the requirements on precision are vastly different.

FIGURE 8.3. Principe Perfeito ready to go.

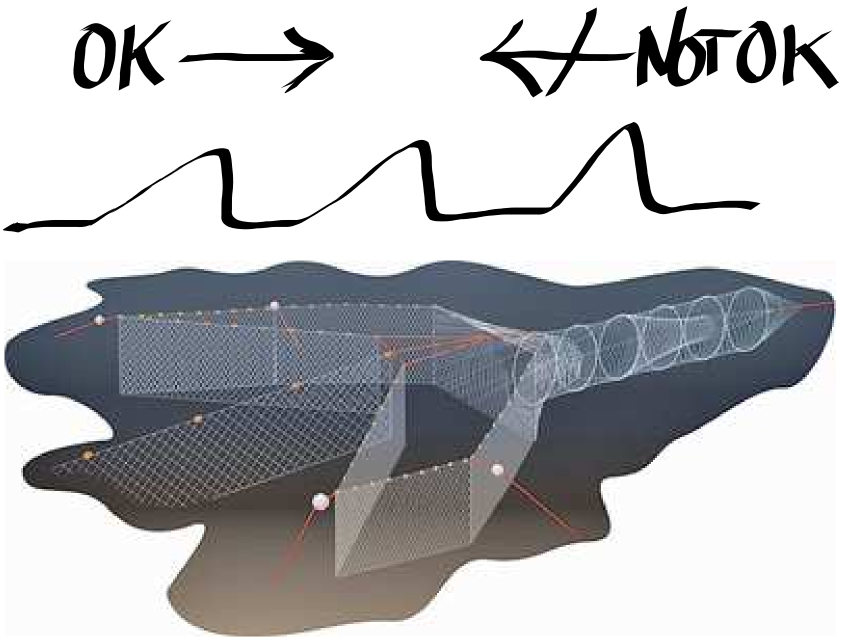


FIGURE 8.4. Visualizations of Principe Perfeito: Motion to the right is easy, but motion to the left is difficult.

Another formulation of Principe Perfeito is expressed in the seemingly innocent statements:

- *mixing is easy (fast) and can be done with low precision,*
- *unmixing is difficult (slow) and requires high precision.*

To mix milk into your coffe is easy, to unmix is virtually impossible. Simple as it seems, this idea contains a deep truth. Yet another formulation is:

- *imprecise separation may be easy and fast*,
- *precise separation may be difficult and slow.*

To rip a piece of paper apart is easy and goes quick, to separate a tumor from healthy tissue may require extreme precision and may take long time.

The essence of Principe Perfeito can also be expressed as:

- *a mechanical clock shows time but has no direction*,
- *life is a clock with direction.*

There is thus a close connection between *life* and the Arrow of Time. A life process from birth to death has an Arrow, and the Arrow is defined by what could be referred to as life processes.

What is then a *life process*? Well, the life of a living cell can be described as an interplay of the two processes of

- *creation of difference* or *anabolism*,
- *destruction of difference* or *catabolism*,

where anabolism represents growth and division of cells and catabolism represents production of energy and building material for the anabolism. Anabolism is slow/precise, while catabolism is fast/imprecise and this makes life processes irreversible.

Life could in principle have been reversible using the same precision in both anabolism and catabolism, but such forms of life would not be competitive in the battle of survival of the fittest.

Other basics aspects of life connecting to Principe Perfeito are

- *desire to live,*
- *failure to live.*

Without a desire to live, there will be no life, but the desire to live eventually has to give in to the greatest failure of all of death, which is the ultimate imperfection of life. But every moment of life contains smaller imperfections, since a perfect life is not competitive. Life can thus be viewed as a continued unsuccessful effort to live a perfect life.

There is thus a close connection between Principe Perfeito and life processes and the Arrow. In this book we explore these connections in different fields including

- philosophy – poetry – epic literature,
- music,
- mathematics – physics – chemistry,
- biology,
- economy – politics,

with the Arrow of Time as common denominator. Of course with so many themes, the presentation can only be very sketchy in each one of them.

Principe Perfeito represents a new key to unlock the secret of the Arrow of Time, a key caught in the new net of *computation* in our new age of the *computer*. But the key also may reveal some secrets of both the *real World*, since the real World is realized in some form of an analog computation or processing of information, and the *imaginary World* based on the mental computation of our thought processes or the digital computation of virtual reality and computer games.

To keep the discussion as transparent as possible, we stay away from Einstein's theory of relativity and its mixture of time with space into "curved space-time". This is because there is no Arrow of Time in Einstein's relativity, since "curved space-time" is not directed. The interested reader can find the views on relativity of the second author presented in the recent book [8].

8.4 Science vs Humanities and the 2nd Law

There is a deep gap separating *science* and *humanities* (which is harmful to progress in both disciplines according to the influential pragmatic philosopher Richard Rorty (1931–), and the dividing principle is *mathematics*. Science uses the language of mathematics, and humanities uses common languages. In both cases the language is used to create models of real or imagined phenomena.

The mathematics of science is (primarily) *Calculus*, which is the mathematics of *derivatives* and *integrals* founded by Leibniz and Newton in the second half of the 17th century and perfected during the 18th and 19th century by many great mathematicians.

The use of mathematics excludes people from understanding science, but it also excludes most scientists; only an expert scientist can master the mathematical language of specific discipline and claim understanding.

The blame for the separation thus can be put on difficult mathematics, but is all mathematics difficult? No. Everybody understands that $1+1=2$ and so there is mathematics which can be understood by many. The great mathematician David Hilbert (1862-1943) stated:

- *A mathematical theory is not to be considered complete until you have made it so clear that you can explain it to the first man whom you meet on the street.*

Most scientists read novels, go the theatre and listen to music, while most people (including also the majority of scientists) are denied access to the secrets of statistical mechanics, relativity theory and quantum mechanics, the pillars of modern physics.

This book is an attempt to bridge the gap, by giving open access to the scientific question of the Arrow of Time and by showing that Principe Perfeito offers an answer, which can be understood by non-scientists, and also scientists.

We do this by using both the language of mathematics and common language in parallel. Mathematical language is formalized, uses very special symbols, is sometimes very powerful, but like a Formula One racing car is difficult to handle. And mathematics without the computational power of a computer may be as useful as a car without engine.

A poem in one language can (more or less successfully) be translated to another language. Likewise, a mathematical model of a physical phenomen can (more or less) be translated to common language and thereby be better understood. In this book we seek to accomplish this task concerning the Arrow of Time.

We shall see that the scientific discipline we need to enter is *thermodynamics*, which is the basic area of physics essentially concerned with the transformation between *kinetic energy* and *heat energy*. Thermodynamics is viewed with fear by all scientists, which do not belong to the very small group of experts in the field. The main reason is the *2nd Law of Thermodynamics*, which only experts claim to understand. You can make your own experiment on this issue by asking your favorite physics teacher (who may be a Nobel Laureate) to explain the 2nd Law and carefully noticing the reaction!

In any case, to understand thermodynamics, it is necessary to develop an understanding of the 2nd Law, but this is a pretty hopeless task, unless you already belong to the group of believers. This is the same Moment 22 as in religion with only believers being able to believe. Hilbert expressed the syndrome as

- *Physics is becoming too difficult for the physicists.*

8.5 To the First Man You Meet in the Street

This book presents the 2nd Law in a new form, which fulfills Hilbert's requirement and avoids the mystery surrounding the 2nd Law in traditional books on thermodynamics. We formulate the 2nd Law both in precise mathematical form, and in understandable common language, making it possible for anybody to become an expert of thermodynamics. What you could say to the man in the street is:

Listen, thermodynamics is the study of transformations between heat energy and kinetic energy. The 1st Law states that the total energy, the sum of heat energy and kinetic energy, remains constant (in a closed system). Thus you can change from one kind of energy to another, but the sum remains constant, OK? The 2nd law states that in any real process a significant amount of large scale kinetic energy is irreversibly transformed into small scale heat energy by turbulence. Further, heat energy can be transformed into kinetic energy by expansion, e.g by letting steam in a steam engine expand and move a piston, while work by compression adds heat energy. To form a cycle, an engine has to be cooled and thereby loose heat to the exterior. You know this too well: A car engine without cooling over-heats, and cooling means that you loose heat energy to the surrounding, which you cannot get back and which is not useful for the operation of the engine. OK?

This is pretty much the whole story, without any mathematics, and any mentioning of entropy: Whatever you do, some of your effort goes into heat which has to be lost in cooling.

8.6 Oneliners

The following statements will be understood after reading the book:

- *Time is the price you pay to live.*
- *Walking is the process of avoiding falling on your nose.*
- *Only the dead have no ambitions.*
- *Fall comes before Spring. Spring comes before Fall.*
- *Perfection kills.*
- *Difference is life, indifference is death.*

If you intuively feel that some of these statements ought to be true, then you have a good starting point.

In particular we feel that mathematics can be viewed as a form of poetry and vice versa, with both mathematics and poetry offering models of the same reality using different languages. The book was written in short time by mixing ideas and avoiding precise separation.

FIGURE 8.5. Equipment for Exploration.

8.7 Mathematics of Postmodernity

The *industrial society* emanating from the scientific revolution and the Enlightment of the 17th and 18th century, developed in the late 19th century into the *modern society*, which transformed into the *postmodern information society* at the turn to the new millenium. The evolution of society from (i) industrial over (ii) modern to (iii) postmodern, is paralleled in physics by a development from (i) Newtonian mechanics over (ii) quantum mechanics to (iii) universal computation, and in mathematics from (i) finding analytical solutions using Calculus, over (ii) proving that unique exact solutions exist again using Calculus, to (iii) computing approximate solutions using *Computational Calculus*, which is the postmodern form of Calculus of the new millemium.

One may summarize these parallel developments in society, physics and mathematics as follows:

(i) industrial – Newtonian mechanics – Calculus,

(ii) modern – quantum mechanics – Calculus-Statistics,

(iii) postmodern – simulation – Computational Calculus.

The step from (i) to (ii) is in physics and mathematics represented by the development of statistical mechanics and quantum mechanics replacing classical determinism by microscopic non-determinism: Elementary particles of modern physics are believed to play games of roulette in the Giant Casino of Modernity, which also may represent modern (democratic capitalistic) society.

The step from (ii) modern to (iii) postmodern is described by the leading postmodern French philosophers Jean Baudrillard (1929-2007) and Gilles Deleuze (1925-1995) as a step from reality to *hyperreality*, with hyperreality consisting of *simulations of a reality which does not exist.* In this process the objectively existing real world of the modern society, in the postmodern world is "deconstructed" and is replaced by a "simulacra" of hyperreality, which according to Baudrillard masks the non-existence of a real reality and according to Deleuze is the only reality there is.

The step from (ii) to (iii) in mathematics, is reflected by the insight that the basic conservation laws of physics of mass, momentum and energy, have no exact mathematical solutions (because of the appearance of turbulence as we will see below), and that the only existing solutions are computational approximate turbulent solutions. This is is a remarkable recent discovery, which shows that the mathematics of the new millenium is Computational Calculus, rather than classical Calculus and modern Statistics.

Thus, Baudrillards and Deleuze's main thesis of hyperreality as a simulation of a non-existing reality, has a concrete mathematical interpretation as computational turbulent solutions of equations without exact solutions. What a wonderful example of Grand Unified Theory in the form of mathematics of postmodernity. One may ask if Baudrillard and Deleuze would have been surprised to see this connection, or if this is precisely what they anticipated.

We shall see that the non-existence of exact solutions is closely connected to the Arrow: If exact solutions had existed, they would have been reversible, but exact solutions do not exist, and existing computational approximate solutions are irreversible, because they involve an irrecoverable cost for being non-exact, a cost which does not decrease to zero with increasing precision in the computation. We can thus summarize the main message of the book as follows:

- *Hyperreality is irreversible simulation of a non-existing reality.*

The famous computer scientist Dijkstra expresses a similiar idea:

- *Originallly I viewed it as the function of the abstract machine to provide a truthful picture of the physical reality. Later, however, I learned to consider the abstract machine as the* true *one, because that is the only one we can* think*; it is the physical machine's purpose to supply a* working model*, a (hopefully) sufficiently accurate physical simulation of the true, abstract machine.*

8.8 Hyperreality: Nonsense or a Reality?

What can we say to the large group of scientists who are sceptical to both French postmodern philosophy, computer science and Computational Calculus, whose scientific basis is Calculus and a firm belief in the existence of exact solutions to the equations of classical/quantum mechanics? It is likely that the reader belongs to this group, since is it encompasses so many.

Well, we would ask the reader for a proof of existence of exact solutions to the basic equations of fluid mechanics (or quantum mechanics). The reader would then have to admit that no such proofs are known, as evidenced by the fact that a proof would represents a solution to one of the seven one million dollar *Millenium Prize Problems* of the *Clay Mathematics Institute*, and nobody has been awarded the one million dollar Prize. And nobody will, most likely, because there is evidence that exact solutions cannot exist.

But isn't this really strange: Equations without solutions? Can we see this phenomenon in a context where it is easier to understand? Yes: We know that we are supposed to follow the parking regulations in the city we happen to be in, and other laws as well, but we also know that we are not always able to do that, and if discovered breaking the law, we have to pay a fine. In most cities the number of cars seeking parking is bigger than the number of available parking places, and thus *there is no exact solution*, only approximate solutions with some parking laws violated. We will return to this situation below.

It seems that we have to admit that just because we can write down a set of laws, a solution satifying all the laws does not come for free. Maybe there is no solution, because the laws we wrote down may be asking for too much! To write down a recipee for a cake is one thing, to actually bake a cake following the recipee is another thing, right? A new recipee has to be tested in practice before it can be launched in a cook-book.

This is exactly the situation in mechanics: We can write down the basic conservation laws using Calculus, but there is no guarantee a priori that they can be solved exactly, while there are many indications that they cannot. But computational approximate solutions do exist, because they can be computed, which can can be viewed as simulations of a non-existing exact solutions. Thus hyperreality of Calculus seems to be a reality rather than nonsence.

8.9 An Outline of the Book

The book is divided into the following Parts I-IV:

- *Inventio*: Introduction and overview.
- *Solutio*: Principe Perfeito in basic form.

FIGURE 8.6. Hyperreality (masking non-existing reality?) according to Magritte.

- *Theme and Variations*: Applications of Principe Perfeito.
- *Mathematics of Principe Perfeito*: Thermodynamics and turbulence.

In Part I we present the problem of the Arrow of Time, in Part II we present a solution in the form of Principe Perfeitio, and in Part III we explore the functionality of the principle in different fields. Part IV is mathematically oriented, but the intereset reader can digest most of with a just a bit of high-school mathematics and some imagination. And mathematics is like poetry: Evidently, it tells us *something*, but it is not immeditely clear *what* it is, and thus both time and patience may be required to separate the meaningful from the meaningless.

8.10 The Authors

The two authors have their main experience from the different worlds of poetry-literature and mathematics-physics with a bridge of common interests in philosophy, music, arts and life in general. We wish to explore the possibility of reaching understanding through a combination of theories, reasoning, and modes of expression from these worlds.

As we are both approaching mature age, we seek synthesis rather than dialectical debate. However, we do not (necessarily) seek *consensus* in the form of a *one-mind synthesis*, but rather in a *many-minds* multi-faceted form, based on the shared insight that no single view can capture the whole truth of such a complex phenomenon as time.

9
Modern Society

> Henceforth space by itself and time by itself, are doomed to fade away into mere experience shadows, and the only kind of union of the two will preserve an independent reality. (Hermann Minkowski, 1908)

> Let us draw an arrow arbitrarily. If as we follow the arrow we find more and more of the random element in the state of the world, then the arrow is pointing towards the future; if the random element decreases the arrow points towards the past. That is the only distinction known to physics. This follows at once if our fundamental contention is admitted that the introduction of randomness is the only thing which cannot be undone. I shall use the phrase "times arrow" to express this one-way property of time which has no analogue in space. (Arthur Eddington in *The Nature of the Physical World*, 1928)

9.1 Automation

Our modern (and postmodern) society is based on *automated mass production* of material goods by machines and *automated processing* of *information* by *computers*. In an automated process, material in the form of *physical matter* or *information* is being modified following a given step-by-step sequential scheme, *flow chart*, *algorithm* or *computer program*, which is repeated over and over with new material each time the program is executed.

The concept *sequential* reflects the Arrow of Time, in the sense that the steps of a sequential scheme are performed one after the other following the Arrow of Time, like the sequence of steps we go through when we bake a cake. The *order in time* of the steps expresses the aspect of being sequential (in time), and of course can be essential: If we forget *mixing* the ingredients *before* putting them into the oven, then there will be no cake to eat.

9.2 Sequential and Parallel Processing

We can number the steps in a *sequential process* by the natural numbers $1, 2, 3, ...$, and then follow the *ordering* of the natural numbers during execution of the process. We can then view the process as a form of *clock* measuring the *flow of time*: If each step takes about one second, then we can say that the total time for executing a process consisting of 10 steps is about 10 seconds. This represents *taylorism* as developed by Fredrick Taylor in the late 19th century for the automation of e.g. car manufacturing, with the time duration of each step carefully measured by a *time study specialist* equipped with a clock, following the mantra of the industrial society of *saving time* (but not energy). The time study is also necessary for *coordination* (in time) of processes so that *queing* is avoided (and time is saved).

Not everything has to be performed sequentially in time. There are tasks that can be done in *parallel processing* by executing many copies of the same program with different data. For example, you can hire 10 bakers to bake 10 cakes in 10 ovens simultaneously, all working independently, and deliver 100 cakes by the end of the day. Instead of hiring one baker to bake 100 cakes in 1 oven requiring 10 days. Parallel processing is essential for mass production.

9.3 Time in Nature and Society

It is important to make a distinction between the role of time in Nature and in Society. The water molcules in a water wave are not equipped with clocks (as far as we know), yet they do just the right thing at the right moment (as far as we know). The flowers and the birds do not have any watches either, but follow the variations of the seasons just as homo sapiens were doing during all the hundreds of thousands of years before the industrial society developed starting in the 17th century and the information society of our time.

In our developed human societies clocks are necessary to coordinate the actions of many people, and for navigation. The GPS system is based on measuring the time it takes for a light signal to pass from a satellite to a receiver on the Earth, and requires synchronization of all satellite clocks and and receiever clocks on the ground. The GPS system works remarkably well, which shows that it is possible to set up a system of synchronized clocks around the Earth, and probably in our Solar system when the need from space travel arises.

9.4 Deteterministic Cause-Effect Processes

Algorithms for automation are *deterministic* in the sense that the steps follow according to specified rules with effects of *randomness* or *chance* made as small as possible. A deterministic algorithm encodes a sequence of cause-effect events, expressing the essence of a *rational materialistic mechanistic* world view, as opposed to an *irrational idealistic magical* view allowing things to happen "out of the blue", by chance or by the influence of *ghosts* of some form.

9.5 Cause-Effect and Arrow of Time

The order in a sequential cause-effect process defines an Arrow of Time, with the cause occuring *before* the effect. The challenge is to explain what makes certain processes irreversible in the sense that they cannot be run backwards in an effect-cause manner. The challenge is thus to explain what makes the cause to be the cause in a cause-effect process, and not the cause the effect and the effect the cause. This is the objective of this book.

9.6 Operational Definition of Time

The *operational definitions* of *space* and *time* is made in terms of the units for *measuring* length and time. Length is then what you measure as length and time what you measure as time. Simple and clear!

According to the presently generally adopted *1983 SI standard of Conference Generale des Poids et Measure* the *time unit* is *seconds s* with one second equal to 9192631770 cycles of a cesium clock (more precisely the duration of that number of periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the cesium-133 atom at rest at temperature 0 Kelvin). The *length unit* is *meters m* with one meter being the distance traveled by light in 0.000000003335640952 seconds or 9192631770/299792458 cycles of a cesium clock. Equivalently, the length standard can be chosen as *lightsecond* or 299792458 meters.

Do we have to say more? Time is what you measure with a cesium clock, and length what you measure in lightseconds.

Yes, we have to say more, because it does not show us what the Arrow of Time is. We do not have any operational definition of entropy, because we do not know what entropy is, and thus we do not how to measure it, and even less why it can only increase.

9.7 Marx on Time

Karl Marx predicted an irreversible inevitable development of human civilization through the following successively higher stages:

- *feudalism* of the middle age,
- *capitalim* of the scientific revolution leading into our days,
- *scientific socialism* in a world state with a centralized economy.

Karl Marx'basic vision is to give the control of the *means of production* to the people, not to feudal land-lords or caplitalists with capital. Maybe this is reasonable, but is it therefore necessary to also embrace scientific socialism?

Yesterday the anwer could have been yes, but today it may be different. Why? Because, today the basic mean of production is a computer, and everybody can afford to have a Personal Computer, a PC. This means that the means of production today largely is in the hands of the people, and thus Marx' vision is about to be realized in the era of the information society of the Third Millennium. And what is Linux and Google but scientific socialism?

FIGURE 9.1. A classical analog devise for measuring time. When the upper container is empty, turn the glass and reset for a now period of time.

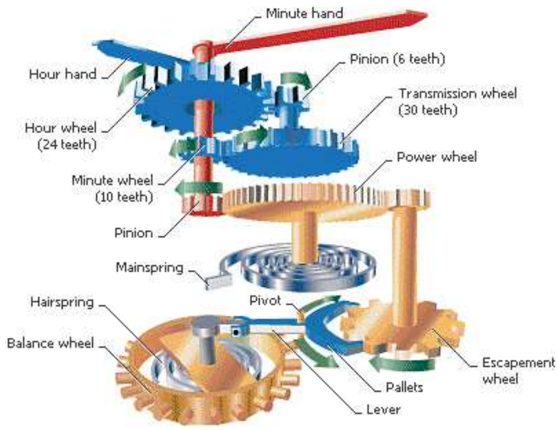


FIGURE 9.2. Principle of a mechanical clock.

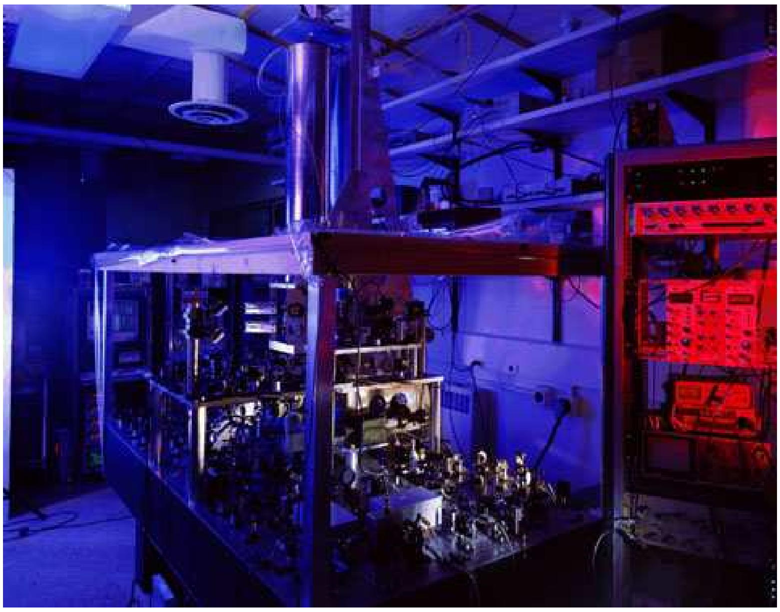


FIGURE 9.3. The cesium fountain atomic clock at the NIST laboratories in Boulder, Colorado, USA, defining Cordinated Universal Time, the official world time. The precision is less than a second over 60 million years.

10
A World of Computation

All physical systems can be thought of as registering and processing information, and how one wishes to define computation will determine your view of what computation consists of. (Seth Lloyd)

Every physical system registers information, and just by evolving in time, by doing its thing, it changes that information, transforms that information, or, if you like, processes that information. (Seth Lloyd)

10.1 The Arrow of Information Flow

Since we live in the beginning of the *Information Age*, we are led to view any process in the the real or the virtual World as a sequence of transformations of data or processing of information by some form of analog or digital computation. In each step input is transformed into output, which serves as input in the next step. The complete process may be described in a flow chart specifying input and output in each step. A flow chart defines a (local) Arrow of Time for each step in the sense that the input information has to be available *before* output data can be produced. In natural processes the scheduling of events in time is automatic: The lion awaits the appearance of the prey at the water-hole, and the tennis player waits for the right moment to hit the ball. In industrial processing of material goods or digital computation timing and scheduling serves an important function to reduce waiting time.

10.2 Seth Lloyd

The principle of the World as a computer performing a massive computation has been advocated by the physicist Seth Lloyd (1960–), with particular focus on *quantum computing*. Seth Lloyd summarizes his approach as follows:

- *I have not proved that the universe is, in fact, a digital computer and that it's capable of performing universal computation, but it's plausible that it is.*
- *In order to figure out how to make atoms compute, you have to learn how to speak their language and to understand how they process information under normal circumstances.*
- *It's been known for more than a hundred years, ever since Maxwell, that all physical systems register and process information.*
- *Merely by existing and evolving in time - by existing - any physical system registers information, and by evolving in time it transforms or processes that information.*
- *Nothing in life is certain except death, taxes and the second law of thermodynamics.*
- *Of course, one way of thinking about all of life and civilization is as being about how the world registers and processes information. Certainly that's what sex is about; that's what history is about.*
- *One of the things that I've been doing recently in my scientific research is to ask this question: Is the universe actually capable of performing things like digital computations?*
- *Science consists exactly of those forms of knowledge that can be verified and duplicated by anybody.*
- *Similarly, another famous little quantum fluctuation that programs you is the exact configuration of your DNA.*
- *So science is basically, at it most fundamental level, a public form of knowledge, a form of knowledge that is in principle accessible to everybody.*
- *That is not to say that these three processes don't have fringe benefits: taxes pay for roads and schools; the second law of thermodynamics drives cars, computers and metabolism; and death, at the very least, opens up tenured faculty positions.*
- *Thinking of the universe as a computer is controversial.*

10.3 Clock Cycles

The *clock rate* is the fundamental rate in cycles per second (Hertz or Hz) at which a computer CPU performs its most basic operations such as adding two numbers or transferring a value from one processor register to another. The original IBM PC from 1981 had a clock rate of about 5 MHz (5×10^6 cycles/second), Intel's Pentium from 1995 ran at 100 MHz, and the Pentium 4 from 2002 at 3 GHz (3×10^9 cycles per second), thus with almost a factor 1000 over 20 years, roughly corresponding to Moore's Law of doubling each 18 months.

The rate of a cesium clock is about 10^{10} Hz which may be the clock rate of the CPU of the World, and thus microprocessor clock rates cannot continue to increase according to Moore's Law. Nevertheless, the computing power seems to continue to double each 18 months, but now by increasing the number of processors combined with more efficient computational algorithms.

10.4 The Wealth of Nations

Knowledge appears as a particular form of information in Lloyd's paradigm, and has an important role in Paul Romer's extension to the Information Society of Adam Smith's classical analysis of the economy of the Industrial Society in *The Wealth of Nations*, as outlined by David Warsh in *Knowledge and the Wealth of Nations* [52].

10.5 Computer Games and Global Warming

The computer game industry is today boomimg offering new possibilities to human experience and interaction. Second Life is one of the many new virtual worlds with a rapidily increasing population of virtual citizens. Virtual reality instead of real reality, e.g in the form of video-conferences or virtual tourism, saves energy and may be the feasible way of handling the threat of global warming.

FIGURE 10.1. Hyperreal party in Second Life

FIGURE 10.2. Hyperreality of World of WarCraft

11
A World of News

Literature is news that stays news. (Ezra Pound)

Listening to a news broadcast is like smoking a cigarette and crushing the butt in the ashtray. (Milan Kundera)

A novel that does not uncover a hitherto unknown segment of existence is immoral. Knowledge is the novel's only morality. (Milan Kundera)

Business has only two functions - marketing and innovation. (Milan Kundera)

11.1 The News Arrow

We noted above that a flow of information defines a local Arrow. We may say that *The News* (televised all over the Earth by a *BBC* or *CNN* or in personal blogs), represents the constantly changing present common to everybody, separating the past in the form of stored *old news*, from the future in the form of speculations. The flow of The News defines an common Arrow: What everybody knows represents old news, what nobody knows represents the future and The News reported in news reports and blogs, represents the present.

The Internet defines a common notion of present, past and future, over the Earth. In former times Paris fashion could reach Sweden with a delay of a year, and there would be no common present.

The News then represents the current position of a spotlight sweeping over a time-sequence of news events.

FIGURE 11.1. Typical surreal News blog.

FIGURE 11.2. Typical News defining The Arrow.

12
Ghosts and Clocks

> Hominids turned to the sacred realm because they evolved to relate in deeply emotional ways with their social partners....and because the human brain evolved to allow an extension of this belongingness beyond the here and now. (Barbara J. King in *Evolving God*)

> Then I went back into the house. It is midnight. The rain is beating on the window. It was not midnight. It was not raining. (Beckett in *Molloy*)

> The dogs are sleeping. The doors open.
> Clocks are gently drifting down times of still black water.
> (L.G. Euforic Imaginations, 1968)

12.1 Religious DNA

Some experts of human genetics claim that homo sapiens probably has a "religious gene" giving us a particular capability of "believing in ghosts", which has turned out to give an advantage in Darwin's struggle for existence. The "ghost" may have religious, political or scientific character or a combination thereof, and different "ghosts" have dominated during different periods of the evolution of human society.

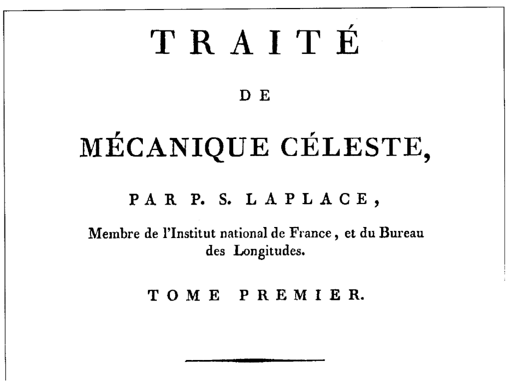
12.2 The Ghost of Science and Global Warming

Today, the "ghost of science" has taken the initiative from religion and politics: The general belief seems to be that the threat of *global warming* can only be met by clever scientists in cooperation with educated responsible citizens, and not by prayers, healing or simply relying on "fate".

12.3 The World as a Clock

Our modern society is thus based on a *deterministic mechanistic* view of the world as a *Clock* (in principle like the one in Fig. (16.2) but of course with a much more complicated machinery), which became the leading principle of science and technology in the 17th century in Europe based on the mathematical *Calculus* of Leibniz and Newton. This development was boosted by the tremendous success of *Newtonian mechanics* offering man a key to control the world according to his will, and not only according to the will of Gods or fate as before. From one basic *law of gravitation* (the inverse square law), Newton could explain, using only Calculus, the motion of all celestial bodies, an unsurpassed triumph of mathematics and rational mechanics! Now the World lay open to exploration by *Newtonian mechanics*!

Laplace (1749-1827) perfected Newton's mechanics in his monumental Mécanique Céleste in five volumes appearing during 1798-1825, describing the Universe as a Clock following immutable laws of mechanics. A beautiful reversible Universe which could as well go backwards in time...


TRAITÉ

DE

MÉCANIQUE CÉLESTE,

PAR P. S. LAPLACE,

Membre de l'Institut national de France, et du Bureau des Longitudes.

TOME PREMIER.

FIGURE 12.1. Laplace mathematical analysis of the Clock.

13
Mathematics of Change

Change is the law of life. And those who look only to the past or present are certain to miss the future. (John F. Kennedy)

An invisible hand is floating over each straw of grass,
silently insisting: Grow!
(L.G. Sonetter V)

13.1 Aristotle: What Time Is

Aristotle states in Section 11 entitled *What Time Is* in Book IV of his *Physics* lecture notes (compiled by his students):

- *What is worth considering is the prevalent idea that time is variation and change.*
- *For without change (or any noticable change) in our minds, time does not seem to pass, as in the story about those who sleep in the sanctuary of the heroes in Sardinia, who wake up and do not think that time has passed. Clearly time does not exist without change.*
- *Time is thus change, or rather an aspect of change.*
- *Because change is continuous, time is too.*
- *Time is that feature of change that makes number applicable to it.*

- *In a sense, the now is something single and identical, but in a sense it is not. In so far as it is to be found at successively different points, its is different–this is what it is to be "now"–but the actual thing that is now is the same.*
- *By the same token, a moving object, by which we know change, and what is before and after in change, follows a point. The actual thing, that is the moving object is the same, but in definittion it is different, just as the sophists take Coriscus in the Lyceum to be something differebt from Coriscus in the city square. A moving object, then, is different by being successively in different locations, and now follows a moving object just as time follows change, for it is the moving object that enables us to know before and after in change, but the now exists in so far the before and after are numerable.*
- *So in a sense the now is always the same, and in a sense it is not, because the same goes for a moving object.*

In short, Aristotle explains that time is a feature of change which can be measured by a pointer moving along a line of numbers, such as an analog clock with moving arms. We believe this is still convincing and we will consider time and change to be closely related.

Concerning the Arrow, Aristotle hesitates and gets into lengthy discussions about concepts like "first change" and cause-effect, without clear conclusions.

13.2 Calculus

Time is change (and change is life) and the mathematics of change is Calculus. Change is measured mathematically by *derivatives*. The time derivative of some quantity measures how much the quantity changes per unit time step. The derivative of the *distance* you travel on a highway is your *velocity*, and the derivative of your velocity is your *acceleration*. Newton denoted time derivative by a dot. If $u(t)$ is your distance traveled at time t, then $\dot{u}(t)$ is your velocity and $\ddot{u}(t)$ is your acceleration, at time t. Newton's time is often referred to as the *dot-age*.

Newton's dots should not be confused with dots used in e.g. German and Swedish spelling making $\ddot{a}$ and $\ddot{o}$ sound different from plain a and o, but in English spelling you don't have this problem.

Leibniz did not use dots to denote derivative, and wrote $\frac{du}{dt}$ instead of $\dot{u}$, which is much better since it precisely expresses change per unit time step with du the change in u over the time step dt. It is believed that this was the reason that mathematics in Germany flourished after Leibniz but mushroomed in England after Newton. We use here anyway the dot to denote time derivative, which is ok if we remember that it means $\frac{du}{dt}$.

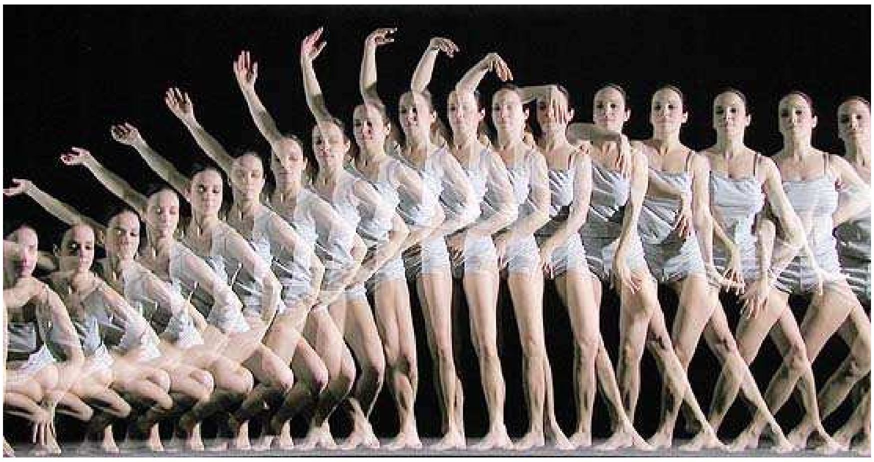


FIGURE 13.1. Time sequence of motion.

13.3 Newton's Mechanics

Newton's law for the motion of a body B of mass m subject to a force f, reads

$$ma = f,$$

where a is the acceleration of B, and can thus also be formulated

$$m\ddot{u}(t) = f(t) \tag{13.1}$$

where $u(t)$ is the position of B, $a(t) = \ddot{u}(t)$ and $f(t)$ is the force acting on B, at time t. If you know the initial position $u(0)$ and initial velocity $\dot{u}(0)$ at the initial time $t = 0$ together with force $f(t)$, then the position $u(t)$ for $t > 0$ is determined as a solution to the *differential equation* (13.1).

If $f(t) = 0$, then the solution is $u(t) = u(0) + t\dot{u}(0)$ stating that B moves with constant velocity along a straight line, which is nothing but Newton's 1st Law(?).

If B is the Earth and $f(t)$ is the gravitational force of the Sun, then $u(t)$ traces an elliptical orbit around the Sun. Thus Kepler's laws follow from (13.1).

Newtons equation (13.1) is a model of the World as a giant clock of amazing simplicity and generality: If you know the initial data of the clock at $t = 0$ and the force $f(t)$, then you can by solving the equation for $t > 0$ *predict the future* state of the clock.

In general, the state $u(t)$ is a vector-function and the force f depends on the present state $u(t)$ so that $f(t) = f(u(t))$. Newtonian mechanics can thus be summarized in a vector equation of the form (setting $m = 1$)

$$\ddot{u}(t) = f(u(t)), \tag{13.2}$$

Wonderful! Man in control of the Universe! You just need to know the inital condition and to solve the differential equation. How do you do that?

13.4 Time-Stepping

Well, simply by *time-stepping*: First you rewrite the equations as a first order system:

$$m\dot{v} = f, \quad \dot{u} = v, \tag{13.3}$$

or formally,

$$mdv = fdt, \quad du = vdt. \tag{13.4}$$

Now, given $u(t)$ and $v(t)$ at a time t, you can compute the changes du and dv over a short time interval dt, and compute $u(t+dt) \approx u(t) + du$ and $v(t+dt) \approx v(t) + dv$. This way you can *time-step* the solution from $t = 0$ to dt to $2dt$ and so on to any time you like, just as the real system will "tick" forward in time. Simple, if you have a compter, because you need to take small time-steps and thus to take many time-steps to get anywhere.

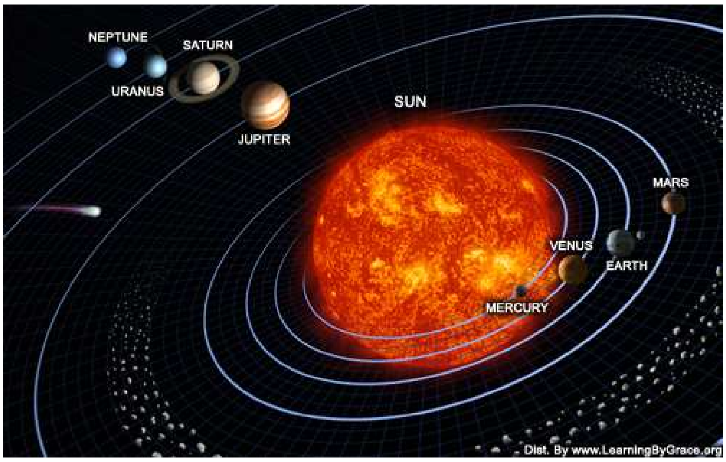


FIGURE 13.2. A reversible Solar system, computed from $m\ddot{u} = f$.

13.5 Reversibility of Newtonian Mechanics

It seems that you can also *predict its past* by solving the Newton's equation (13.1) *backwards in time* for $t > 0$. Even more amazing. This reflects the *formal reversibility* of Newtonian mechanics. If we change the direction of time, then the first time-derivative changes sign, but the second time-derivative does not since it corresponds to changing the sign twice. Thus the equation $m\ddot{u} = f(u)$ takes the same form with time reversed. Just by looking at the equation $m\ddot{u} = f$, we cannot tell the direction of time.

Thus Newtonian mechanics is *formally reversible*, while the World apparently is not, and so there is something essential missing in Newtonian mechanics. But what could that be? A ghost?

The riddle of irreversibility of reversible Newtonian mechanics thus presented itself from the very start, but it took another 200 years before it really became a pain in the neck to scientists. There were so many questions that *could* be answered by Newtonian mechanics, which filled the day, and the irreversibilty riddle could be buried for the moment. But it did not disappear for good but just bided its time...

We shall below return to Newton's equation (13.2), admire its beauty and see its usefulness, and most importantly, we shall explain *why* the *formally reversible* equation (13.2), in *reality is irreversible*, and thus defines an Arrow of Time. This is the essence of the mathematics of this book. To understand this, you don't need to be a Calculus specialist, but you only need an intuitive understanding of the concept of time derivative, or change per unit time step. And of course you have that understanding, right?

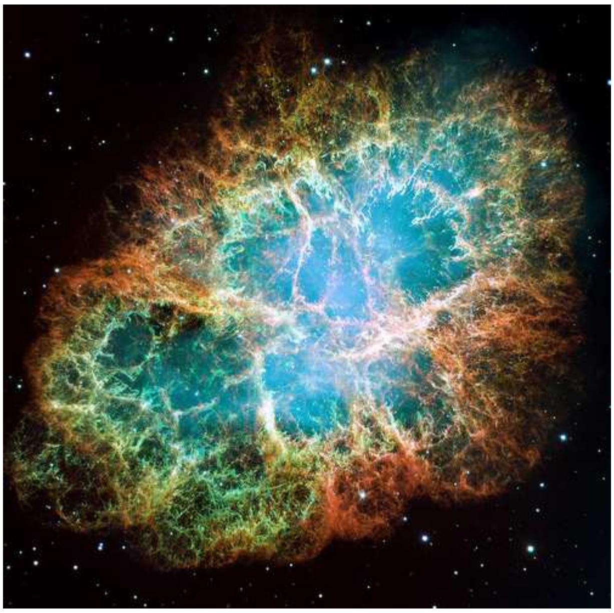


FIGURE 13.3. The Crab Nebulosa resulting from a super-nova explosion: Is it a result of solving $\ddot{u} = f(u)$?. Yes, what else? The picture was taken by the Hubble telescope in 2000. The nebulosa was first observed by naked in 1054 by Chinese astronomers.

14 Memory

Memory is deceptive because it is colored by today's events. (Einstein)

Memory... is the diary that we all carry about with us. (Oscar Wilde)

Every man's memory is his private literature. (Aldous Huxley)

It's a poor sort of memory that only works backwards. (Lewis Carroll)

Time and memory are true artists; they remould reality nearer to the heart's desire. (John Dewey)

Life is all memory, except for the one present moment that goes by you so quickly you hardly catch it going. (Tennessee Williams)

Yesterday's just a memory, tomorrow is never what it's supposed to be. (Bob Dylan)

The heart's memory eliminates the bad and magnifies the good. (Gabriel Garcia Marquez)

Although computer memory is no longer expensive, there's always a finite size buffer somewhere. When a big piece of news arrives, everybody sends a message to everybody else, and the buffer fills. (Benoit Mandelbrot)

Memory believes before knowing remembers. Believes longer than recollects, longer than knowing even wonders. (William Faulkner)

I do have a blurred memory of sitting on the stairs and trying over and over again to tie one of my shoelaces, but that is all that comes back to me of school itself. (Roald Dahl)

> Their memory's like a train: you can see it getting smaller as it pulls away And the things you can't remember Tell the things you can't forget that History puts a saint in every dream. (Tom Waits)

> The life of the dead is placed in the memory of the living. For what is man's lifetime unless the memory of past events is woven with those of earlier ... (Marcus Tullius Cicero)

> I, entelechy, form of forms, am I by memory because under ever-changing forms.(Stephen Dedalus)

> Memory is the real name of the relation to oneself, or the affect of self on self. (Deleuze, Foucault)

> Memory
> All alone in the moonlight
> I can dream of the old days
> Life was beautiful then
> I remember the time I knew what happiness was
> Let the memory live again
> Daylight
> I must wait for the sunrise
> I must think of a new life
> And I mustn't give in
> When the dawn comes
> Tonight will be a memory too
> And a new day will begin
> Touch me
> It's so easy to leave me
> All alone with the memory
> Of my days in the sun
> If you touch me
> You'll understand what happiness is
> Look, a new day has begun...

14.1 Frozen Moments

What is a memory? We could view it as a *frozen moment* kept to a later time. Like a photo of an anniversary, kept in a photo album. Or a videofilm as a sequence of still images kept in the memory of a computer. Or a funny story about a family event kept in the collective memory of the family. Or the memory of scent from your childhood somehow stored in your brain.

14.2 Storing Information

To record and store memories, or more generally information, requires both work and physical space. To maintain stored information requires more

FIGURE 14.1. Memory allocation of character attributes

work, because stored information has a tendency to degrade. To secure that your hard disk will be kept into the future requires attention.

14.3 Natural Memory

14.4 Individual Memory

Individual memory can be broken into three classes:

- *personal memory* of events in the past, which figure significantly in our self-descriptions, also called episodic memory,

- *cognitive memory* of things we learned in the past, also called semantic, or categorical memory,

- *habit-memory* of capacities to reproduce performances, like riding a bicycle, also called procedural memory.

14.5 Collective Memory

14.6 Would You Like to Relive Your Life?

Most people do not seem to embrace a offer to relive life very enthousiastically. Why?

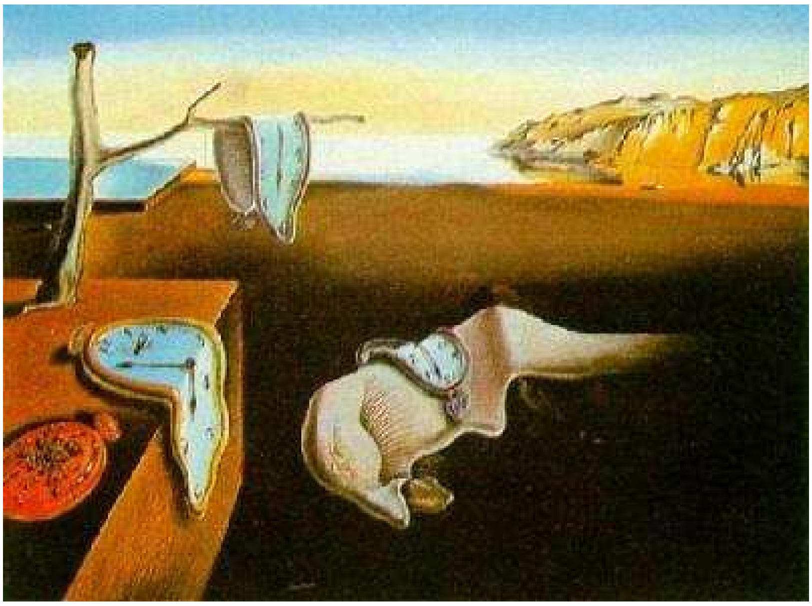


FIGURE 14.2. Persistence of Memory according to Dali

14.7 The Time Traveller

H.G Wells' (1846-1946) Time Traveller delivers the following breath-taking report in *The Time Machine*, see Fig. 14.3:

- *I am afraid I cannot convey the peculiar sensations of time travelling. They are excessively unpleasant. There is a feeling exactly like that one has upon a switchback–of a helpless headlong motion! I felt the same horrible anticipation, too, of an imminent smash. As I put on pace, night followed day like the flapping of a black wing. The dim suggestion of the laboratory seemed presently to fall away from me, and I saw the sun hopping swiftly across the sky, leaping it every minute, and every minute marking a day. I supposed the laboratory* *had been destroyed and I had come into the open air. I had a dim impression of scaffolding, but I was already going too fast to be conscious of any moving things. The slowest snail that ever crawled dashed by too fast for me. The twinkling succession of darkness and light was excessively painful to the eye. Then, in the intermittent darknesses, I saw the moon spinning swiftly through her quarters from new to full, and had a faint glimpse of the circling stars. Presently, as I went on, still gaining velocity, the palpitation of night and day merged into one continuous greyness; the sky took on a wonderful deepness of blue, a splendid luminous color like that of early twilight; the jerking sun became a streak of fire, a brilliant arch, in space; the moon a fainter fluctuating band; and I could see nothing of the stars, save now and then a brighter circle flickering in the blue.*

FIGURE 14.3. Entrance to The Time Travel Machine

15
The Unsatisfied Pendulum

I can't get no satisfaction
I can't get no satisfaction
'Cause I try and I try and I try and I try
I can't get no, I can't get no
When I'm drivin' in my car
And a man comes on the radio
He's telling me more and more
About some useless information
Supposed to fire my imagination
I can't get no, oh no no no
Hey hey hey, that's what I say
(The Rolling Stones)

15.1 A Fundamental Dynamical System

The basic dynamical system of Newtonian mechanics is the *harmonic oscillator*

$$\ddot{u} = -u, \tag{15.1}$$

with $f(u) = -u$, which in first order system form reads

$$\begin{aligned} \dot{u} &= v, \\ \dot{v} &= -u. \end{aligned} \tag{15.2}$$

The equation $\ddot{u} = -u$ models the motion of a unit mass connected to two linear springs, with $u(t)$ the position of the mass at time t and $-u(t)$ the spring force, see Fig. (15.1).

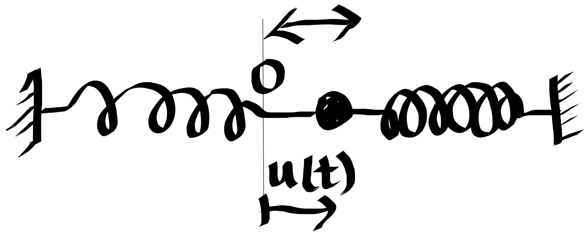


FIGURE 15.1. Harmonic Ocillator

We can get an intuitive feeling for the dynamics, by noting that the springs pull the mass to the left if the mass is to the right of O (with $u > 0$), and pull the mass to the right when the mass is to the left of O. This makes the mass oscillate back and forth (with period 2π).

The equation $\ddot{u} = -u$ also models the motion of a pendulum of unit length and mass with u the angle of the pendulum from the vertical position, if we assume that u stays small, see Fig. (15.2). We know that a pendulum swings back and forth, like a harmonic oscillator.

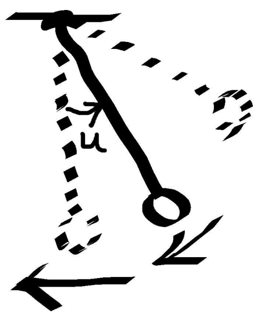


FIGURE 15.2. Pendulum.

15.2 Atomic Clock as Harmonic Oscillator

The mathematical model for a harmonic oscillator of *angular frequency* ω reads: Find the function $u(t)$ such that

$$\begin{aligned} \ddot{u} &= -(2\pi\omega)^2 u, \quad \text{for } t > 0, \\ u(0) &= 1, \dot{u}(0) = 0, \end{aligned} \tag{15.3}$$

where we made a specific choice of initial data. In this case the solution is given by the formula

$$u(t) = \cos(2\pi\omega t), \tag{15.4}$$

If you do not know the cosine-function $\cos(2\pi\omega t)$, then you can simply define it as the unique solution to the initial value problem (15.3.

An cesium clock is a harmonic oscillator with $\omega = 9192631770$. Thus you can view the variable t in the function $\cos(\pi 2\omega t)$ as representing time measures in seconds. The clock makes one tick or complete revolution for every $\frac{1}{\omega}$ seconds.

A clock represented by $\cos(\pi 2\omega t)$ does not have a direction, since the cosine function is invariant under reversal of the time variable from t to $-t$: $\cos(\pi 2\omega t) = \cos(-\pi 2\omega t)$. A clock does not know of any direction of time; it only ticks forward or backward time as you like.

The clock solution $\cos(2\pi\omega t)$ is *peridodic* with period $\frac{1}{\omega}$:

$$\cos(\omega t) = \cos(\omega t + 2\pi) = \cos(\omega(t + \frac{2\pi}{\omega})). \tag{15.5}$$

A periodic solution repeats itself after every period, and thus represents *cyclic time*. Our heart beats mark cyclic time as well as the seasons variations over the year.

15.3 The Life of a Pendulum

What would a life as a pendulum or harmonic oscillator be like? Repetitive of course, like go to work – come home from work – go to work – come home from work, in and endless repetition.

We can express this repetitive motion as an oscillation between two basic forms of energy, namely *potential energy* E and *kinetic energy* K with the sum $E + K$ being constant. If $u = 0$, then $E = 0$ and K is maximal (the speed is maximal), and if $|u| = u_{max}$ then $K = 0$ (the speed is zero) and E is maximal (the spring is maximally stretched or the pendulum is at maximal height), and if $|u| < u_{max}$ then K and E share the energy in some proportion.

15.4 The Addicted Pendulum

We can view the oscillation between potential and kinetic energy as an inability of the pendulum to be satisfied: When the pendulum has a lot of potential energy (in the top position), it seeks to get rid of it (by moving down), and in doing so it picks up kinetic energy, which it then seeks to get rid of by moving up on the other side picking up potential energy, which it seeks to get rid of.... and so on, in an endless cycle driven by a constant dissatifaction.

It is like a drug addict, seeking to give up smoking by by eating chocolate, and trying to stop eating chocholate by smoking, in a endless cycle, with all the tine the sum of the addictions being constant and the addict never satisfied.

What drives the motion of the pendulum is the constant dissatisfaction with its present state. This seems to be the essence of Newtonian mechanics. Satisfaction means equilibrium in a stationary immobile state. Dissatisfaction means endless motion in an unsuccessful search for equilibrium. The Sun always seeks to swallow the planets by attracting them by the gravitational force directed towards the Sun, but the planets always (miracolously) manage to escape by always moving at an angle to the line of attraction (perpendicular if the orbit is a circle).

FIGURE 15.3. Focault's pendulum experiment in Pantheon in Paris, 1851

15.5 Foucault's Pendulum

The Foucault pendulum, named after the French physicist Lon Foucault, was conceived as an experiment to demonstrate the rotation of the Earth. It is a tall pendulum free to oscillate in any vertical plane. The direction along which the pendulum swings rotates with time because of Earth's daily rotation. The direction of a pendulum at the North Pole will rotate once in 24 hours, at the equator it will not change. Foucault motivated more precisely that at a latitude of θ the period will be $24/\sin(\theta)$ hours, which at the latitude of Paris of $\theta \approx 50$ degress give a period of about 32 hours. Thus you may need to wait for an hour to see a distinct change in direction. The first public exhibition of a Foucault pendulum took place in February 1851 in the Meridian Room of the Paris Observatory. A few weeks later, Foucault made his most famous pendulum experiment, when he suspended a 28-kg bob with a 67-metre wire from the dome of the Panthon in Paris: And yes, the Earth did indeed rotate!

But wasn't it known long before 1851, by all the followers to Galileo including Newton, that the Earth was rotating around its axis? Yes, of course, but the motion of a pendulum on a rotating Earth had not received a correct mathematical analysis. On the contrary, the famous mathematician Laplace had erronously predicted a neglible influence on the direction of a pendulum from the rotation of the Earth. Foucault was not a mathematician and thus his discovery was first met with scepticism, and then with envy when it showed that his formula indeed was correct.

15.6 Thermodynamics in a Nut-Shell

We have said that thermodynamics is the study of transformations between kinetic and heat energy in a gas/fluid. If we view heat energy as kind of potential energy, then we can say that thermodynamics concerns transformations between kinetic and potential energy. As a simple model of thermodynamics, we can thus choose a pendulum or a harmonic oscillator.

We now rewrite the equation for a pendulum or harmonic oscillator so that it connects to both the 1st and 2nd Laws of thermodynamics, as we will meet them below. Multiplying the first equation in (15.2) by u and the second by v, and noting that $\dot{E} = \dot{u}u$ and $\dot{K} = \dot{v}v$, we get the system

$$\begin{aligned} \dot{E} &= -W, \\ \dot{K} &= W, \end{aligned} \tag{15.6}$$

where $K = \frac{v^2}{2}$ is the kinetic energy, $E = \frac{u^2}{2}$ is the potential energy and $W = -uv$ represents the transfer of energy from potential to kinetic energy in the form of *work* performed by the system. If $W < 0$ with the velocity v and the position u having different signs, then the pendulum is moving down from its top position and performs work by increasing its speed and thus its kinetic energy. If $W < 0$, then the pendulum is moving up from the bottom position and stores energy in the form of potential energy.

We can see the dynamics of a pendulum in (15.6): First we note that adding the two equations gives for the *total energy* $K + E$,

$$\frac{d}{dt}(K + E) = \dot{K} + \dot{E} = 0, \tag{15.7}$$

that is, the total energy stays constant. In the top position on either side the kinetic energy is zero and in the bottom position the potential energy is zero, and thus the motion of the pendulum is nothing but a repeated transformation from only potential energy in the top position to only kinetic energy in the bottom position.

The system (**??**) expresses the 1st Law. This equation is time reversible: Changing the direction of time and the direction of the velocity v, leaves the system invariant. In other words, the transfer of energy from kinetic energy to heat enargy is reversible. Whatever you invest in potential energy by supplying kinetic energy, you can get back, and vice versa. And there is no transaction cost.

Below we will see that the 2nd Law is the following variant of (15.2)

$$\begin{aligned}\dot{E} &= -W + D,\\ \dot{K} &= W - D,\end{aligned} \tag{15.8}$$

where $D > 0$. The novelty of the 2nd Law is evidently the positive D-term. The sign of the D term means that kinetic energy is transformed into heat/potential energy, but not the other way around. This gives time a direction in (15.8): The 2nd Law defines the forward direction of time to be the direction in which kinetic energy is transformed into heat/potential energy as defined by the D-term. As before, the work W can freely be transformed back and forth from kinetic to potential energy, but the D-term only allows transfer from kinetic to heat energy.

We will see that if $W > 0$ in the thermodynamics of a gas, then the gas performs work under expansion increasing its speed and thus its kinetic energy. If $W < 0$, then the gas stores energy under compression in the form of heat energy.

The 2nd Law (15.8) is *not* reversible: Changing the direction of time and the sign of the velocity v, gives the system

$$\begin{aligned}\dot{E} &= -W - D,\\ \dot{K} &= W + D,\end{aligned} \tag{15.9}$$

with different signs of the D terms, corresponding to transfer from heat energy to kinetic energy, which is unphysical.

We shall see below that the 2nd Law (15.8), which is a true physical law, is a consequence of the 1st Law combined with Prinicple Perfeito of edge stablity and finite precision. The formally reversed law (15.9) is thus incorrect and does not correspond to a physical law.

Again: Principe Perfeito combined with the 1st Law imply the 2nd Law. This is thermodynamics in a nut shell: Principe Perfeito + 1st Law is enough. The 2nd Law is just a corollary and not an independent basic law. The net result is that we do not have to worry about satifying the 2nd Law: It is automatic, which makes life (in particular for a thermodnamicist) much easier.

This is like automatic payment of your bills from your Internet bank. You don't have to worry any more about paying your bills in time (and about the currencies), as long as you have money on your bank account.

15.7 The 2nd Law for a Pendulum

What do we have to do to get a 2nd Law with a positive D-term for a pendulum? Well, of course, you say: Just add a little bit of friction or viscosity, and the pendulum will eventually come to rest with all of its kinetic energy transformed into heat energy. That is correct! In a sense, but the scientific question is from where does the friction or viscosity come? This question is answered by Prinicipe Perfeito and the answer is: Turbulence.

If the pendulum is swinging in air, then it will generate turbulence in the air which will transform kinetic energy into heat energy through a process of *turbulent dissipation*, and eventually bring the pendulum to rest in the bottom position (with a bit higher temperature). But why is turbulent dissipation consuming kinetic energy inevitable? Let's look at analogy.

15.8 Parking in Stockholm City

The authors live in the City of Stockholm and thus face the problem of parking the car over night. On the level of the City this is a problem without a solution, since there are many more cars than parking places. The result is that every evening there is a fierce fight for finding a legal over-night parking place, which is free but difficult to find. Since there is no solution, an approximate solution is somehow reached every might at around midnight, when the last drivers simply give up and choose any illegal place and prepare for paying a fine.

The non-existence of an exact legal solution is thus handeled by approximate solution combined with a penalty, and the penalty corresponds to turbulent dissipation. A life process shares the same impossibility of finding an exact solution and therefore pays a penalty which makes the process irreversible. As a summary of the book we may say that

- *irreversibility is the price we have to pay to live.*

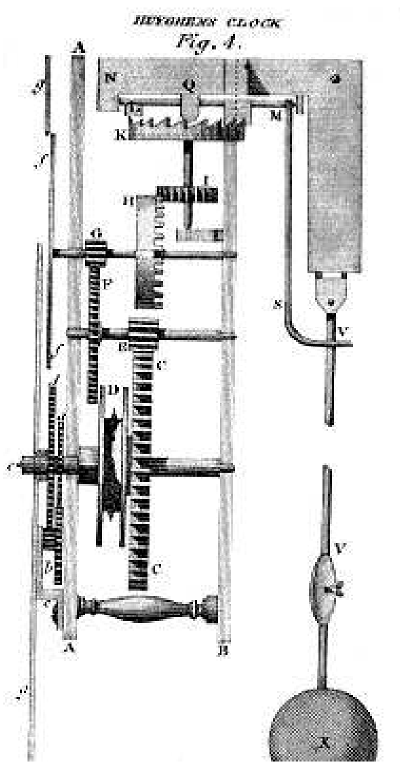


FIGURE 15.4. Huyghens pendulum clock.

16
Models of Time

The flow of time is like the flow of water in a river, into which you never step twice. (Herakleitos)

The touch of the present is like a kiss from eternity. (unknown)

Another thing that freaks me out is time. Time is like a book with a beginning, middle and end. (Mike Tyson)

Time is like money. The less we have of it to spare the further we make it go. (Josh Billings)

16.1 Models and Languages

Even if we cannot say what time really *is*, we can construct *models* of time, which may capure some more or less essential aspect of time. The model may be a *material model* consisting of some mechanical or electromechanical device, or the model may be an *immaterial model*. A material model is constructed out of physical matter by hand or machine.

An immaterial model is constructed using a, *language*, which may be Swedish or Chinese or the language of mathematics and theoretical physics, to formulate the *elements* of the model and the *rules* for combining the elements, like Commedia dell'Arte theatre with a fixed set of charachters in improvised dynamic interaction.

16.2 A Material Model of Time

A mechanical clock can be seen as a mechanical material model of time...as well as the endless breaking of the waves on a shore of the coast of Brittany...But we know that a mechanical clock shows no Arrow, so it is only a partial model.

FIGURE 16.1. A model of a rabbit with a clock.

16.3 An Immaterial Model of Time

The sequence of natural numbers $1, 2, 3, 4, ...$, can be seen as a simple mathematical model of time, including an Arrow in the direction of increasing numbers.

Most novels describes a flow of events over time, e.g. a 24 hour stream-of-consciousness of Stephen Dedalus in *Ulysses* by James Joyce. Of course, in a novel, time travel is possible and is often used as a writing trick.

16.4 Poetic Models

The flow of a river, the breeze over the island, the parade of jumping sheep to make you go to sleep....

16.5 The Use of Models of Time

A model of time may allow time travel, looking back to the past, looking forward to the future. Your calender is such a time travel machine.

FIGURE 16.2. Models of models.

16.6 100m Hurdling

As another model of time illustrating Principe Perfeito, we consider *hurdling*, more precisely 100 meter hurdling for women, focussing on the Swedish runner Susanna Kallur, Fig. [?], with personal record of 12.49 just 0.02 away from the Swedish record of 12.47 seconds set by Ludmilla Engquist at OS 1996. Instead of using a clock to record the time of the race, we can use Susanna as a clock, where time is given by the position of Susanna: We can thus agree to say that the clock is e.g. 4 when Susanna passes hurdle number 4, and interpolate between the hurdles to get a continuos time. We can then change time scale so that the total time is 12.49 seconds according to Susanna time.

As we follow Susanna through the race from start to goal, time is thus changing from 0 to 12.49, and in this model there is an Arrow because

FIGURE 16.3. Susanna Kallur in action at hurdle 4.

Susanna is running forward, not backwards. Reversing time would correspond to asking Susanna to run backwards from goal to start taking all the hurdles backwards. Would that be possible? Of course not: Even with a lot of practice, Susanna would not be able to jump the hurdles backwards, because the dynamics is so awkward that the required precision can never be met; the legs will necessarily tangle with the hurdle and Susanna will fall. Thus Susanna time has an Arrow pointing forward, according to Principe Perfeito.

17
Shortcut Through Time

> It is generally belived that there is color, something which is sweet and something bitter; in fact there are only atoms and emptiness. (Democrite (460-370 BC)
>
> It is also clear that if there were no such thing as time, there would be no such thing as the now, and that if there was no such thing as the now, there would be no such thing as time. (Aristotle, *Physics*, Book IV)
>
> Life presents itself to us as evolution in time and complexity in space. Regarded in time, it is the continuous evolution of a being ever growing older; it never goes backwards and never repeats anything. Considered in space, it exhibits certain coexisting elements so closely interdependent, so exclusively made for one another, that not one of them could, at the same time, belong to two different organisms: each living being is a closed system of phenomena, incapable of interfering with other systems. A continual change of aspect, the irreversibility of the order of phenomena, the perfect individuality of a perfectly self-contained series: such, then, are the outward characteristics–whether real or apparent is of little moment–which distinguish the living from the merely mechanical. (Henri Bergson in *Laughter: An Essay on the Meaning of Comic*, 1901)

17.1 From Ancient Greece to Modern Society

The rational materialistic mechanistic world view can be traced back two millenia to the school of the *atomists* in ancient Greece formed by *Dem-*

ocrite around 400 BC and widely spread by Epikuros during the later half of the 3rd century BC. According to the atomists, *matter* is formed by (very small) indivisible *atoms* (from Greek *atomos* meaning uncuttable) and all physical phenomena ultimately result from interactions of atoms in an empty *space* over *time*. The atomists were remarkably visionary, but since the atomistic nature of matter was experimentally detected first in the beginning of the 20th century, they lost the initiative to the idealistic philosophy of Socrate, Plato and Aristotle, the geometry of Euclide and likewise idealistic religious scholastics, together dominating science into the 16th century. We will return below to Aristotle's (successful) attack on the atomists and ask if without Aristotle the industrial revolution could have started in Greece before Christ was born, instead of in England almost 2000 years later.

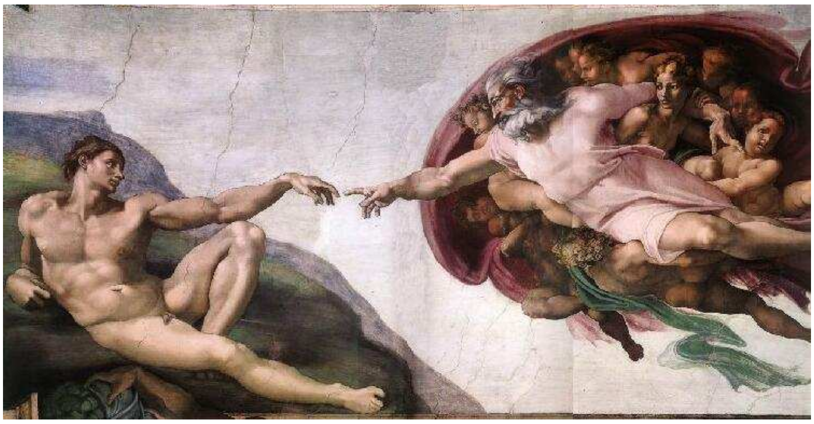


FIGURE 17.1. Local interaction.

17.2 Action at Distance

There was one important novelty in Newton's theory of gravitation: *instantaneous action at distance*. The atomists and also Aristotle believed that only *local interaction* as in direct collisions of atoms, was possible, while Newton's law of gravitation states that the Sun attracts the Earth with a force inversely proportional to the square of the *instantaneous* distance between the Sun and the Earth. Both the atomists and Newton needed an *absolute space* (like a big empty container), where atoms or celestial objects could move around. Action at distance also required an *absolute time* flowing at the same rate everywhere (like water flowing out of an standardized faucet), so that a notion of *simultaneity* could be established.

FIGURE 17.2. Action at distance.

It is important to note that Newton's law still today controls the motion of the Earth around the Sun: The Earth accelerates towards the instantaneous position of the Sun, and not towards the position you see in the sky, which is the position of the Sun 8 minutes ago, because it takes 8 minutes for the light to pass from the Sun to the Earth. Thus *instantaneous action at distance* seems to be a reality, but how is the action transmitted? And at what speed? Is it really instantaneous? Can it be transmitted infinitely fast? We will come back to these (interesting) questions below.

17.3 A New Brave World of Relativity

In the beginning of the 20th century the concept of simultaneity was scrutinized and dismissed by Einstein claiming that "that there is no such thing as simultaneity". This was the first and very crucial step in Einstein's crusade against Newtonian mechanics and absolute space and time, which gave room to the new brave world of *relativity* and *curved space-time*. To make room for a new building you first have to tear down the old one occupying the space. However, there is no Arrow of Time in Einsteins space-time and therefore we search for the Arrow elsewhere. Einsteins's theory of relativity rather concerns a static space-time where the history of an object is a *world-line* without direction.

17.4 Parmenides and Herakleitos

Going back to ancient Greece, we recall that Zeno of Elea (490-430 BC), member of the pre-Socratic Eliatic School founded by Parmenides, questioned the concept of *change* and *motion* in his *arrow paradox*: “How can it be that an arrow is moving when it at each time instant is still?”

Parmenides and Zenon were followed Plato seeking a timeless reality without a flow of time towards death. Parmenides argued that if there was Becoming, a thing must grow from nothing into something, which he regarded to be logically impossible.

Parmenides was opposed by his contemporary Herakleitos, who claimed that

- *All things are in flux.*
- *Becoming is the very essence of life.*
- *You cannot step twice into the same river, for fresh waters are ever flowing in upon you*
- *The sun is new every day.*
- *If you do not expect the unexpected, you will not find it; for it is hard to be sought out and difficult.*
- *For it is death to souls to become water, and death to water to become earth. But water comes from earth ; and, from water, soul.*
- *Wisdom is one thing. It is to know the thought by which all things are steered through all things.*
- *The bow is called life, but its work is death.*
- *Time is a child playing draughts, the kingly power is a child’s.*
- *Mortals are immortals and immortals are mortals, the one living the other’s death and dying the other’s life.*
- *God is day and night, winter and summer, war and peace, satiety and hunger; but he takes various shapes, just as fire, when it is mingled with different incenses, is named according to the savour of each.*
- *Fire lives the death of earth, and air lives the death of fire; water lives the death of air, earth that of water.*
- *All things are exchanged for Fire, and Fire for all things as wares are exchanged for gold, and gold for wares.*
- *Dogs bark at every one they do not know.*

- *The beginning and the end are common (to both paths).*
- *The Ephesians would do well to hang themselves, every grown man of them, and leave the city to beardless youths; for they have cast out Hermodoros, the best man among them, saying: We will have none who is best among us; if there be any such, let him be so elsewhere ,and among others.*
- *Nature loves to hide.*
- *It is cold things that become warm, and what is warm that cools; what is wet dries, and the parched is moistened.*

We believe Herakleitos was surprisingly visionary, and we give more support to his views below.

17.5 St. Augustine

We cite from Chapter XIV of Book XI of St. Augsutine's autobiographical *Confessions*:

- *There was no time, therefore, when thou hadst not made anything, because thou hadst made time itself. And there are no times that are coeternal with thee, because thou dost abide forever; but if times should abide, they would not be times.*
- *For what is time? Who can easily and briefly explain it? Who can even comprehend it in thought or put the answer into words? Yet is it not true that in conversation we refer to nothing more familiarly or knowingly than time? And surely we understand it when we speak of it; we understand it also when we hear another speak of it.*
- *What, then, is time? If no one asks me, I know what it is. If I wish to explain it to him who asks me, I do not know. Yet I say with confidence that I know that if nothing passed away, there would be no past time; and if nothing were still coming, there would be no future time; and if there were nothing at all, there would be no present time.*
- *But, then, how is it that there are the two times, past and future, when even the past is now no longer and the future is now not yet? But if the present were always present, and did not pass into past time, it obviously would not be time but eternity. If, then, time present– if it be time–comes into existence only because it passes into time past, how can we say that even this is, since the cause of its being is that it will cease to be? Thus, can we not truly say that time is only as it tends toward nonbeing?*

This is all quite confusing, but representative of classical ideas about time. Many books could be written on this theme, but we have to that leave aside, because time is short, and we want to get to the Arrow. We just comment on some essentials:

17.6 Newton

We saw that Newton's theory of gravitation involves action at distance in space, which reuqires a notion of *simultaneity* and a uniform flow of time at different locations in space, as if there was an *absolute time* flowing at the same rate forward everywhere. Newton thus views time as part of the fundamental structure of the universe, a dimension in which events occur in sequence, and time itself is something that can be measured.

17.7 Leibniz

Leibniz defines the concepts of *space* and *time* as follows:

- space is the *order of coexistence*,
- time is the *order of succession*.

This is quite clever, as always with Leibniz, exhibiting the sequential character of time as "order of succession". Leibniz does not seem to need any absolute space or time in which "objects" can "swim", but emphasizes that it is the "order" (of objects) which defines the space and time separating them. In short "order creates space and time". However, there is no Arrow in Leibniz order of succession, and so it misses the most essential.

Leibniz emphasizes that space and time are different: time is sequential while space is not, and that makes a big difference. In particular, it restricts time to be one-dimensional, since you can direct a line but not (except trivially) a plane, while space without directionality can have any number of dimensions (in principle). Thus Leibniz believes that space is three-dimensional and is separated from one-dimensional time. This was a good idea in Leibniz' time, and we advocate below that it is still quite good, despite what relativists say about "curved space-time" with space mixed into time.

17.8 Kant

Kant proposed that the construction of our brain somehow reflects the physical world, and therefore we may by pure reflection (without a posteriori observation) just using our brains, discover a truth about the physical world. This is referred a *synthetic a priori truth*, while an *analytic truth* results from logic only and does not concern the physical world. Clearly our perception of time and the way we may think of time, must be influenced by the design of our brain used for perception and thinking. Kant says that there may be synthetic a priori judgements about time which turn out to be true. Kant is led to consider the flow of time as a subjective perception, which may be difficult to rationalize by objective science.

The design of our brain with only *one* consciousness per brain, representing some form of tip of an ice-berg of all sorts of unconscious brain activities, of course restricts our conception of time to be (essentially) one-dimensionl. It is true that we can listen to the radio, watch the television and talk in our mobile telephone all at the same time, possibly following different time zones, but our conception of this productive activity is (probably) that we "swap" from one medium to the other, and do not really have three independent minds working in parallel. Or?

If we believe that we are just one person, and thus do not have a split personality, then we would naturally perceive time as being sequential. This insight could represent a true a priori synthetic judgement.

17.9 Henri Bergson

The French philosopher Henri Bergson (1859-1941), Nobel Prize in Literature, created a philosphy for which the essence of of life of Becoming is the essence of time, in the spirit of Herakleitos.

In *Laughter: An Essay on the Meaning of the Comic* from 1901, that *comedy* arises from the counterparts of the essential elements of life of irreversibility and individuality, that is, comedy results from *repetition* and *inversion*, which represent *mechanized life*. A dancing doll is comical because it mecanically mimics a real dancer. By mechanically putting on a new hat, a person changes character, and this is funny.

If you meet a friend in the street whom you have not seen for an age; there is nothing comic in the situation. However, if you meet the person again the same day, you will find it funny and a third time will be absolutely hilarious. You laugh, because repeated life is surprising and the way to cope with surprise is to laugh. Repeated life is funny because it is a form of mechanized life.

A situation is invariably comic when it belongs simultaneously to two altogether independent series of events and is capable of being interpreted in two entirely different meanings at the same time. An everyday situation interpreted equivocally becomes irresistibly funny. All forms of disguise is comical, because individuality is lost, and disguise is possible in mechanized life.

Bergson argued that the intuition is deeper than the intellect. His Creative Evolution (1907) and Matter and Memory (1896) attempted to integrate the findings of biological science with a theory of consciousness. Bergson's work was considered the main challenge to the mechanistic view of nature. He is sometimes claimed to have anticipated features of relativity theory and modern scientific theories of the mind:

- *In reality, the past is preserved by itself automatically. In its entirety, probably, it follows us at every instant; all that we have felt, thought and willed from our earliest infancy is there, leaning over the present which is about to join it, pressing against the portals of consciousness that would fain leave it outside.* (from Creative Evolution)

From his first publications, Bergson's philosophy attracted strong criticism. accused of intuitionism, indeterminism, psychologism and confused interpretation of the scientific impulse. Among those who explicitly criticized Bergson were Bertrand Russell, G. E. Moore, Ludwig Wittgenstein, T. S. Eliot, Andre Gide, Theodor W. Adorno, Lucio Colletti and Jean-Paul Sartre, Irving Babbitt, Arthur Lovejoy, Josiah Royce, Daniel-Henry Kahnweiler, Roger Fry, Virginia Woolf and C. S. Peirce who wrote: "A man who seeks to further science can hardly commit a greater sin than to use the terms of his science without anxious care to use them with strict accuracy; it is not very gratifying to my feelings to be classed along with a Bergson who seems to be doing his prettiest to muddle all distinctions." According to Russell, Bergson uses an outmoded spatial metaphor ("extended images") to describe the nature of mathematics as well as logic in general: "Bergson only succeeds in making his theory of number possible by confusing a particular collection with the number of its terms, and this again with number in general".

Nevertheless, we believe Bergson was largely misunderstood and in fact was very much on the right track...

17.10 Baudrillard

Jean Baudrillard (1929-2007) was a French cultural theorist, philosopher, political commentator, and photographer. His work is frequently associated with postmodernism and post-structuralism.

In *Symbolic Exchange and Death* he argued that in the modern information society, simulated virtual reality is replacing reality in a new form of *hyperreality*. This connects to the fable *On Exactitude in Science* by Borges where the map by the perfectionist Cartographers of the Empire eventually becomes so detailed that it covers the whole Empire, which is the beginning of the end:

- *In that Empire, the Art of Cartography attained such Perfection that the map of a single Province occupied the entirety of a City, and the map of the Empire, the entirety of a Province. In time, those Unconscionable Maps no longer satisfied, and the Cartographers Guilds struck a Map of the Empire whose size was that of the Empire, and which coincided point for point with it. The following Generations, who were not so fond of the Study of Cartography as their Forebears had been, saw that that vast Map was Useless, and not without some Pitilessness was it, that they delivered it up to the Inclemencies of Sun and Winters. In the Deserts of the West, still today, there are Tattered Ruins of that Map, inhabited by Animals and Beggars; in all the Land there is no other Relic of the Disciplines of Geography.*

Baudrillard followed up on Bergson's idea of the meaning and role of images. Rather than arguing, as did Susan Sontag in her book *On Photography*, that the notion of reality has been complicated by the profusion of images of it, Baudrillard asserted: "the real no longer exists". In so saying, he characterised his philosophical challenge as no longer being the Leibnizian question of:

- *Why is there something, rather than nothing?*

but, instead:

- *Why is there nothing, rather than something?*

Of course our question in this context is if the Arrow of Time is the same in hyperreality as in reality? Of course, you may answer yes, if hyperreality is more real than reality. On the other hand, hyperreality allows time travel in the sense that you can restart a simulation and relive a hyperreal experience as many times you wish. But doing so it will be difficult to deny that each repetion will make the cells of your body a bit older, and eventully they will cease to function. The question is if this means the end also of your hyperreal self, or if it can continue to exist, like a hyperreal web page of a deceased person?

17.11 Deleuze

The French philosopher Gilles Deleuze (1925-1995) states in his lecture *La Taverne* on Leibniz, connecting to Herakleitos:

- *What you call to die is completing the act of living, and what you call to be born is to start dying, just as what you call to live is to die while living. You don't wait for death to come; rather you are its perpetual companion.*

Deleuze's Ph D thesis *Difference and Repetition* from 1968, led Michel Foucault to declare that "one day, perhaps, this century will be called Deleuzian". Deleuze, for his part, said Foucault's comment was "a joke meant to make people who like us laugh, and make everyone else livid." Deleuze considers the concept of *repetition* in three models of time representing the present, the past and the future:

The first is time as a circle. The subject then experiences the passing of moments cyclically (the sun will come up every morning), and contracts habits which make sense of time as a continually living present. Habit is thus the passive synthesis of moments that creates a subject.

The second is time as a straight line of successive events. In this model habit has no role, since nothing ever returns, and instead Deleuze introduces memoery as an active process of synthesis giving past instances a meaning. Unlike habit, memory does not relate to a present, but to a past which has never been present, since it synthesises from passing moments a form in-itself of things which never existed before the operation. The novels of Marcel Proust are for Deleuze the most profound development of memory as the pure past, or in Proust's terminology, as time regained. In this second model of time, repetition thus has an active sense in line with the synthesis, since it repeats something, in the memory, that did not exist before.

The active constitution of a pure past of the second model, and the disparate experience of a present yet to be synthesised of the first model, produces for Deleuze a radical splitting of the subject into two elements, the I of memory, which is only a process of synthesis, and a self of experience, an ego which undergoes experience.

In the third and final model, Deleuze proposes to make repetition itself the form of time. In order to do this, Deleuze relates the concepts of difference and repetition to each other. If difference is the essence of that which exists, constituting beings as disparates, then neither of the first two models of time does justice to them, insisting as they do on the possibility and even necessity of synthesising differences into identities. It is only when beings are repeated as something other, that their disparateness is revealed. Consequently, repetition cannot be understood as a repetition of the same, and becomes liberated from subjugation under the demands of traditional philosophy.

To give body to the conception of repetition as the pure form of time, Deleuze turns to the Nietzschean concept of the *eternal return*, which is not is not the circle of habit allowing only the return of something already existing.

While thus habit returned the same in each instance, and memory dealt with the creation of identity in order to allow experience to be remembered, the eternal return is the repetition of becoming being and thus represents the time of the future.

FIGURE 17.3. Reflections of Deleuze

FIGURE 17.4. Image of Consumer Society by Baudrillard

18
A Best World of Thermodynamics

> We live in a Best of Worlds, which is a world with maximal complexity governed by simplest possible laws. (Leibniz)

> Everyone knows that heat can produce motion. That it possesses vast motive power no one can doubt, in these days when the steem engine is everywhere so well known. The study of these engines is of great interest, their importance is enormous, their use is continually increasing, and they seem desined to produce a great revolution in the civilized world. (Carnot [17] 1824).

> Emergence means complex organizational structure growing out of simple rules. Emergence means stable inevitability in the way certain things are. Emergence means unpredictability, in the sense of small events (possibly) causing great and qualitative changes in larger ones. (Robert Laughlin in A Different Universe, 2005)

> Boltzmann has proved that the entropy of a given state is connected by a simple relationship to the probability of the state....only those spontaneous transformations occur which take the system to states of higher probability. (Enrico Fermi, Nobel Prize in Physics, in *Thermodynamics* 1936)

18.1 The Laws of Thermodynamics

Newton's mechanics thus seemed to require both absolute space and absolute time, and even if these concepts were questioned (on good grounds) by e.g. Leibniz, they did not seem to pose any real severe problems to science until the mid 19th century, when energy demands from the quickly growing industrial society pushed the development of *thermodynamics* as the scientific study of transformations between heat energy and kinetic energy.

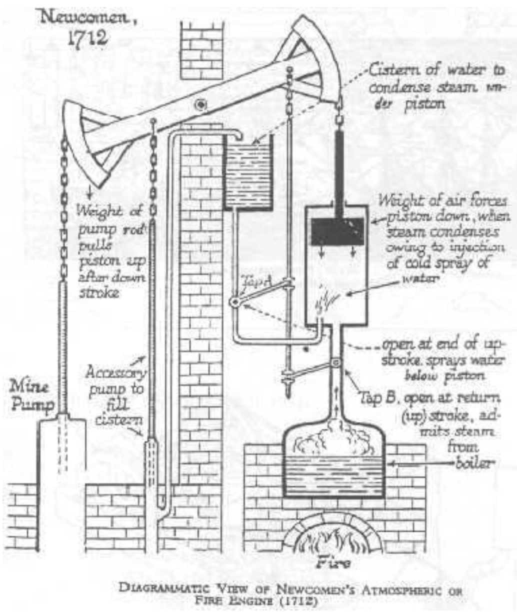


FIGURE 18.1. Converting heat to mechanical energy in 1712.

Kinetic energy can be transformed to heat energy by compression or friction, and heat energy can be transformed to kinetic energy by expansion but not through a reverse process of friction. The industrial society of the 19th century was built on the use of steam engines, and the initial motivation to understand thermodynamics came from a need to increase the efficiency of steam engines for conversion of heat energy to kinetic energy, see Fig. (18.1). Thermodynamics is closely connected to the dynamics of compressible gases, since substantial expansion can occur in a gas but not in a solid. More generally, thermodynamics is fundamental in a wide range of phenomena on macroscopic scales in the Universe all the way down to microscopic scales of life and chemical reactions.

Thermodynamics is based on two postulates: the 1st and the 2nd Law of thermodynamics. The *1st Law* states that the total *energy* (in a closed system) is conserved: Energy can be transformed form one form to the other, e.g. heat energy can be transformed into kinetic or potential energy as in a steam engine, but the total energy remains constant. Energy cannot simply disappear, nor can it suddenly appear from nothing. This is not so difficult to understand and accept.

The 2nd Law has a different form and states that the total *entropy* can never decrease over time in a (closed) thermodynamic process, but may strictly increase and when so shows that the process is *irreversible*. The 2nd Law states that an irreversible process cannot be reversed in time, since in the reversed process the entropy would decrease strictly and that is prevented by the 2nd Law.

The role of the 2nd Law was in particular to explain why transformation of kinetic energy into heat energy cannot be fully reversed, which sets a limit to the efficiency of e.g. a steam engine.

The 2nd Law can be used to explain why a stone heated by being dropped to the ground, cannot lift itself by simply cooling off. Or why you can warm your hands by rubbing them against something, but not rub your hands simply by warming them. Or why it is impoosible to construct a perpetuum mobile transforming kinetic energy to heat energy and back again in a cyclic process.

FIGURE 18.2. The irrversible process of an asteroid colliding with the Earth transforming kinetic energy into heat energy.

18.2 The Mystery of the 2nd Law

The 1st Law states conservation of energy, while the 2nd Law states that entropy can only increase, as if there was an endless supply of indestructible something called entropy. But what could that be? The questions were lining up after Clausius had formulated a form of the 2nd Law in 185?:

- If entropy is a *state variable* describing an aspect of a physical system over time, what physical law prevents it from decreasing?
- If entropy is not a state variable, what is it then?
- If entropy can only increase, how can there be cyclical processes?
- If entropy measures disorder and disorder can only increase with time, how come that the initial state was ordered?
- How to explain irreversibility without entropy?

But like the riddles of Princess Turandot, see Fig. (36.2), they seemed very difficult to answer.

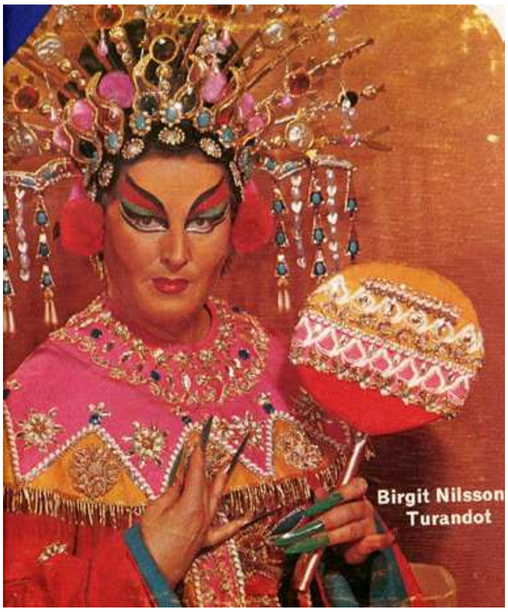


FIGURE 18.3. Princess Turandot's three riddles: *Why is time always moving forward? What do you have but cannot get back? What do you get every day, but can never keep?*

The seemingly unsurmountable difficulty was that while the 2nd Law showed irrversibility and an Arrow of Time, Newtonian mechanics seemed to be fully reversible: If at a given moment all velocities were reversed, then the entire history of the world up to that point would be replayed in reverse. In Newtonian mechanics a stone can lift itself by cooling off, and you can relive your life in reverse. The riddle was to explain from where the 2nd Law and irreversibility comes from, if not from reversible Newtonian mechanics?

The scientists wrestled in agony over the riddle without any convincing results, and the Princess of Science started to get impatient. If no answers came, maybe heads would start to roll.

18.3 Boltzmann Enters the Stage and Leaves

It was the young German physicist Ludwig Boltzmann (18??-1906) who first claimed to have found a solution to the riddle. Of course any solution would have to involve a step away from Newtonian mechanics, since Newtonian mechanics is reversible, and what Boltzmann proposed was to introduce an element of chance or statistics: When atoms interact in some form of collision, they do that not simply by following the laws of Newtonian mechanics, but they also to a certain degree play dice or roulette. The atom velocities before collision thus were assumed to be statistically independent or random, while just after collision they would be correlated because of their interaction. But still the atomistic nature of matter was only a hypothesis, just as it was for the atomists in the 4th century BC, and thus Boltzmann's assumption seemed highly hypothetical.

Nevertheless, based on his assumption of statistical independence of atom velocities before collision, the very ambitious Boltzmann formulated an equation for the thermodynamics of a dilute gas, referred to as *Boltzmann's equation*, and proved that solutions of this equation do satisfy a 2nd Law with a certain entropy state variable, and the solutions thus are irreversible in cases of increasing entropy. So far so good.

18.4 The Physical Meaning of Entropy

The remaining challenge was now to give the entropy as meaning as a physical state variable, and after a long struggle Boltzmann came up with the idea of interpreting the entropy not really as a physical quantity, but rather as a *probability* or measure of *disorder* of a *macroscopic thermodynamic state* quantified by the number of *microstates* corresponding to the macrostate. The 2nd Law would then express a statistical tendency of thermodynamic processes to move from *less probable* macrostates to *more probable* macrostates or from *less disordered* towards *to more disordered* macrostates. According to Boltzmann, entropy thus is a state variable measuring the disorder of a (macro)state.

This looked like a quite clever solution, but other scientists also seeking an answer to the riddle, viewed it to be a bit *too* clever, more like some form

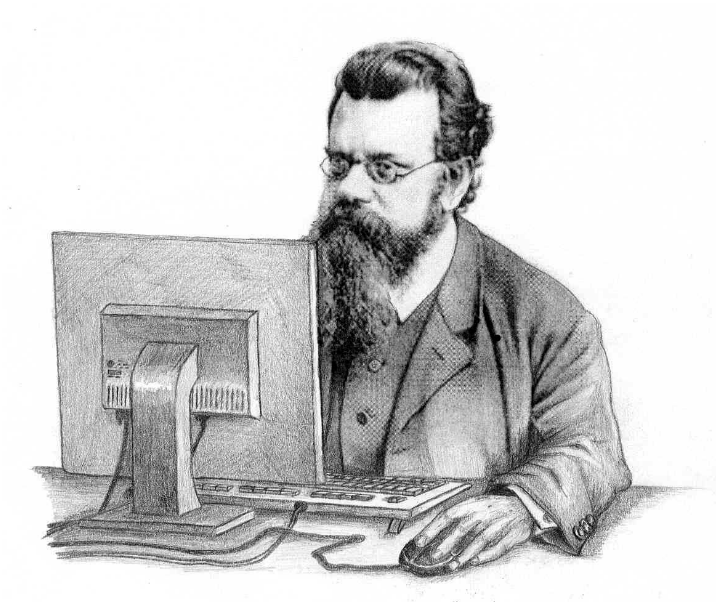


FIGURE 18.4. Ludwig Boltzmann updating his web page on statistical mechanics.

of *pseudo-science* impossible to either prove or disprove. So Boltzmann had to struggle hard to convince the scientific world about the relevance of his concept of entropy as a state variable measuring disorder, with disorder more probable than order. The semantics was tricky (is it more probable or less probable to move from a less probable state to a more probable state?), and Boltzmann was not easy to debate with.

Slowly Boltzmann's ideas gained some acceptance, since no other scientist dared to propose a solution, but shortly before the Princess was about to give Boltzmann her hand, his own disbelief in his own ideas took over and he tragically ended his life himself in 1906. The game of roulette was played with high stakes.

Ironically, quickly after Boltzmann's death the existence of atoms was verified experimentally and the resistance to statistics in mechanics faded and the new theory of *statistical mechanics* started its transformation of classical physics based on Newtonian mechanics into *modern physics* based on *quantum mechanics*. This transformation follows a strange logic leading into our time, which we now briefly recall in the following couple of sections.

18.5 Are Atoms Game Addicted?

The first step in the chain of strange logic was to take the atomistic character of matter as a confirmation of Boltzmann's statistics. But it is not at all clear that the mere existence of atoms and molecules, forbids them from following deterministic laws. And *if* atoms really do play roulette, *how* can you verify that?

To see the difficulty you may compare with the problem of checking if a roulette table is fair, that is, is not favoring certain numbers. You may do that either by making a very large number of tests to see that the frequencies of the different numbers are equal, or you can check the design of the table itself to see that everything looks fully symmetric. None of these possibilities is available in the case of atomistic games of roulette. So how can you check Boltzmann's assumtion? Or maybe you do not have to check it? It is only an assumption, and we can choose to take it or leave it. We choose to leave it, which we motivate below.

We conclude that experimental verification of both Boltzmann's basic assumption of statistical independence and his 2nd Law seems to be very difficult (or simply impossible), and therefore the physical significance of Boltzmann's entropy is unclear. This was expressed by the famous mathematician von Neumann (1903-1957) suggesting Shannon (see below) to use this term, because "it will give you a great edge in debates nobody really knows what entropy is anyway". So there may a role for entropy in debate, but not in physics as we will see below.

Nevertheless, physicists including Nobel Laurates, act as if they all belong to the group of true experts understanding that Boltzmann's statistical mechanics based on the principle that a more probable state is more likely to appear than a less probable state, reveals a deep secret of Nature. But what do you as non-expert say?

Is it surprising that a more probable event is more likely to appear than a less probable event? Isn't this just a nonsensical play with words, with a very small probability of having any meaning? It is more probable than less probable that you have a good answer.

18.6 Planck's Black-Body Desperation

Even if the threat to science from the 2nd Law of thermodynamics had been evaded (at least for the moment), the riddle of irreversibility in reversible mechanics instead showed up as the problem of *black-body radiation* in Maxwell's new mathematical theory for *electromagnetic waves* formulated in 1864, neatly condensed into *Maxwell's equations.*

A *black-body* absorbs incoming light of all frequencies but only emits low frequency light in the form of heat radiation, thus with a *high-frequency cut-*

FIGURE 18.5. The roulette table of statistical mechanics in action.

off. The irreversible nature and high-frequency cut-off of this phenomenon could not be explained by Maxwell's deterministic wave mechanics, which like Newtonian mechanics looked fully reversible and undeniably stated that what comes in must go out!

The Princess again started getting impatient waiting for an answer. Max Planck was educated in Boltzmann's statistical mechanics and as a leading physicist of his generation, he took on the responsibility of solving the riddle of black-body radiation: Why are all frequencies absorbed but only low frequencies emitted? Why is there a high-frequency cut-off?

In an "act of desperation" [9], Planck resorted to statistics in 1900 by introducing the concept of *quantum of light energy*, like a small indivisible packet of energy, of size $h\nu$, where ν is the frequency of the light and h is *Planck's constant*, an incredibly small quantity of size 10^{-34} joule-seconds. The frequency of visible light is around 10^{14}, so a quantum would be of size 10^{-20} joule, a very small quantum of energy indeed. Anyway, using the concept of quantum Planck motivated the high-frequency cut-off by statistics: since a high-frequency quantum has more energy it would be less likely that this amount of energy could be collected and emitted. Planck was not very happy with the statistical aspect of his solution and viewed it rather as a formality than a reality. But the Princess seemed to reasonably satisfied, for the moment...

18.7 Microscopics of Microscopics

There is an obvious difficulty, mostly forgotten, with molecules which play games of roulette, in the sense that a game of roulette necessarily has its own microscopics. Thus statistical mechanics is based on microscopics of microscopics in an endless regression and therefore does not appear to *explain* anything. Of course it can serve as an ad hoc model, with some predictive capacaity, but not for *understanding*, as far as we can see at least.

18.8 Classical Thermodynamics in a Nutshell

Classical Thermodynamics is ambigous concerning the nature od the 2nd Law: Is it "only" a summary of experience without theoretical support, or is it based on theory? Is statistical mechanics such a satisfactory theory? There are no clear answers in the literature. Go look, if you don't belive what we are saying, which you should not do without checking.

First Law of Thermodynamics – *Conservation of Energy*
Second Law of Thermodynamics – *It is not possible to create a cyclical heat engine that draws heat from a reservoir without wasting some heat energy*.
Entropy – is a measure of the disorder in the Universe. It must always increase; local decreases make a bigger mess elsewhere.

FIGURE 18.6. Classical 1st and 2nd Laws.

Scientific Method
It is important to note that the second law cannot be **derived** from any more basic underlying principle. Rather, it is an **experimental law** in that every experiment to date has confirmed the validity of this law in nature. The Second Law therefore is rather unique in that unlike other laws such as gravitation or quantum mechanics, it is not something that results from some deep mathematical formulation of nature's laws.

FIGURE 18.7. Classical view on the 2nd law.

In any case we cite Wikipedia:

- *Statistical mechanics is the application of statistics, which includes mathematical tools for dealing with large populations, to the field of mechanics, which is concerned with the motion of particles or objects when subjected to a force.*
- *provides a framework for relating the microscopic properties of individual atoms and molecules to the macroscopic or bulk properties of materials that can be observed in everyday life, therefore explaining thermodynamics as a natural result of statistics and mechanics (classical and quantum) at the microscopic level. In particular, it can be used to calculate the thermodynamic properties of bulk materials from the spectroscopic data of individual molecules.*
- *This ability to make macroscopic predictions based on microscopic properties is the main asset of statistical mechanics over thermodynamics. Both theories are governed by the second law of thermodynamics through the medium of entropy. However, Entropy in thermodynamics can only be known empirically, whereas in Statistical mechanics, it is a function of the distribution of the system on its micro-states.*

We see that the standard opinion is that the 2nd Law is either empirical or statistical, and thus the determinsitic formulation we present is new.

To boost the interest of the reader in thermodynamics, we now quickly browse through some of the many fields, where thermodynamics is essential and they all follow the Arrow. The scope is really amazing, when you start to think of it.... which we hope you will do...

19
Dynamics of Thermodynamics

> Those who have talked of "chance" are the inheritors of antique superstition and ignorance...whose minds have never been illuminated by a ray of scientific thought. (T. H. Huxley)
>
> There are great physicists who have not understood it. (Einstein about Boltzmann's statistical mechanics)
>
> There is apparently a contradiction between the law of increasing entropy and the principles of Newtonian mechanics, since the latter do not recognize any difference between past and future times. This is the so-called reversibility paradox (Umkehreinwand) which was advanced as an objection to Boltzmann's theory by Loschmidt 1876-77. (Translators foreword to Lectures on Gas Theory by Boltzmann).

19.1 Cosmology and Big Bang

Cosmology is the scientific study of the large scale properties of the universe as a whole, including its origin, evolution and ultimate fate. The Big Bang model postulates that 12 to 14 billion years ago, the universe was in a very hot very dense state, which expanded along with galaxies and stars being formed by gravitation from variations in density. It is believed that we can see remnants of the hot dense matter as the now very cold cosmic microwave background radiation, which still pervades the universe as a slightly varying glow across the entire sky, a discovery made by the Cosmic Background Explorer COBE-telescope, which gave the Nobel Prize in 2006 to John Mather and George Smoot. Cosmology is basically a very (very) large scale application of thermodynamics as an interplay of mass, momentum and energy governed by gravitational and inertial forces and driven by nuclear reactions.

19.2 Astronomy and Nuclear Energy

The stars were formed in the early Universe by accretion of mass by gravitational collaps increasing the temperature of a central core and thus igniting the star in a nuclear fusion process with first deuterium and then hydrogen being transformed to helium under intense release of energy (according to Einsteins famous $E = mc^2$ formula) increasing the pressure and counterbalancing the collaps. Planets may be formed around stars and under favorable conditions give rise to life. Stars of 0.4-10 times the mass of our own Sun expand into red giant very bright stars, when the supply of hydrogen in the core is empty and fusion starts in an outer core. Our own Sun thus eventually will swallow the Earth into a fusion process, but this is estimated to be a couple of billion years away. The thermodynamics of the Sun thus is the basis of both life and death of the Earth.

19.3 Geology and Global Warming

Geology or earth science contains the subfields of geophysics, glaciology, volcanology, climatology and meteorology connecting to the the central issue of the thermodynamics of global warming. Computational modeling of global climate change has a very important role to play to find out what actions are beneficial for sustainable development and long-time survival. In particular, thermodynamic modeling of (shrinking) glaciers and (melting) arctic sea ice, today is a very "hot" topic.

19.4 Black Body Radiation and the Sun

A *black body* absorbs incoming white light of all frequencies, from high frequency ultraviolet to low frequency infrared, but only radiates low frequency light (with color depending on the temperature of the body). This is the basis of the gross energy balance of the Earth absorbing white light from the hot Sun and radiating low frequency light into empty space. One can view black body absorption/emission as an (irreversible) thermodynamic process transforming high frequency light to low frequency light energy.

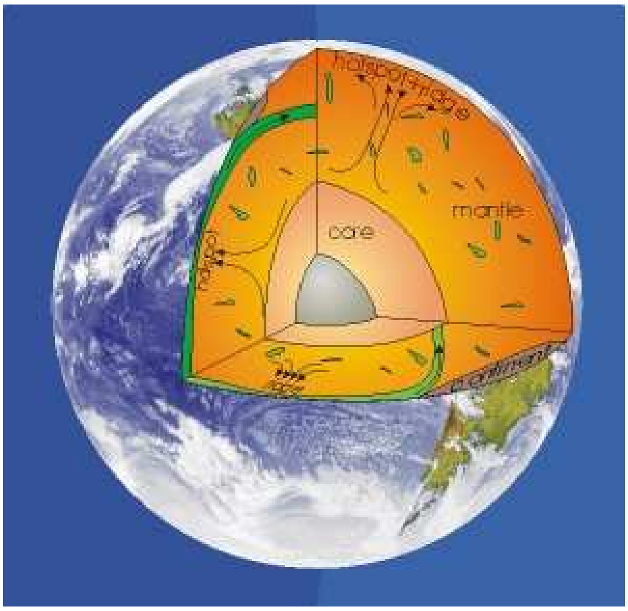


FIGURE 19.1. The Earth

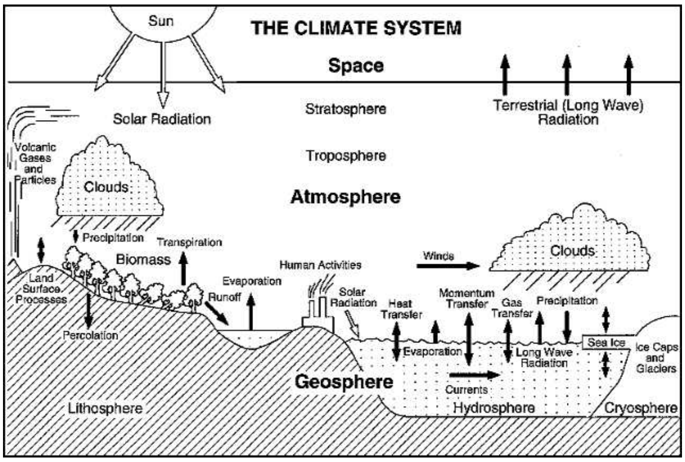


FIGURE 19.2. Global heat balance.

FIGURE 19.3. Life in action.

19.5 Biology and Life

Most forms of biological processes build on conversion of chemical energy into heat and kinetic energy, and thus ultimately on Solar energy converted to chemical energy in the photo-synthesis. The emergence of biological life may naively appear to contradict the 2nd Law in its classical form, by creating ordered structures out of disordered, while the death of a living organism with order dissolving into disorder, reflects the classical 2nd Law very well. We shall see that in the new formulation not relying on notions of ordered/unordered, there is nothing (in principle) that prevents ordered structures to develop from unordered (for example in Irak), assuming there is some input of energy (oil).

19.6 Molecular Biology and Protein Folding

Biology builds on cell microbiology based on the thermodynamics of chemical reactions governed by the chemistry of the protein chains of DNA put together in a process of *protein folding* from amino acid molecules. Computational thermodynamics of the cell is becoming an increasingly important tool in medicine and drug design.

19.7 Quantum Physics and Chemistry

The thermodynamics of chemical reactions and radiation build on the quantum mechanics of electrons, and the thermodynamics of nuclear reactions build on quantum electrodynamics of elementary particles. Computational

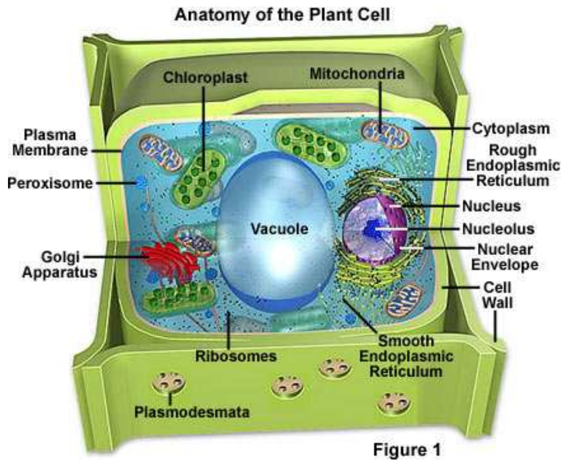


FIGURE 19.4. Inside a plant cell.

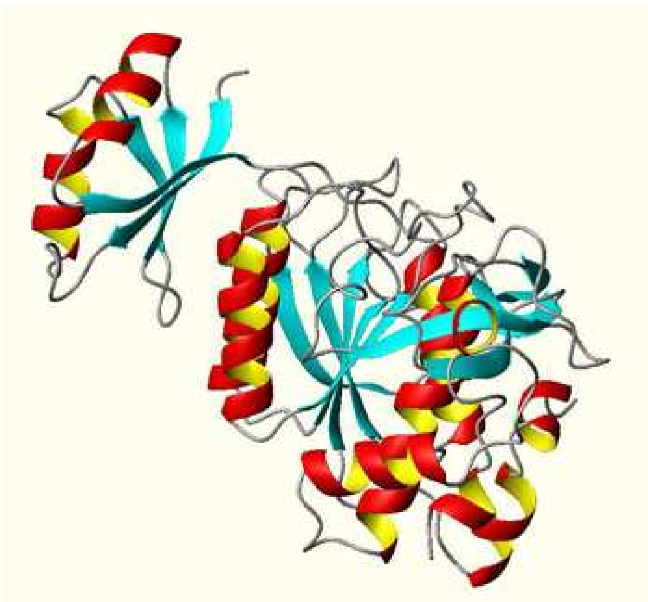


FIGURE 19.5. Protein folding

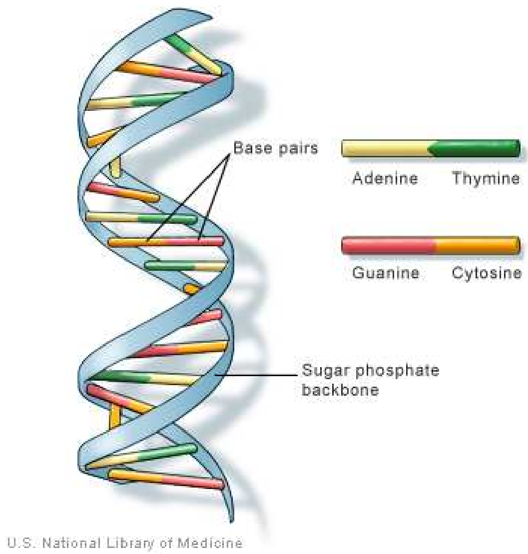


FIGURE 19.6. The double helix of DNA

solution of the equations of quantum dynamics presents a tough challenge, because of the richness of the the wave function solution with in principle three independent space coordinates for each particle (electron) involved. Methods reducing the dimensionality are today routinely used in massive computations in quantum chemistry, and could open to new insights of the nature of the quarks of elementary particle physics.

19.8 Energy Generation and Consumption

Our industrial society is based on production and consumption of energy in thermodynamic conversion processes of the form:

- nuclear/fossile/biological/chemical → heat/kinetic/electric,
- wind/wave kinetic → electric,
- solar radiation → heat/electric.
- electric → heat/kinetic.

In all conversion of energy, minimization of losses into useless heat is of prime concern, for which computational thermodynamics opens new possibilities.

19.9 Heat Engines and Industrialization

The early development of thermodynamics was motivated by the need of understanding the steam engine, underlying the industrialization of the Western world in the 19th century. A steam engine is a particular form of a *heat engine* converting heat to mechanical work in a thermodynamical process. The modern combustion engine in a car is another form of heat engine. The efficiency of a heat engine is of prime importance, and can be studied by computational thermodynamics. The necessary cooling of a car engine represents a loss of energy which is not transformed into useful mechanical work.

19.10 Heat Pumps and Oil Crisis

The *heat pump* is replacing the increasingly expensive oil for heating of houses. The heat pump converts low temperature heat (from the earth, sea/lake or air) to higher temperature useful heat, by supplying the necessary conversion energy from electricity. The efficiency is typically around 2/3, that is, for 1/3 unit of electric energy, you get out 1 unit of useful heat energy. You can thus reduce your electrical bill by a factor of 3 by changing from full electrical heating of your house to heating by a (good) heat pump. Of course, it is of interest to seek to increase the efficieny even more. Can we reach 99% efficiency, and if not why?

19.11 Refrigerators and Urban Civilization

A refrigerator is a form of heat pump taking heat form inside of the refrigerator and delivering it to the surrounding. The refrigerator is an absolute necessity of modern urban civilization.

The standard design builds on cycling a fluid alternating between expansion/evaporation to gas phase with temperature drop, and compression/condensation to liquid phase with temperature increase, with the cold gas in contact with the interior of the refrigerator and the warm liquid phase in contact with the exterior. For the compression an electric motor is used, which consumes the energy required to maintain the cooling.

The first design of an absorption refrigerator, without compressor and moving parts and thus silent, was invented by the two young Swedish engineering students Carl Munters and Baltzar von Platen during their class in thermodynamics at the Royal Institute of Technology in 1922 (although they slept through the lectures working all night on their invention). This invention together with a vacuum cleaner gave the impetus of the quick expansion of the Electrolux company. The production of the Munters-Platen

FIGURE 19.7. The principle of preservation of food in a refrigerator.

refrigerator has continued at Motala in Sweden uninterrupted since 1925 with today a total of 10 million units being produced. We hope this book may be useful for young minds of today in search of new inventions.

19.12 Information and Communication

Information theory was created by Shannon [22] in the 1940s borrowing the concept of *entropy* from *thermodynamics*, with the idea of measuring communication channel capacity requirements for different types of information. Random information would then represent information with maximal entropy, in principle requiring maximal capacity (although random information would seem like useless information).

Alternatively, one can view communication of information as a thermodynamic flow with the heat energy representing loss of information during the communication. This is the approach we will take below.

19.13 Economy and Welfare

One can also view an evolving economy as a thermodynamic flow process transforming resources into utilities. In (a free) economy the entropy could be viewed as a measure of necessary losses during the process, in the form of interest rates, taxes, bribes, thefts, which cannot (fully) be avoided. The flow of the World economy represents a complex process of prime importance to all of us. An economist with (some) understanding the process can be raised to fame and fortune.

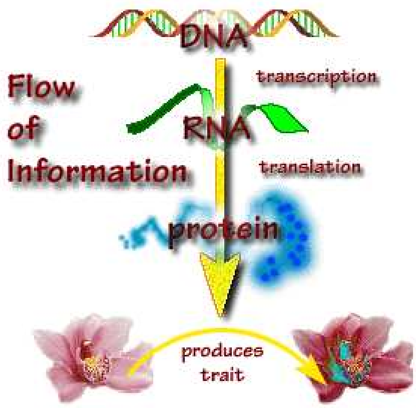


FIGURE 19.8. Flow of information in a flower.

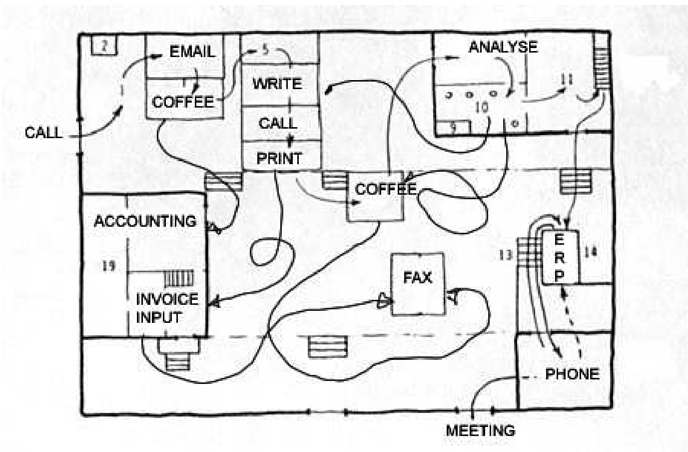


FIGURE 19.9. Flow of information in a modern office.

19.14 Emergence: A New Approach to Physics

Emergence is the process of complex pattern formation from more basic constituent parts or "particles". Turbulence represents emergence in fluid dynamics, which cannot be understood by considering only a single fluid particle, only by considering the interaction of many. The 2nd Law expresses the basic emergence phenomenon of thermodynamics as a *collective* behavior of many fluid particles to irreversibly transfer kinetic energy to heat energy. Thus thermodynamics naturally connects to the new approach to physics based on emergence, which is now developing (emerging) with input from e.g. 1988 Nobel Laurate Robert Laughlin [50], and which is radically different from the *reductionist* approach of elementary particle physics completely dominating the scene since the birth of quantum mechanics in the beginning of the last century.

Since emergence concerns the interaction of many particles, analytical methods fall short (which lies behind the reductionist obsession with a single particle hopefully allowing analytical mathematical description), while computational methods open new possiblities of simulating emergent phenomena. This book gives evidence that this possibility can be turned into reality. Computational simulation of emergence seems to open many possibilities to new insights.

19.15 Ilya Prigogine

Ilya Prigogine (1917-2003), Nobel Prize in Chemistry 1977, see Fig. (19.10) and Fig. (19.11), has questioned the rationale of Boltzmann's statistical thermodynamics, because it fails to explain emergence of ordered structures, and has stressed the necessity of microscopic irreversibility, which connects to Principe Perfeito. Prigogine writes in *Les Lois du Chaos* (Flammarion, 1994):

- *Boltzmann's attempt to explain irreversibility on the basis of reversible laws, failed.*

However, Prigogine also resorted to statistics in his own explanation, and therefore probably also failed.

19.16 Physics: Flow of Information: Computation

We understand that the evolution of a physical system can be viewed as a form of analog computation, which possibly can be modeled by digital computation. We can connect analog physics with digital computation through a concept of flow of information, which reflect the time-line of action of

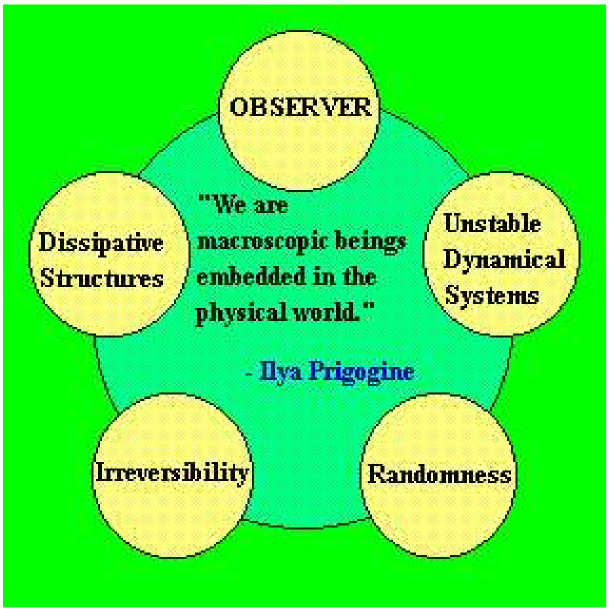


FIGURE 19.10. The World according to Ilya Prigogine.

FIGURE 19.11. Ilya Prigogine receiving the Nobel Prize in Chemistry in 1977 from the hands of King Karl XVI Gustav.

forces from one part of the physical system to another and the reaction thereof, and the flow of digits from input to output in the execution of a subroutine of the computational code.

The information flow is reprsented in the flow chart of a computer code and thus obviously is of main concern, for the programmer. Also in understanding physics it may be useful to study the flow of information, in particular, to study the minimal amount of information needed to allow the physical system to work.

For example, in the evolution in time of a galaxy of stars interacting by gravitation. each pair of stars will have to agree on their mutual instantaneous distance, but not necessarily on the distance to a third star, since this information is not needed. In [8] we that this opens to a new approach to relativity, avoiding the many difficluties of Einstein's theory of relativity. But this is another story...

19.17 Thermodynamics as a "Best of Worlds"

The above survey indicates that thermodynamics is a fundamental part of science and technology and thus serves a very important role in our society. Thermodynamics is maybe the scientific field closest to Leibniz' definition of a *Best of Worlds* as a world, which is richest in variation of ordered complex structures or emergence, such as different forms of life and conscience, while being governed by simplest possible principles or laws.

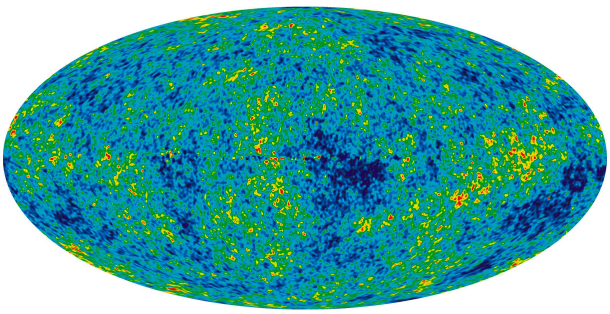


FIGURE 19.12. The Best of All Possible Worlds: Picture of the background radiation of the Universe by the COBE satellite.

20
Quantum Mechanics

> I don't like it (quantum mechanics), and I am sorry I ever had anything to do with it. (Erwin Schrödinger)
>
> ...the whole procedure was an act of despair because a theoretical interpretation (of black-body radiation) had to be found at any price, no matter how high that might be... (Planck introducing quantum of energy)

20.1 Rutherford's Model of the Atom

After atoms and *electrons* had been discovered experimentally in the early 20th century, a mathemattical theory for the atom had to be found, and for this purpose classical Newtonian mechanics was not suitable: The first idea was to view the atom like a tiny planetary system with a swarm of *negative electrons* orbiting a positively charged *atom kernel* subject to attractive electromagnetic forces instead of gravitational forces. But that did not work out, because orbiting electrons would have to radiate energy and eventually collapse into the kernel. In short, classical wave mechanics could not explain why atoms could exist and thus was a complete failure. What to do? A new crisis of physics was emerging along with the political crisis leading into the devastating 1st World War, and the Princess asked for heads.

In 1911 Rutherford presented a new model which was improved by Bohr connecting to Planck's quanta with the electrons restricted to certain *orbits* or *shells* and emitting light quanta when *jumping* from one orbit to the

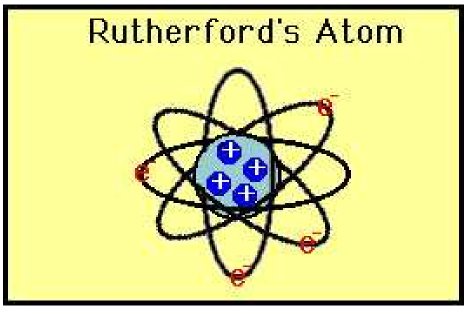


FIGURE 20.1. A positively charged kernel surrounded by a swarm of pointlike electrons according to Rutherford.

other. But it was an ad hoc model without convincing mathematical basis, and still like a little planetary system, see Fig. (20.1).

20.2 Schrödinger's Equation

In 1925 the young physicist Erwin Schrödinger presented a new form of a wave equation, referred to as *Schrödinger's equation*, which (magically) seemed to offer a useful mathematical model on atomistic scales. A solution of the *Schrödinger equation* is called a *wave function* and represents the distribution of electrons around a kernel, and more generally the distribution of electrons and kernels in any aggregate of atoms and molecules. Schrödinger's electrons thus were represented by a *wave* distributed in space and not *particles* localized in space as in Rutherford's and Bohr's models.

20.3 What is Schrödinger's Wave Function?

Schrödinger's wave equation showed to be a stroke of genius with very good predictive capabilities: By solving the Schrödinger equation you can explain and predict properties of atoms and combinations of atoms in chemical reactions, including the periodic table, more or less.

But there was one serious problem with Schrödinger's wave function: It seemed to formally depend on the distributions of all the electrons as if each electron had its own private full three dimensions of space to roam in without any access for the others. For N electrons that gave a wave function depending on $3N$ variables, plus time, thus a veritable monster for more than a few electrons. What could the physical significance of such a monster be? The next crisis of physics presented itself! What to do now?

Again statistics showed up as some kind of resolution or relief of pain: The *very clever idea* was to view the wave-function as representing the *prob-*

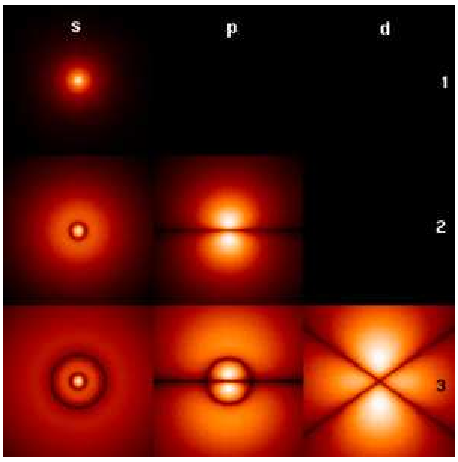


FIGURE 20.2. The (modulus squared of the) wave function for a Hydrogen electron with different energy. The higher the energy, the more spread out is the electron. It is not necessary to interprete the wave function as a probability density of a particle-like electron playing roulette around the kernel; isn't it more natural to interprete it simply as a distributed electron density?

FIGURE 20.3. Werner Heisenberg with older brother and father ready to fight in the 1st World War.

FIGURE 20.4. A model of a Hydrogen atom with one electron flying around a proton.

ability of certain electron configuration, and now the monster had a *name*, even if its monstrousity of many-dimensionality remained. This view was forcefully preached by Heisenberg and Born, while Schrödinger objected in dismay to this maltreatment of his baby, but to no effect and Born-Heisenberg wiped the table, completely.

The result is that still today the wave function is supposed to represent a probability of an electron distribution, as if particle-like electrons are playing roulette, just as game addicted gas molecules in Boltzmann's statistical mechanics, or Swedish tax payers at *Casino Cosmopol*, the Swedish State monopoly of roulette.

20.4 Formally Reversible but Irreversible

Schrödinger's equation is, just like Newtonian mechanics, formally reversible. Thus there seems to be a rewind button in quantum mechanics, which brings modern physics back to pre-Boltzmann time: If ultimately the World is based on quantum mechanics (or classical Newtonian mechanics), then it is also formally reversible.

So the old question pops up again, even with a statistical interpretation of the wave function: How can irreversibilty arise in a formally reversible system? And now there was no Boltzmann around that could that solve *that riddle* by statistics.

And there modern physics stands still today: Quantum mechanics seems to be formally reversible, but yet has to describe an irreversible world to serve as a model. The Princess wants an answer...now. But no answer is coming. And the books claiming "the end of physics" are piling up in the book stores.

It seems that physcists have pretty much given up on giving the wave function an interpretation, and seem content to say that whatever it means it gives good predictions, so why bother? But the irreversibility riddle cannot be circumvented this way: It is a *real problem* and not just a matter of one *interpretation* or the other, although there have been attempts to claim that the Arrow is just fiction and interpretation. But it cannot be.

20.5 The Crisis of Modern Physics

The crisis of modern physics may be a result of a clash or incompatibility of an idealistic world view based on exact mathematics and physics of *infinite precision*, with a materialistic world view based on mathematics and physics of *finite precision*.

An ideal(istic) mathematician firmly believes that mathematics is exact and an ideal(istic) physicists firmly believes that physics is exact. Both jump to statistics if the exactness is questioned: If you cannot express exactly what you want to say, then just choose a random quote.

We know that if idealism and materialism is not clearly separated, it fosters *hypocrisy*, that is pretending what is not. The way out of hypocrisy is to understand that idealism and materialism have different roles and that confusion of one with other leads to contradictions and irrationality.

If you cannot express exactly what you mean, then try to find as good an approximation as possible. Or if you cannot live up to your ideals, admit that, but try your best to do it andway, and do not give up completely. Simple everyday psychology, but seemingly forgotten in idealistic mathematics and physics.

20.6 Leibniz and the Nobel Prize

Is it necessary to interprete (the square of the modulus of) Schrödinger's wave function as a probability density? A physicist of today would have to say YES, since nothing better seems to be available. The reason is that the wave function *formally* depends on so many variables, $3N$ variables for N electrons and kernels, a monstrosity.

If Leibniz was active today, he would probably take another approach, based on his *monadology*, which is a world view or philosophy based on the idea that everything is made up by *monads*, which are like little immaterial atoms. Leibniz says that each monad is like a little "soul" taking in (more or less blurry) impressions from the other monads and acting accordingly. If we replace monad by electron, then this can serve as an interpretation of the wave function: each electron solves its own version of the Schrödinger equation (in 3 space dimensions plus time) to get information about the others, and that determines the action of the electron. But this is not a problem in $3N$ variables, but N (coupled) equations in 3 dimensions, which is not monstrous at all.

In this perspective each electron is like a human being and the atom with many electrons is like a group of people interacting with each other. The wave function then corresponds to the fictional quantity of the *total interaction* between all the people, which is fictional because nobody ever percieves this quantity: Each member of the group has a (more or less blurry) impression of all the others in the group, but there is no *Big Brother* that knows everything about everybody and all relations. Except possibly in the form of an (ideal) *writer* of fiction, who has full control of the totality of the interactions of all the characters. Or maybe not even a (real) writer understands completely what he has written and all the interactions?

In the same way the full wave function of all electron interactions satisfying Schrödinger's equation, does not exist. It is a fictional quantity. Nevertheless, an approximate solution can be constructed from the (blurry) interaction of each electron with the others, which is not fictional because it is constructed. This double insight of impossibility of exact solution and possibility of approximate solution, gave Robert Kohn the Nobel Prize in Chemistry 1998. This idea is followed up in [7].

21
A Challenge

I know that most men, including those at ease with problems of the highest complexity, can seldom accept even the simplest and most obvious truth if it be such as would oblige them to admit the falsity of conclusions which they have delighted in explaining to colleagues, which they have proudly taught to others, and which they have woven, thread by thread, into the fabric of their lives. (Tolstoy)

The simulacrum is never that which conceals the truth–it is the truth which conceals that there is none. (Baudrillard)

21.1 The Joule-Thompson Experiment

Before passing to Part II Solutio and Principe Perfeito, we challenge the reader by asking for an explanation of the following basic experiment of thermodynamics first performed by Joule in 1845 and repeated with higher precision together with J.J Thompson, later Lord Kelvin. This could be one of the Princess riddles. By answering this riddle the reader will be well prepared to continue to the real thing.

The experiment is very simple to describe: Joule filled a container or chamber with a gas to high pressure, let the gas come to rest at temperature $T = 1$. Then he immersed the chamber into a bucket of water also of temperature $T = 1$, together with an empty container, opened a valve between to two containers and allowed the gas to expand (all by itself) into the double volume and then come to rest, see Fig. (21.7) displaying the set-up of the original experiment. Joule measured the temperature in the water during and after the expansion.

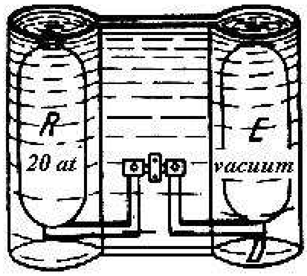


Fig. 358 Concerning overflowing experiment of Joule (Scientific Papers). *R* contains at first air compressed to 20 atm, *E* is initially a vacuum, *D* the tube

FIGURE 21.1. The Joule-Thomson experiment

What was Joule expecting to see? Of course, he was expecting to find a temperature drop during the expansion. Why? Because, as we all know, a gas cools off when it expands. This is why a spray can cools off when you let the spray out. Try it!

This is the same phenomenon, in reverse, what makes the bicycle pump warm up as you compress air into the inner tube of the tire. Try it!

A refrigerator uses this principle in the followiung cycle: The refrigerant (freon) in liquid form passes an expansion valve and evaporates to a gas while cooling off, absorbs heat from the interior of the fridg, is compressed to a liquid delivering heat to the exterior and then repeats the cycle. The net effect is that heat is moved from the interior of the fridg at low temperature to the exterior at higher temparature, thus making heat flow from cold to warm, by spending the energy to run the compressor.

Back to the experiment: To his surprise, Joule could not detect any temperature drop during the whole process. How come? That is the riddle, which we will answer below.

21.2 A Hyperreal Experiment

How are we going to find the answer? Right, by a *computational simulation* of the experiment on a computer. We can then follow what happens and come to understand the process. Computational simulation gives us a very precise and flexible laboratory for scientific experiments. This is hyperreality in the sense of Baudrillard. Let's use it.

What the computer does is to solve the mathematical equations expressing *conservation* of *mass*, *momentum* and *energy*, which is the 1st Law, by the same time-stepping procedure we used above to find the distance from knowing the velocity. What about the 2nd Law? Don't we have to satisfy that as well? Don't worry, it will come for free, and you will understand why if you continue reading.

To avoid the vacuum, which is a bit extreme, we changed the data so that initially the pressure and density in the right chamber is half of that in the left, not zero as in the original experiment, while the temperature $T = 1$ also in the right comtainer. The essence of the experiments remains the same.

We display some snap-shots of computed density and temperature. What do you see looking at the figures? Well, you see as expected the gas expand into the right chamber with the lower pressure and density, and you see that there a complex turbulent flow develops. If you continue the simulation you will find that eventually the gas comes to rest in the full volume of the two containers with the temperature $T = 1$ everywhere. Surprise? No temperature drop, at the end? Despite the expansion?

Of course you say that the temperature eventually will have to be uniformly $T = 1$ at the end with the gas at rest, just because of conservation of energy. You don't get more money on the table just by spreading it out!!

So what about temperature drop? Is there no drop? But the gas expands into the double volume, so there must be a drop somewhere on the line from initil rest state to final rest state. On the following page you the results. Take a look and analyze what you see. Remember that the total energy, which is conserved, is the sum of the *kinetic energy* (from the (larger scale) motion of the gas) and the *heat energy* or *iternal energy*, which you may think of as very small scale vibrational motion.

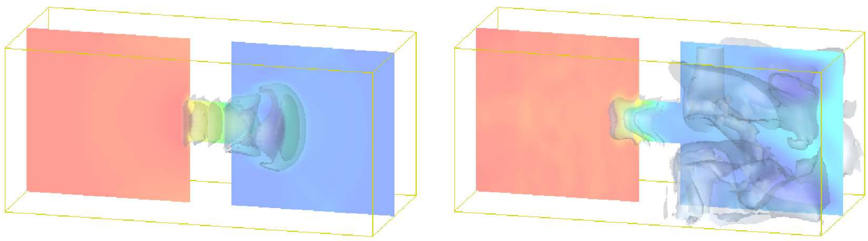


FIGURE 21.2. Density at two time instants

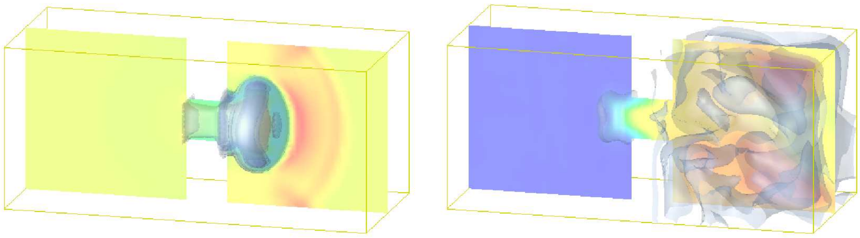


FIGURE 21.3. Temperature at two time instants

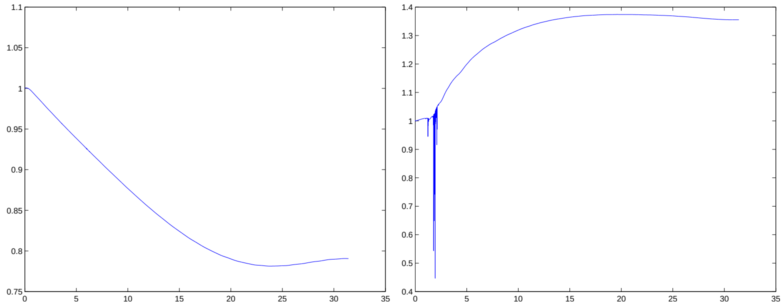


FIGURE 21.4. Average temperature in left and right chamber

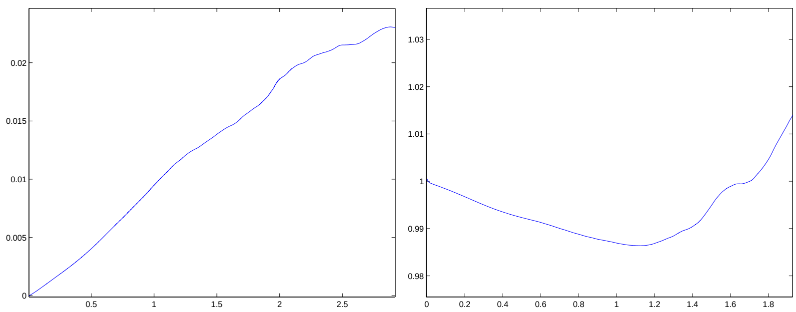


FIGURE 21.5. Average kinetic energy and temperature: short time

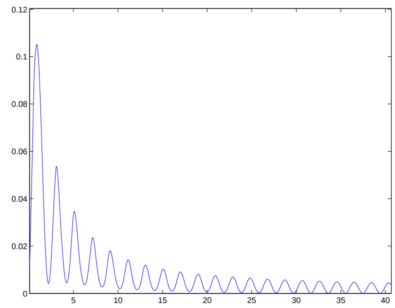


FIGURE 21.6. Average kinetic energy: long time

21.3 Analysis

So what do you see? Well you see that initially the temperature drops in the left chamber as you expect. So some internal energy is lost, and where does it go? Of course, you say that it is converted to kinetic energy, when the gas is put into motion. You also see that the temperaure increases in right chamber, and from does that internal energy come? Of course, you say that it comes from the turbulent dissipation in the right chamber heating the gas.

So you understand both the temperature drop in the left chamber and the temparature increase in the right chamber, as an interplay between heat energy and kinetic energy, which is the essence of thermodynamics. So you understand basic thermodynamics without knowing anythig about entropy. You also understand that at final equilibrium with the gas at rest in both chambers, all the kinetic energy will have been transformed back to heat energy and the temperature is back to $T = 1$ everwhere as observed.

21.4 Irreversibility

What about irreversibility? Can the process be reversed? If you sit and wait, will the gas by itself quitely return to the left chamber after its visit in the right chamber, or not? Of course, not. The gas will show no tendency to go back again. Why? This is where Principe Perfeito as a new form of the 2nd Law is needed. But not the classical based on entropy, which is difficult to understand and rationalize, but a new form, given in detail in the mathematics section below.

Principe Perfeito in this form states that heat energy can be converted to kinetic energy under expansion, but only under expansion, not compression. This makes it possible for a gas at rest under high pressure to expand, gaining kinetic energy from the internal energy and lowering its temperature. But you cannot convert heat energy to kinetic energy under compression. Thus the gas will not be able to get back into the left chamber by itself. It can get out by itself, but will not go in by itself. Only if you force it back by compression, and that takes energy.

Of course this is a familiar phenomenon: A herd of sheep will easily escape through a hole in the fence, but will not go back by itelf unless forced by a sheep dog, see Fig. (**??**).

We have now met a basic irreversible thermodynamic process of relevance in all forms of *heat engines* converting heat energy to kinetic energy. Thermodynamics originated from studies of the efficiency of heat engines, like steam engines.

More generally, life is a form of heat engine: You eat and burn calories to get your body and mental processes moving. That is an irreversible thermodynamic process. If you have understood the Joule-Thompson experiment, you have understood a good deal of thermodynamics, without thinking of entropy, and a good deal about all the processes around us and inside us which are based on thermodynamics. And you have then also understood some of the mystery of the Arrow of Time. You will understand more as you go along.

FIGURE 21.7. A sheep dog compressing a sheep herd.

21.5 What Would Boltzmann Say?

What does classical thermodynamics say about a gas expanding to its double volume? Well, it says that a gas in a bigger volume has more entropy and is less ordered, because it is more spread out. Maybe this catches something essential, but it also raises a lot of questions concerning the physical meaning of entropy and order/disorder which have no good anwers. You can stay away from this without missing anything if you instead use Principe Perfeito.

21.6 Principe Perfeito in Mathematical Form

We have already announced that the 2nd Law according to Principe Perfeito takes the following form for a closed system:

$$\begin{aligned} \dot{K} - W &= -D, \\ \dot{E} + W &= D, \end{aligned} \tag{21.1}$$

where K represents kinetic energy, E represents heat energy, W represents work performed and $D > 0$ represents the fine or cost payed for not being able to exactly satisfy the 1st Law. The work W is positive under expansion and negative under compresssion.

The 2nd Law (21.1) states that there is always a transfer of kinetic energy to heat energy, because the cost D is positive. This acts is like a tax on (high quality) kinetic energy , which is transferred to (low quality) heat energy, like a Robin Hood transfer from rich to poor. This transfer only goes one way.

The work W, on the other hand, can have both signs, but is positive under expansion and negative under compression, and the 2nd Law thus shows that the kinetic energy can only increase under expansion, and that heat energy will always increase under compression. The transfer of W between kinetic and heat energy is reversible, so that if you heat a gas by compressing it, you can retrieve the kinetic energy spent on compression, by letting the gas expand. In other words, the gas acts like spring in which you can store kinetic energy as heat energy and then release it.

The meaning of the 2nd Law in the form (21.1) is easy to understand, we just understood it, and by using it we can analyze and understand the Joule-Thompson experiment. In particular, we understand why the process of letting the gas expand and then come to rest, is irreversible. To get the gas back again, you have to force it by compression.

What is truely remarkable with the 2nd Law in the form (21.1) is that the entropy does not appear!! We can thus forget about this quantity, which makes the science of thermodynamics much better according to Ockham's principle that a simple scientific explanation is better than a complicated explanation!! Why? Because, what is simple can be understood better than what is complicated, and thus can be more useful to more people.

21.7 An Illuminating Comparison

Let us compare the Joule-Thompson experiment with an experiment you can do yourself if you just have a U-glass or something similar, see Fig. (21.8). If not, you can make a thought-experiment: Start with a volume of fluid at rest in the left half of the glass, and open a valve at the nbottom to let the fluid free. It will then swing to the right just like a pendulum and then back again. But not quite, because inevitable turbulence will develop and in each swing some kinetic energy will irreversibly be transformed into heat energy, so that eventually the fluid comes to rest in a symmetric equilibrium configuration with all kinetic energy transformed to heat energy. We understand that the dynamics is similar to that in the Joule-Thompson gas experiment, with the difference that the initial energy appears in the form of compression in the gas and as potential energy in the fluid.

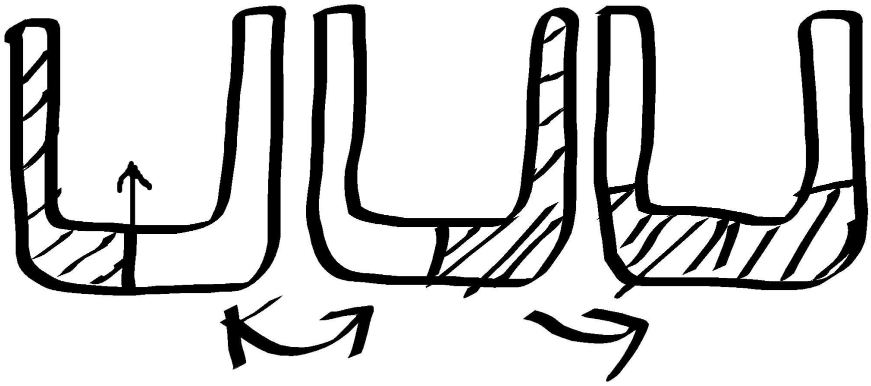


FIGURE 21.8. Water in a U-glass oscillating back and forth until it eventually comes to rest in equilibrium.

Part III

Solutio

22
Principe Perfeito

Equilibrium is the very opposite of disorder. (Rudolph Arnheim)

A life is like a wave forming and breaking on the shore. (Unknown Neanderthaler)

22.1 Finite Precision and Edge Stability

Luckily (or maybe unfortunately) none of the authors is a physicist, and so we do not have to believe in statistical mechanics and entropy as disorder, nor in any statistical interpretation of quantum mechanics including particle-wave duality. We are thus free to seek new solutions to the riddle of the Arrow of Time without resorting to the roulette table or semantic equilibristics.

What is even better, we have a clue to solution of the riddle, and we are not just searching in empty space after something which may not exist at all. The clue is of course *Principe Perfeito*, which we give yet another formulation:

- *finite precision and edge stability*,

We have already met the fundamental aspects of Principe Perfeito in the fish trap model: A basic aspect of edge stability is reflected by the fact that it is easy to get in but difficult to get out of the trap. And of course a real fish has finite precision (while an ideal fish with infinite precision would be able to escape). We met the aspect of precision also in connection with the process of separation, which may require both care and time.

We now develop Principe Perfeito using different languages, and in the rest of the book we add more body to this skeleton.

22.2 The Breaking Wave

Take a look at Fig. (22.1). You see the dynamics of a wave breaking on a shore. The dynamics follows Newtonian mechanics and thus is formally reversible. We see a *slow build-up* of the wave followed by a *quick break-down.* We understand that this process cannot be reversed. There is no way you can make the reverse process happen by changing the sign of velocity and time. so that there would be a *quick build-up* and a *slow break-down* It is impossible, yet it should be possible by reversible Newtonian mechanics.

So what does Principe Perfeito say? It says that it is because of the finite precision that the reverse process cannot be realized. To build up takes time, to break down can go quick.

The breaking wave also illustrates the concept of edge stability, at the border between stability and instability. We see that the slope of the shore determines how fast waves will break. With a small slope, it can take a very long time to build up a wave and it can keep rolling for a long time without breaking. To build up a wave is not possible it the flow is too stable; then all tendencies to create waves will be dampened. This would be the case if the fluid was not water but thick viscous syrup. On the other hand, with a steeper slope the wave forms quickly and also quickly break. The most interesting case is just in between these two cases, with a wave forming and almost breaking for long time until it eventually breaks. That is edge stability, which you see in life process: creation-life-destruction. Your life like a wave forming and breaking on the shore.

22.3 Why is the Wave Breaking?

Is it necessary for the wave to break? What makes it break? Well, we understand that the tendency to break come from the fact that the bottom of the wave is slowed down by the shore while the upper part is not, which means that the steepness of the wave increases, until the wave tips over and breaks. We are familiar with this scenario: some parts move faster than the others and the tension builds up, until something breaks.

We can see that the wave before breaking down completely, breaks just a little bit on the top, seemingly in an attempt to slow down the top and keep going for a while. But it does not really help in the long run, it has to break completely anyway, and we see little possibility to avoid this. Of course, we can slow down the process by decreasing the slope of the shore,

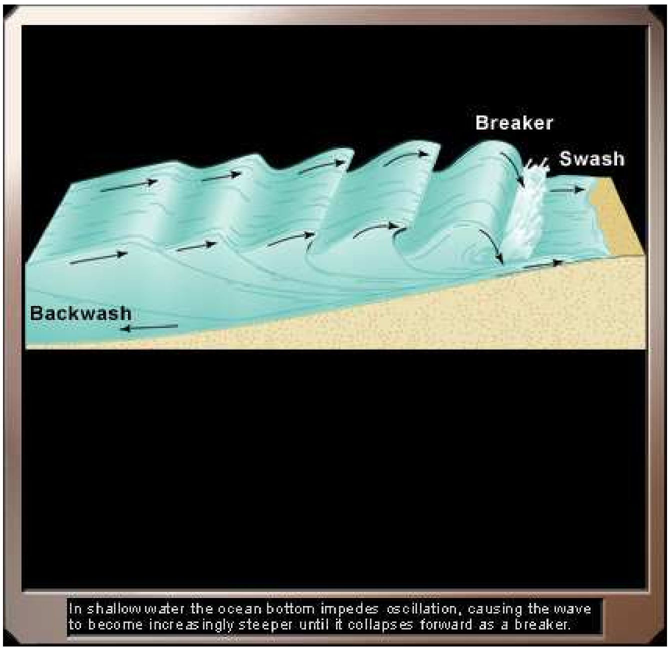


FIGURE 22.1. The Clue: Breaking Wave.

but there are practical limits to that kind of solution, and so we have to allow waves to break on the shore, since there is no way we can prevent it.

22.4 More Body to Principe Perfeito

Let us give a couple of more examples of processes which show slow creation and quick destruction:

- To write a book may take years, but it can be erased in seconds or killed by critics in hours.
- To grow up takes many years, but life can be ended in seconds.
- To tell a funny story (correctly) may take time, but the resulting laughter is over in seconds.
- The foreplay may take hours while the climax is over in seconds.
- To develop human civilization took millions of years, but it can be ended in seconds.
- To build up your body cell by cell took years, but after death you disintegrate in hours.

- To reach a new all-time high on Dow Jones may take years, but the index can collapse in hours.
- To build a sand castle can take days, but can be erased in seconds.
- To paint an oil painting may take months, but can be destroyed with one stroke of the brush.
- To build confidence in a relation can take years, but can be eliminated by one blow of your hand.

We see the pattern of Principe Perfeito: Creation requires precision and therefore takes time, while destruction does not require precision and can be quick. A process of slow build-up and quick break-down, can not be reversed, because it would require a quick build-up (reverse of breakdown) which is impossible. Build-up cannot be quick. Do you get the idea? If not take a look at Fig. (22.2) and you will understand.

22.5 Create Difference-Destroy Difference

We can express the dynamics described by Principe Perfeito as

- create difference-destroy difference,
- create tension-release tension,
- build up-break down,
- form-deform,
- paint-erase,

The irreversible nature of such processes comes from the different requirements of precision and tine: Creation requires precision and takes time, destruction does not. Creation always takes time, destruction not always. Principe Perfeito also explains *why* destruction is necessary, *why* death cannot be avoided, *why* continued creation inevitable leads to final destruction in an edge stable system.

22.6 It Takes Time to Sharpen a Pencil

Why does it take so long time to create (but so little time to destroy)? Jacques Brel answers in *Chanson Sans Paroles* why it took so long to write a love letter, too long:

J'aurais aimé ma belle
T'écrire une chanson
Sur cette mélodie
Rencontrée une nuit
J'aurais aimé ma belle
Rien qu'au point d'Alencon
T'écrire un long poéme
T'écrire un long "je t'aime"

Je t'aurais dit "amour"
Je t'aurais dit "toujours"
Mais de mille facons
Mais par mille détours
Je t'aurais dit "partons"
Je t'aurais dit "brulons"
Brulons de jour en jour
De saisons en saisons

Mais le temps que s'allume
L'idée sur le papier
Le temps de prendre une plume
Le temps de la tailler
Mais le temps de me dire
Comment vais-je l'écrire
Et le temps est venu
Ou tu ne m'aimais plus

Yes, it takes time to build a house, because you have to put brick to brick in the correct order, and there are many bricks. Yet you can blow up a house in a second and rip the bricks apart. Glueing together takes time, ripping apart does not.

When you rub your hands to warm them by friction, you rip molecules apart, which creates heat, but you cannot reverse the process and rub your hands by heating them, because you cannot reverse the ripping. You can rip a piece of paper apart in a second, but you cannot unrip it exactly even if you have a life time, letting each pair of atoms ripped apart meet again. Ripping families apart to different camps, can never be fully reversed.

22.7 Scale and Finite Precision

We shall below in the mathematics part of the book study the notion of finite precision with higher precision than in this preliminary study. We shall then see that precision is connected to the space scale of a certain process. The *macroscopic* scale of a volume of many atoms, which could be a *meter*, is different from the *microscopic* scale of individual atoms, which could be a *nano-meter* $= 10^{-9}$ meters. This means that a precision of 10^{-9} meters may seem like low precision for an atom, that is microscopically a

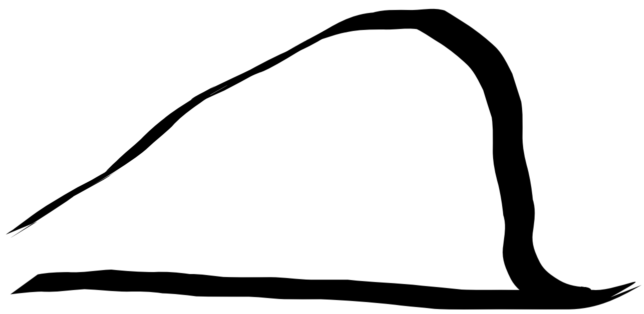


FIGURE 22.2. Irreversible life-death dynamics: slow build up followed by quick decay.

low precsion, but of course on a macroscopic scale of meters, it may seem like a very high precision.

22.8 Finite Precision instead of Statistics

The effect of this that natural laws may be of very high precisison macroscopically, but of low precision microscopically. This of course makes a connection to the microscopic games of roulette of statistical mechanics, but it does not throw determinism over-board, only takes the precision relative to the scale into account. This way it is possible to achieve, what statistical mechanics seeks to achieve, and more so, without paying the very high price of indroducing microscopic games of roulette, thus following *Ockham's razor* of scientific economy.

22.9 Microscopic Irreversibility

The key point, which we will develop in more detail in the matheamtics part, is that a *formally reversible* system like Newtonian mechanics or quantum mechanics, can be *practically irreversible*, because on microscopic scales the natural laws *can only be satisfied to a very low precision*, barely at all as we will see, and the fine for violation acts like a dissipative effect. Moreover, the dissipative effect is not small and cannot be diminish by introducing finer scales. The impossibility of time reversal will remain even if you improve the precision of the Clock. When you make the Clock more delicate and precise in order to reverse it, you will find the increased precision is cancelled by the delicacy of the machinery with more little things can get tangled under reversal.

Now, of course you ask, *how* can the individual molecules "know" that they cannot satisfy e.g. Newton's law? They will try their best but will

FIGURE 22.3. Lenin creating increased tension in 1920. (Trotsky to the right of the podium was later removed from the photo by reversing his presence.)

not succeed, but why can't they succeed? Because of tension, because of difference: The fluid particle of a whirling turbulent flow lives with very strong velocity gradients with nearby particles moving with vastly different velocities. That is the nature of turbulence. And because a fluid particle has to interact with nearby particles to satisfy Newton's law, it will find it impossible to find the equilibrium of exact satisfaction; all fluid partiucles try their best to satisfy the law, but they can't make it because their environment is changing so fast.

This is like an individual in a society undergoing a revolution: the individidual may not understand anything of what's going on, but surely will note an increased tension everywhere and a resulting difficulty of getting things right. And a child in a marrige breaking down will note the increased tension without understanding the issues, and will not perform well at school...There are many examples of this phenomenon.

The net result that irreversibilty may arise in a formally reversible system, because by the complexity of the flow, the natural laws cannot be satisfied exactly (i.e. there is no exact solution), and the fine is irreversible dissipation. The price for not being able to satisfy the laws is that you have to go forward in time and leave your shortcomings behind. In other words, you have to "loose time", because you are not perfect.

Or put it the other way: You have to pay the dinner you are enjoying in terms of not only money but also time, and in a way you want it to last long, but not too long... because you also want the pleasure of digesting the dinner...which also takes time...

22.10 Edge Stability

A capitalistic economy can be viewed to be edge stable. In general terms, a process is said to *stable* if it does not change much under perturbations, while it is *unstable* if it changes a lot under very small perturbations. Stability thus concerns the *growth of perturbations*: if perturbations don't grow or even shrink, then the process is stable, and if small perturbations can grow large, then the process is unstable. An edge stable process is on the border between stable and unstable, neither very stable nor very unstable, somewhere between *order* and *chaos*.

Since edge stable processes are almost unstable, they need to be controled, and the control amounts to a price to pay or a cost to take like paying interest or tax. We shall below meet more examples of edge stable processes including *life* and *turbulent flow*.

23
Equilibrium

Jag säger ofta till mig själv
Jag är i jämvikt, allt balanserar

Vi säger ofta till oss själva:
Det är i jämvikt, allt balanserar
de översta stenblocken balanserar
på de lägre stenblocken, de lägre
på några som är ännu lägre, och de i sin tur,
tja! Vilken märklig byggnad,
vilken mäktig linje, vilken utmaning,
och tänk att den står, det skulle man inte tro,
om man inte visste att allt är i jämvikt,
allt balanserar, och hur skulle det annars gå?

(L.G. Varma rum och kalla, 1972)

23.1 What makes the World Go Around?

We said that change is time, but why do things change? What makes the World go round? Well, you may say that it comes from a search or drive to equilibrium: Everything, everybody, ultimately is searching for equilibrium. Is it a deep thought? Not really, it just says that if a body B is not in equilibrium, then there must be some forces acting on B which do not balance, and then B is moving so as to decrease the imbalance, and that is towards equilibrium with full balance. The idea is to decrease tension to reach equilibrium with no tension. Simple.

But why is then not everything stand-still in equlibrium since long? A static World without change and thus without time. Well, that happens sometimes, that a system comes to stop, and find an equilibrium, but not always evidently, since in fact the World goes around.

We have already met the basic example of an unsuccessful serach for equilibrium: A pendulum or a clock. Why does not the clock stop? Why does not the pendulum come to a halt? Well, it tries, but does not succeed. Just as in our lifes we all strive for happiness (to be in equlibrium), but rarely really succeed.

23.2 The Wealth of Nations

Adam Smith's *The Wealth of Nations* marks the birth of the economical theory of the industrial revolution. The central idea is that an *Invisible Hand* will lead a *free economy* of *economical men* to equilibrium with supply and demand in balance. We know that economies follow cycles like a (slowly swinging) pendulum, which shows that equilibrium is never attained, but the drive to equilibrium is there.

We return to economy below with particular focus on the Arrow in economies in fruitless search for equilibrium and in need of stabilization to minimize oscillations, by Keynesian control of government spending or Friedman's monetary control. We will see that an economy has an Arrow and thus a study of the dynamics of an economy is helpful in understanding the nature of The Arrow (which is our objective).

23.3 The Flag

The waving flag is an example of a system seeking equilibrium but never succeeding: The static equilibrium is a flat flag in the direction of the wind, but that is unstable and instead the flag waves from one side to the other, always searching equilibrium but never succeeding. In a *Perfect Sweden*, flags would not wave but stay flat and still, but that country does not exist (fortunately).

The flag is also a model for turbulent flow: a flow searching equilibrium but never succeeding, and therefore oscillating. In fact the wavy motion of a flag is caused by turbulent motion of the air around the flag. Without turbulence the flag would be flat.

FIGURE 23.1. Dynamics of the Swedish society. In a perfect society the flag would be flat.

24
Order and Disorder

> We abandon the past, but the past does not abandon us. (Erwin Strittmatter in *Doré's Bible* by Torgy Lindgren)

24.1 The Classical 2nd Law

The classical 2nd Law as interpreted by Boltzmann states that Nature has a tendency to move from order towards disorder. This is supported by the observaton that if you leave your car in the street for a longer time, it will fall apart, by itself.

True, but what about the other things that do not fall apart just because you do not attend to them. What about your children who can take care of themselves, without much of your good advice, or the flowers in the fields and the birds in the sky? They do not disintegrate just because you are not looking after them. And the crystals forming on your window in the winter, and the waves forming on the sea? Is that disorder? Does everything fall apart?

Of course not: There are two forces in Nature, Brahma for creating order and Shiva for destroying order. There is not only Shiva as in Boltzmann's utterly pessimistic world steadily approaching "heat death", but also the possibility of order from chaos. Principe Perfeito expresses the balance (or battle) between Brahma and Shiva, between creation and dstruction, what gives the World such an interesting dynamics.

24.2 Unfortunate Terminology

The terminlogy chosen by Boltzmann is very unfortunate, because order and disorder are so ill-defined concepts, with the negative connotation of disorder making you believe that everything that can go wrong will go wrong. The advantage of ill-defined concepts is that they can be used to fool people, but doing so you may also fool yourself.

You could say that creating difference is like creating order, and destroying difference is like destroying order. Thus creating difference would correspond to t decreasing entropy and destroying difference would correspond to increasing entropy. The classical 2nd Law states that only the former can occur (in a closed system), and thus would prevent creation of difference or creation of order.

But you see creation of difference or order in many processes, and thus Boltzmann has a problem with his entropy as disorder: How about oder? How can order be created?

If you look into the literature on this subject, you find no answer, or an answer suggesting the state of the Universe created at Big Bang was very ordered and after that there has only been erosion to more disorder. This is no more than "believing in ghosts". Or what do you say? Why was there so much order initially? By chance? What was the probability for so much order initially?

24.3 Principe Perfeito instead of 2nd Law

We thus suggest to not use the terms order and disorder, which means that you can stay away from Boltzmann's entropy, and you are relieved from the very difficult taks giving this concept an interpretation, which drove Bolzmann to the end of the line. And you can safely forget entropy, because you can explain irreversibility instead by Principe Perfeito, which is much more understandable, and therefore possibly better from scientific point of view. Why make things so complicated if you can avoid it?

25
Time vs Space

> The distinction between past, future and present is only an illusion; even if a stubborn one. (Einstein)

25.1 Space-Time of Relativity

We must say something about the relation between time and space, since the idea of space-time of relativity theory is so utterly confusing.

25.2 A Time-Line

We can draw a time-line on a piece if paper with for example the years from the birth of Christ at time $t = 0$, over the Battle of Hastings at $t = 1066$, Einstein's Nobel Prize at $t = 1922$ to our time $t = 2007$, with all the years neatly lined up in increasing oder like numbered beads on a string. Or we can make cuts in a sequence on a log like Robinson Crusoe on his lonely island, see Fig. (**??**).

We can also pick our calendar an get a spacial representation of the year to come. We are very familiar with this representation of time as a line in space.

Since space travel is possible, and time is a line in space, maybe also time travel is possible? Just move along the line and you can go anywhere you like, backwards or forwards in time, right?

Yes, space is not directed; you move to the right or left on your walk through the desert. But that does not say that you move backwards in time, that time is not directed, unless you believe that time is like space. But physicists believing in the "ghost of relativity" do that: They believe that space and time are hopelessly intertwined into space-time. They believe that maybe time travel is possible, like traveling with your pen in your calendar. What do you say?

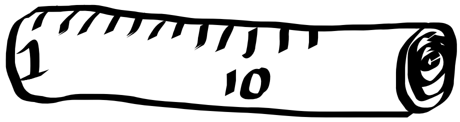


FIGURE 25.1. Robinson Crusoe's spatial representation of time.

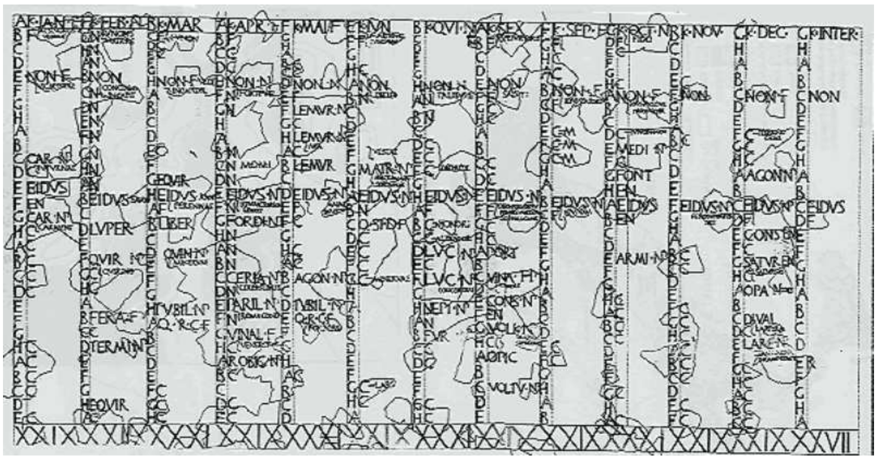


FIGURE 25.2. Spatial representation of time in a Roman calendar.

26
The Arrow and Cause-Effect

He who never made a mistake never made a discovery. (Samuel Smiles)

What makes the the cause the cause and not the effect in a cause-effect relation? You may that the cause comes *before* the effect, so if we know the Arrow, then we know if the cause can be a cause. What comes later cannot be the cause of something occuring earlier.

So we have to consider an irreversible process of cause-effect, because in a reversible process, we can change the order and let the effect preceed the cause. An example, where we cannot say what is cause and what is effect, without changing view all the time, is the reversible motion of a pendulum, where potential energy is transformed to kinetic energy and back again. We cannot say that the potential energy always is the cause of the kinetic energy, as little as saying that the kinetic energy always is the cause of the ponetial energy. In a reversible process the directionality in cause-effect ceases to be meaningful, since it can be reversed.

We recall some examples of irreversible cause-effect processes:

- bake a cake - eat and digest that cake,
- write a poem - erase that poem,
- rub your hands - feel the heat,
- put milk in your coffe and stir - get café crème,
- say something nice to somebody - see the the warmth in the eyes,

- decide to lift your arm - do it,
- stretch a piece of paper - rip it into pieces.

In all these cases the irreversibilty comes from the fact that the reverse process would require a precision that you cannot reach. For example to undigest and uneat a cake requires a new unseen reverse metabolism of incredible precision, as well as unbaking and unmixing the ingredients would require a reverse bakery of extremely high precision.

How about deciding and then lifting your arm? The reverse process would be to see your arm lowering itself (seemingly without cause), whereupon you would say that you have no intention to lift it. Weird? Is precsion involved here? Probably so, because to decide to lift your arm takes precision; there are so many things you could do, so to come up with the idea to lift your arm requires high precision. To actually do it is not so difficult unless you are a dancer and want to do it in a specific way (which takes even more precision to initiate...).

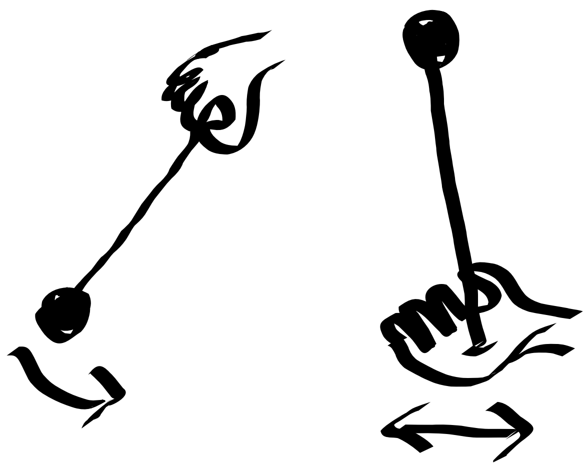


FIGURE 26.1. The motion of a normal pendulum is reversible, but that of a balanced inverted pendulum is not.

27
Past, Present and Future

The most insignificant presence has over the most significant past the advantage of reality. (Shopenhauer)

There is something essential about the now, but whatever it is, it lays outside the realm of science. (Einstein)

Events in the past and future have to be every bit as real as events in the present. (Paul Davies)

Time travels in divers places with divers persons. I'll tell you who Time ambles withal, who Time trots withal, who Time gallops with, and who he stands still withal.

27.1 Time is One-Dimensional

If we agree that Principe Perfeito makes time *directed*, let us draw some logical conclusions from this directedness. First, anything directed is essentially one-dimensional. This is because a direction is given by a *vector*, and a vector is one-dimensional, like an arrow.

So time being directed, cannot be two-dimensional like a plane. Of course, you *can* direct also a plane by putting in arrows everywhere, but time would have to flow in the direction of the local arrow and thus trace a directed curve, a one-dimensional curve, or time-line, see Fig. (27.1). It is conceivable that people in other galaxies may follow a different time-line, but we may not have to worry about that. With the GPS UTC universal time all around the Earth, we all follow the same time-line.

We conclude that time (on and around the Earth) can be represented by a directed line: a *time-line*.

27.2 The Now

Given any point on a time line, say $t = 0$, you can say that $t = 0$ represents *now*, $t < 0$ represents the past and $t > 0$ the future. This is because the time line is directed.

Now, what is the *now*? You would like to say that it is the point on the time line where you happen to be. How do you *know* at what point in time you are? Well, you look at your watch. If it says $t = 23h$, it means that it is time to go to bed. You get that information from the physical sensation you get from watching the reading of the watch. So the *now* is related to the physical sensation you have from being *present* in physical space just at the right time to get the sensation that you are there. Simple, my dear Watson. And it all comes from time being one-dimensional and directed, and that comes from Principe Perfeito.

When you came one hour late to the departure of your flight, then you missed to be present at the right time at the right place, and you know that because you missed the physical sensation of taking off feeling the acceleration. Right? The now comes from the directedness of the time-line.

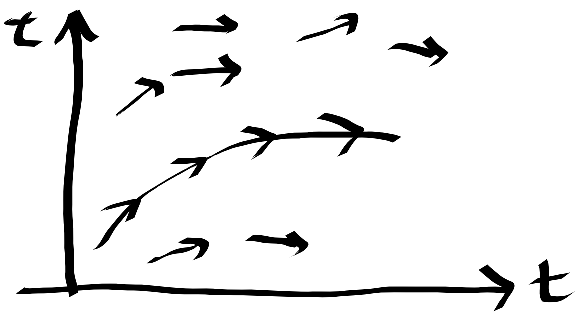


FIGURE 27.1. The Earth time-line imbedded in possibly two-dimensional time.

Part IV

Theme With Variations

28
Capitalistic Economy

28.1 Why Do You Have to Pay Interest?

We start with the area of *economics* because it is so familiar to all of us, yet illustrates essential points. We all know that you have to pay interest on a loan, but why is this necessary?

Well, to seek an answer let us make a *reversibility test*: Suppose we change the direction of time in your morgage plan for your house. Then you would *receieve the interest* instead of paying it! Wonderful, but you probably say that would be a bit too good to be realistic. It would be like having a *negative interest rate.* The Japanese economy has been approaching zero interest rate, but the rate has remained positive. With a negative interest rate, you would earn more the more debts you would have, which would lead into an exploding spiral of debts and revenues. An economy with negative interest rate would be unstable, and thus can not exist over long time.

We have now understood that the interest rate defines an Arrow of Time in an economy: The economy evolves forward in time with positive interest rate. But why does the interest rate have to be positive?

To seek an answer, we first specify what we mean by an *economy.* We decide to consider a *capitalistic economy*, rather than a *socialistic plan economy.* In a capitalistic economy indidividuals or groups of individuals can make money from a (more or less) unique product or service, that is, by *differentiation*, cf. Fig. (28.2). This is Adam Smith's free-market system with its "invisible hand" through which the pursuit of private interest pro-

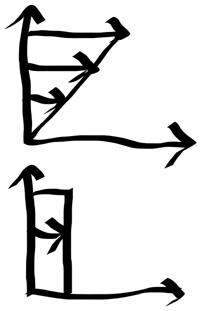


FIGURE 28.1. Capitalistic vs socialistic economy.

motes the public good. In a socialistic economy nothing of this is possible, because everybody is equal and differentiation is not allowed.

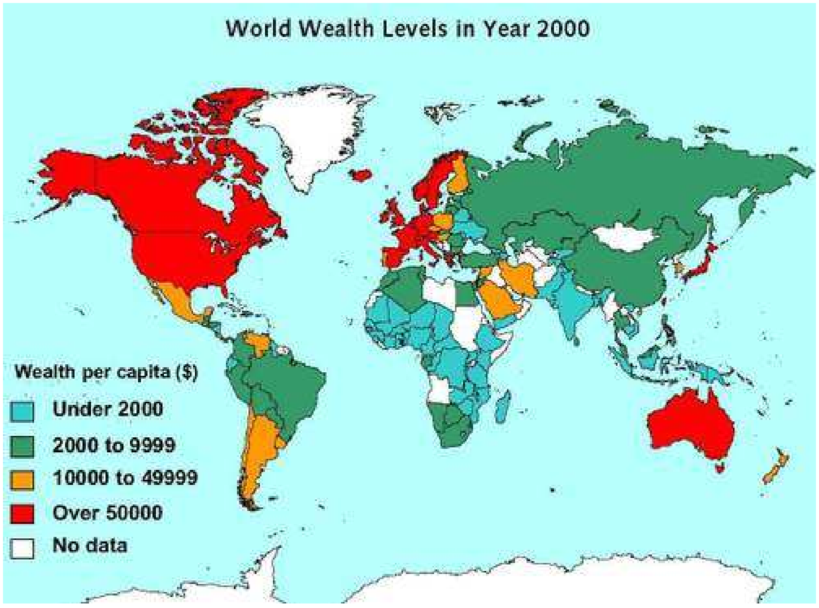


FIGURE 28.2. World distribution of wealth.

We thus consider a capitalistic economy which is growing by differentiation through division of labor and specialization, making some people very rich. Now, why is it necessary with a *positive* interest rate in such an economy? One answer is that if you can borrow money at no cost, then you can implement your unique idea on any scale and thereby become infinitely rich in finite time. But that would be an *unstable economy*, which could not exist over long time.

28.2 Interest as Entropy Production

Taking a closer look on what role the interest rate may have, it appears that it is rather a cost for borrowing more money than your neighbor, than a cost proportional to the absolute amount you borrow. This is because if everybody borrows the same amount, it is like rescaling the value of the money or simply changing currency. In capitalism everything is relative and you have to put a cost on relative difference, by tax or interest rate.

In any case, the Federal Reserve Bank of New York monitors the interest rate with the aim of generating a steady stable growth. A lower rate will accelerate the economoy and a higher rate will slow down the economy, and a zero or negative rate is not allowed.

A capitalistic economy has the feature of *edge stability*, that is, it is not too stable nor too unstable, and also the feature of *finite precision* related to the degree of differentiation which is allowed, which could be measured e.g. by comparing the salary of a CEO with that of an ordinary employee. A capitlistic economy thus is an example of a process combining finite precision and edge stability.

We now suggest to view interest as entropy, cf Fig. (28.3). As you run your business you pay interest on your loans, which you can view as a form "loss" which you can name "entropy". Paying positive interest or "producing entropy", then defines the Arrow of Time. And you have to pay entropy in order to avoid going out of business.

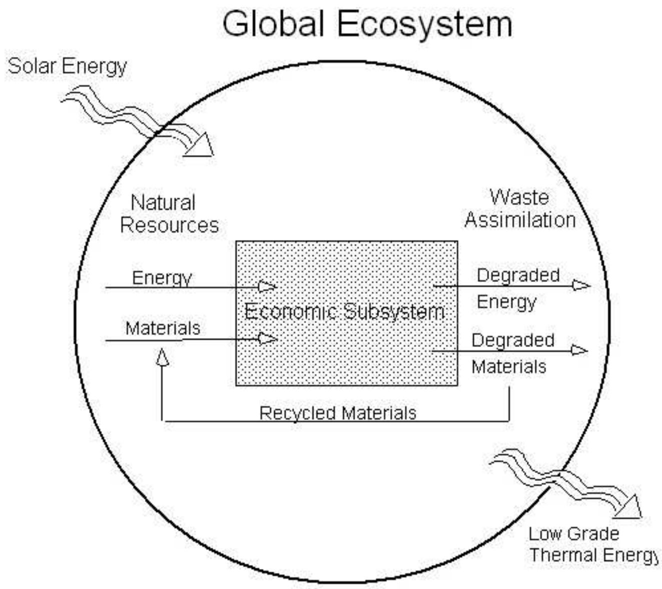


FIGURE 28.3. Economy as a subsystem of a global ecosystem.

If you agree to define entropy as (accumulated) interest, then entropy is not a state variable: The amount of interest you have payed to run your business over a period of time can vary depending on what credit policy you were following, even if the end state is the same. Entropy is not a state variable but measures the necessary payments (interest, tax, bribes...) you have to make to run your business. In this sense you always produce entropy, but the amount can vary depending on what route you are following from one point to another.

To sum up, we can say that a capitalistic economy grows by differentiation, and the degree of differentation represents a form of finite precision. Infinite precision would allow an economy with infinite differentiation, but such an economy would be unstable and cannot exist. There are idealists who believe taking interest on a loan is a sin, but their society has not become a reality.

There is one more point to understand: Differentiation results from sharpening of differences, and to get started you need some initial differences which you can sharpen to increase differentation. This is because the differeniation is done by processes of *migration* or *mixing*, which is different from simply different rates of growth. To illustrate we consider a basic example:

FIGURE 28.4. Capitalism: Runner 1 to 8 lined up for a 100m dash ordered according to speed, with the fastest runner on track 1 and the slowest on track 8, and with a difference of 0.1 seconds in total time between two consecutive runners and 0.7 seconds difference between runner 1 and 8.

28.3 The 100 meter Dash

Let us line up 8 runners transversally on a track for a 100m dash, according to their repspective speeds, with the fastest runner on track 1 and the slowest on track 8, with a linear distribution in between with 0.1 seconds difference in final time between nearby runners, see Fig. (28.4). Start the dash start and assume the runners stay on their tracks. They will then line up at the end with the same linear distribution of speed transversally.

If the runners are no longer required to stay on their tracks, a slight displacement during the race can change the transversal ordering at the end, so that the fastest runner ends up next to the slowest. If this happens, then the differentiation has been sharpened from 0.1 to 0.7 seconds by migration only, and not by changing the speeds of the runners. We thus understand that differences may get sharpened by migration. Sharpening of difference can arise by migration from one population into another of people, goods or ideas.

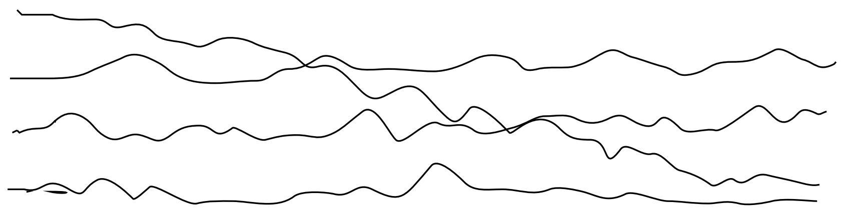


FIGURE 28.5. Principle of migration: track on top slowly approaches track at the bottom and the relative difference is increased.

28.4 The Invisible Hand of Adam Smith

We can formulate Adam Smith's principle of the *Invisible Hand* of the free market as follows: Difference allows making profit by redistribution. This process tends to decrease difference, which is countered by increasing difference by migration with interest rate control. There is always some initial difference from which growth may arise, except in a fully uniform society.

You can view entropy as the accumulated "losses" in the form of e.g. interest you have to make to run your business or economy. By paying the price of producing entropy you maintain stability. An economy refusing to pay entropy is unstable and goes out of control because of the finite precision. With infinite precision an unstable economy could be run, but not with finite precision.

We suggest to formulate the principle of the Invisible Hand as: finite precision and edge stability.

29
Time-Periodic and Cyclic Processes

A *time-periodic* is a process which returns to a previous state after some time and then repeats itself. The seasons variations is a time-periodic process.

In a *cyclic process* a substance is moving in a closed loop and returns to a previous location after some time. There are many cyclic processes including

- the flow of money in an economy, see Fig. (29.1),
- the carbon-oxygen cycle, see Fig. (29.2),
- the nitrogen cycle, see Fig. (**??**).

The losses in a cyclic or time-periodic process define the Arrow of Time of the process. A lossy periodic or cyclic process is thus irreversible, although it repeats itself. Of course this requires interaction with the environment to compensate for the loss. A closed system, without any interaction with any environment, cannot be both irreversible and period/cyclic, but an open system with interaction can.

29.1 Circular and Linear Time

A time-periodic process may be viewed to represent *circular time*, like a classical clock with a period of 12 or 24 hours, while a digital clock can be viewed to represent *linear time* always increasing and never returning.

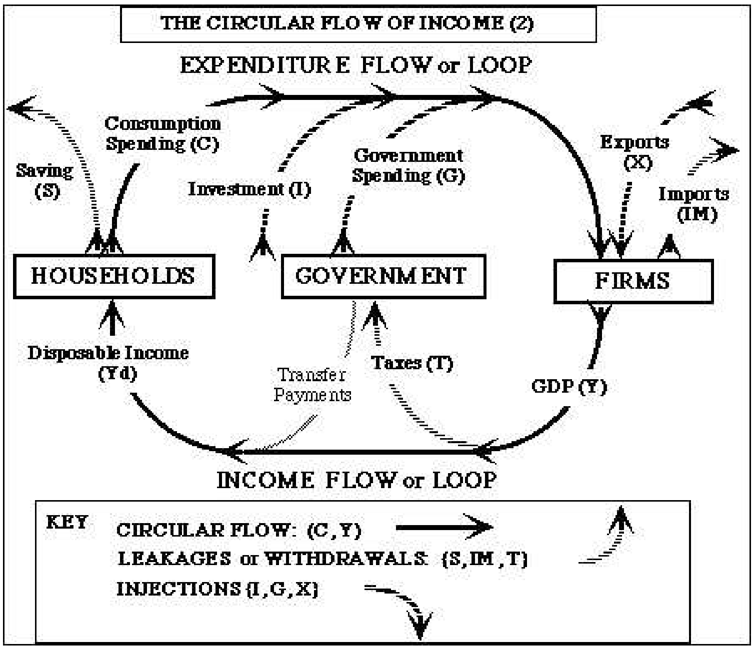


FIGURE 29.1. Cyclic flow of money.

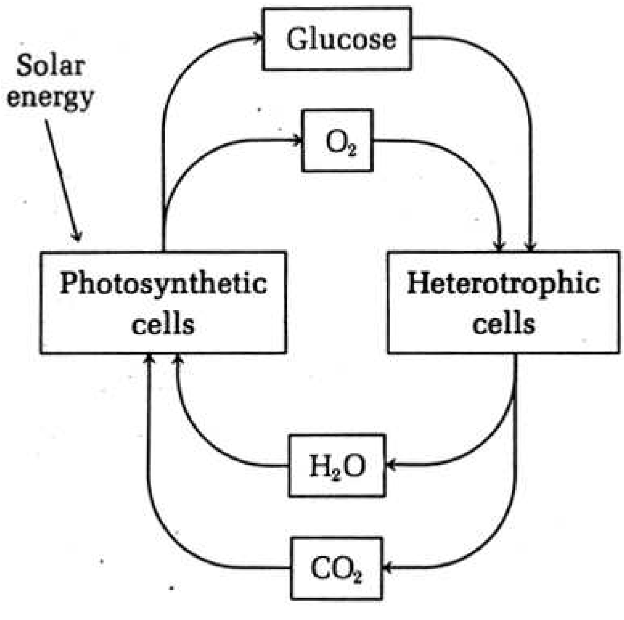


FIGURE 29.2. The carbon-oxygene cycle

29.2 Male and Female Conceptions of Time

You may (conventionally) connect linear time with the psychology of a result-oriented male always seeking to come to a final conclusion at the end of a line, and periodic time with female psychology understanding the dynamics of birth, life, death and new life in a circular process.

FIGURE 29.3. Female conception of time.

FIGURE 29.4. Male conception of time.

29.3 Finnegans Wake

The last line of James Joyce's *Finnegan's Wake* reconnects to the first line and the drama restarts:

- *riverrun, past Eve and Adam's, from swerve of shore to bend of bay, brings us by commodius vicus recirculation back to Howth Castle and Environs. Sir Tristram, violer d'amores, fr'over the short sea, had passencore rearrived from North Amorica on this side of the scraggy isthmus of Europe Minor to wielderfight his penisolate war; nor had topsawyer's rocks by the stream Ocone exaggerated themelse to Lauren County's gorgios while they went doublin their mumper all the time: nor avoice from afire bellowsed mishe mishe to tauftauf thuartpeatrick: not yet, though venisson after, had a kidshad buttended a bland old isaac: not yet, though all's fair in vanessy, were sosie sesthers wroth with twone nathanjoe. Rot a peck a pa's malt had Jhem or Shen brewed by arclight and rory end to the regginbrow was to be seen ringsome on the auqaface. ....There's where. First. We pass through grass behush the bush to. Whish! A gull. Gulls. Far calls. Coming, far! End here. Us then. Finn, again! Take. Bussoftlhee, memmemormee! Till thousendsthee. Lps. The keys to. Given! A way a lone a last a loved a long the (riverrun)...*

In circular time the order from past to future is lost: "Sir Tristram had not yet rearrived...". Does 1 o'clock come one hour before 2 o'clock or eleven hours after?

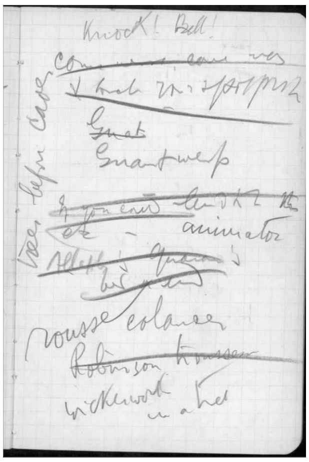


FIGURE 29.5. Creation and destruction of information in Finnegans Wake.

30
Poetry Time Dynamics

30.1 Mechanical Time vs Time of Life

Urets gång är ett konstgjort
hjärtas gång, men hjärtat
är verkligt, en vandring
genom den ödemark,
vi kallar tid.
(Gösta Ågren 2007)

30.2 Actual vs Possible

Vad livet och stunden gav
kan ingen ta ifrån oss.
Så levde och tänkte de gamle.
Sant. Och oss kan ingen befria från
vad livet och stunden kunde ha gett. (Ekelöf)

30.3 Passage of Time

Tidens framfart var det isen stormarna
Jag kom till Dig med det jag har och saknat
med allt som upphör och är kvar

Så är livet byggt
Isen suckar och kvider snön är en psalm
i vintermörkret
Jag såg dig komma mot mig en vinterkväll
i staden
Det var vad jag såg
Du mötte mig du tog emot mig vi fortsatte
genom tunneln
Under gatan är det tyst och stilla som efter
ett attentat
Åldrandets avståendets tillgivenhetens
logistik
Jag såg dig komma mot mig en vinterkväll
i staden
Det var vad jag såg
Tydligare än så blev det inte
Tidens framfart var det isen stormarna
kärleken
(Claes Andersson)

31
Writing a Novel or a Poem

> The art of doing mathematics consists in finding that special case which contains all the germs of generality. (Hilbert)

31.1 Is There an Ideal Writer?

Writing a novel or a poem is a creative process, where you differentiate or select a sequence of words from a set of possible sequences, until you are satisfied or exhausted. Along the way you produce waste in the form of discarded possibilities accumulating in your waste basket representing entropy. A writer must have a will or drive to write, a drive to differentiate, but also needs to destroy what has been written, which is no good or takes to much space. The *ideal writer* would never throw anything he has written, because everuthing he writes is perfect. But that writer does not exist: if the writer never throws anything, then his books cannot be perfect. Again writing defines an Arrow of Time by the process of creation-destruction.

31.2 Creation and Destruction of Information

Differentiation enhances difference and thus creates *information*. An painter starts with a sketch and adds details upon details until satisfaction. The smallest details have a finite size and the painting is of finite precision. A painter seeking infinite precision cannot finish any painting and thus succombs.

The painter has to *destroy information* in the sense that there are details in the motif which he decides to leave out. Information can be destroyed by a process of dissipation where sharp constrasts are smoothed out decreasing the amount of detail. This process can be viewed as a form of entropy production, which as always defines an Arrow of Time: A detail which has been smoothed out cannot fully be recovered.

32
Rythm

32.1 The Beat

The sequential character of *music* is shown by a conductor marking the *beat* or *rythm*, while following the *bars* of the *score*, each bar being divided into a number of beats: 2 in *two-step*, 3 in *waltz*, 4 in *foxtrot*, and 5 and 7 in e.g. Greek folk music.

A steady 4/4 beat does not have an Arrow, and sounds the same if played in reverse. More complex pattern have an Arrow and sound strange in reverse.

32.2 Metronome

A *metronome* is a *pendulum* for which the *effective length* can be regulated by shifting a weight to make the pendulum swing back and forth at different rates from *largo* at 40-60 periods to *prestissimo* at 200-208 periods per second. Below we will see that the length of a pendulum scales like the inverse of the frequency squared so that a shorter pendulum swings quicker, as can be seen in Fig. (32.1).

32.3 Timing and Polyrythm

In *jazz music* the beat is supposed to be very steady, but on top of the steady beat there is a lot of off-beat *syncopes*. The precise *timing* of these syncopes is what gives the *swing*.

Jazz is a combination of African and European music, with the rythmic complexity coming from Arica and the harmonic complexity from European classical music. The rythmic complexity is expressed in *polyrythm* with both 2 beats and 3 beats in a bar at the same time. This is called “triol-feeling”.

I classical music, the beat is either steady or more flowing, with less of syncopation. A classical composer wanting to add a flavor of jazz adds syncopes.

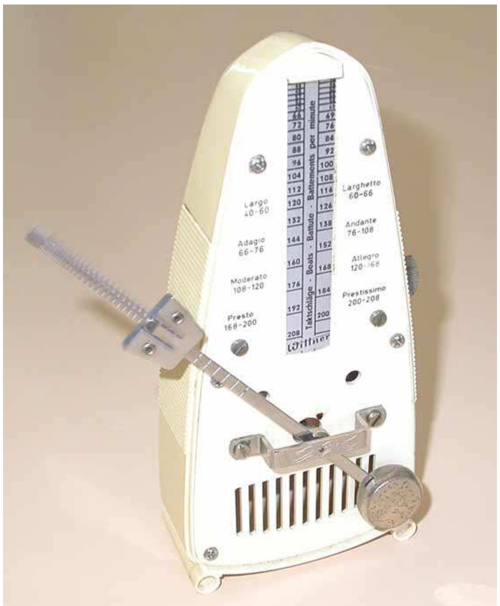


FIGURE 32.1. A metronome. Notice the scaling: the effective length of the pendulum scales like the inverse square of the frequency making the scale look sparser for higher frequencies.

33
Music

33.1 Cadenza

A steady 4/4 beat will sound the same in reverse, but if you add melody and harmony, it will in general soound strange in reverse. A melody may up and then down, and such a movement will be the same in reverse, but of course many musical phrases will sound very different in reverse. Hpw about harmony? Is there an Arrow in a the most common harmonic progression? Let's see:

The most common sequence formed by three chords in the key of C that every guitar player knows is: C, F, G7 and then back to C. This is a *cadenza* or sequence of chords which starts "at home" with a C major chord consisting of CEG, then builds a tension by going away from home from the C major chord to a F major chord consisting of FAC with the the new note F a half tone above E as the most important alteration, and then increases the tension further to a G7 chord consisting of GHDF with the new important note H a half step below C.

The G7 chord has the two notes F and H, which are a half step away from the C and E in the C major chord. Therefore G7 has *maximal tension* and seeks to be resolved into a C major chord by F moving down to E and H moving up to C in halfsteps. The diminished fifth HF is resolved into the third CE. HF is felt more dissonant and wants to be resolved into the harmonious third CE. In freqencies, the two notes of the third CE has (close to) the ratio 5/4, while the diminished fifth is (in the temperate scale) nothing less than the weird $\sqrt{2} \approx 1.41$. Thus the third is much more "at home" than FH which is "out".

It is now important to notice the chord change C to F to G7 to C, which is like an gradually increased tension (C to F to G7) followed by a more abrupt resolution of tension G7 to C. We are familiar with this pattern.

Music is to create tension and to release tension, in melody, harmony and also rythm. To create tension is to increase difference, to release tension is to decrease tension. You may say that to relase tension is to create order and reach equilibrium, and to create tension is to create disorder and leave equilibrium. Completely opposite to Boltzmann!!

FIGURE 33.1. Irreversible Cadenza by Haydn in C major with C, F and G7 chords.

34
Life

De mjuka delarna ska multna bort
de hårda delarana skall återstå
men tiden går sin gång och inom kort
de hårad delarna till mull förgå.
Och snart är deras sångkör lätt förlöst

till trädens kronor och vartenda blad
berättar för en vind som går förbi
hur döden glömd i sommaren susar glad.
Glömsk av sig själv den vackra sommaren går

så livets ande, lika ogripbar
som vackra somrar som har dragit bort
och komma farande på nytt vart år.
(Harry Martinson, Aniara)

34.1 The Will to Live

Life processes involve growth, division and differentation of cells formed by photosynthesis and/or chemical reactions from organic and non-organic substances, cf. Fig. (35.1). Life consists of both the process of creation-growth increasing difference and destruction-decay decreasing difference. Creation consumes energy and destruction produces waste.

Without a drive to live there will be no life and the drive to live is a drive to differentiation, to sharpen difference, and this drive has to be controled by paying some form of interest operating on relative difference.

Life thus needs a process of cell destruction, because not all cells brought to life are healthy cells, and all cells cannot be kept indefinitely. So, cell destruction is as important as cell creation. Cell destruction represents a loss or payment which is necessary for continued survival. If you do not pay this form interest, then your body will get unstable and disintegrate.

34.2 Cells

All organisms consist of small cells, typically too small to be seen by a naked eye, but big enough for an optical microscope . Each cell is a complex system consisting of many different building blocks enclosed in membrane bag. There are unicellular (consisting only of one cell) and multicellular organisms. Bacteria and baker's yeast are examples of unicellular organisms - any one cell is able to survive and multiply independently in appropriate environment.

There are estimated about 10^{14} cells in a human body, of about 320 different types. For instance there are several types of skin cells, muscle cells, brain cells (neurons), among many others. The number of cell types is not well-defined, it depends on the similarity threshold (what level of detail we would like to use to distinguish between the cell types, e.g., it is unlikely that we would be able to find two identical cells in an organism if we count the number of their molecules). The cell sizes may vary depending on the cell type and circumstances. For instance, a human red blood cell is about 5 microns (0.005 mm) in diameter, while some neurons are about 1 m long (from spinal cord to leg). Typically the diameter of animal and plant cells are between 10 and 100 microns.

There are two types of organisms - eukaryotes (see Fig. (34.1)) and prokaryotes, and two types of cells respectively. Bacteria belong to the prokaryotes. However, most organisms which we can see, such as trees, grass, flowers, weeds, worms, flies, mice, cats, dogs, humans, mushrooms and yeast are eukaryotes. The distinction between eukaryotes and prokaryotes is rather important, because many of the cellular building blocks and life processes are quite different in these two organism types. This is believed to be the result of different evolutionary paths. Evolution is an important concept in biology, there is a proverb saying that things only make sense in biology in the context of evolution. Most scientists believe that life first emerged on Earth around 3.8 billion years ago. The oldest fossilised bones that have been found resembling bones from anatomically modern humans are about 100.000-200.000 years old. Nobody really knows how life emerged on Earth, but there is lots of scientific evidence regarding how it may have evolved.

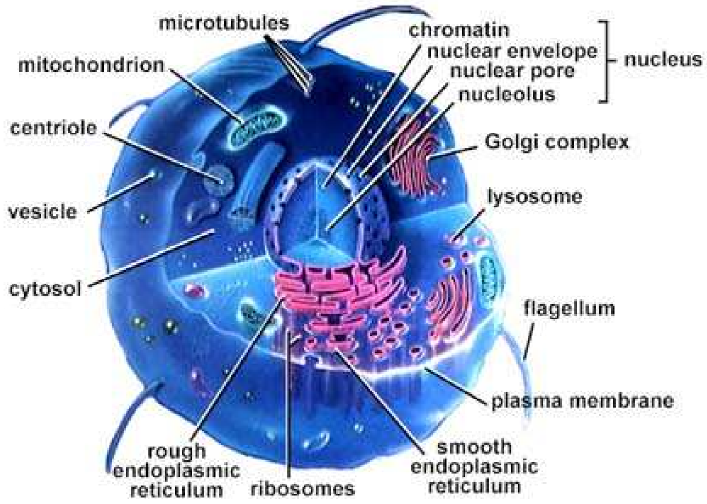


FIGURE 34.1. Eukaryotic cell.

34.3 Metabolism of the Cell

The *metabolism* of a living cell is the set of chemical reactions of the life process, and can divided into to categories of processes: *anabolism* and *catabolism*. Anabolic reactions construct cell components such as proteins and nucleic acids allowing the cell to grow and divide. Catabolic reactions break down large polymeric molecules such as proteins and polysaccharides into their constituent monomeric units such as monosaccharides, nucleotides and amino acids, offering energy and building material for the anabolism.

The metabolism of a cell thus consists of a combined process of creation-destruction. If the destruction does not work properly on the cell level, cancer develops.

We understand that it is the destruction in the catabolism which makes life into an irreversible process with an Arrow. To live and create you have to destruct, and that makes life irreversible.

34.4 The World

You find the same phenomenom on a bigger scale in the metabolism of the World.

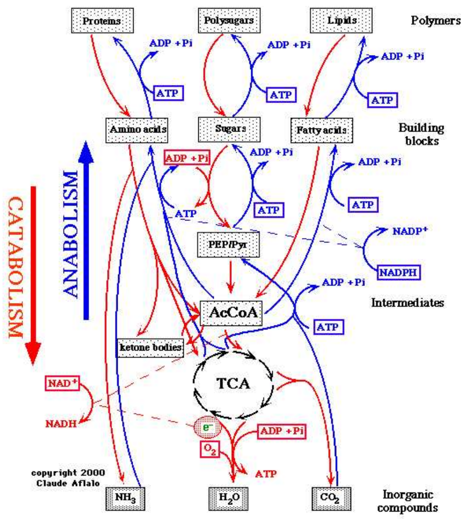


FIGURE 34.2. Cell metabolism.

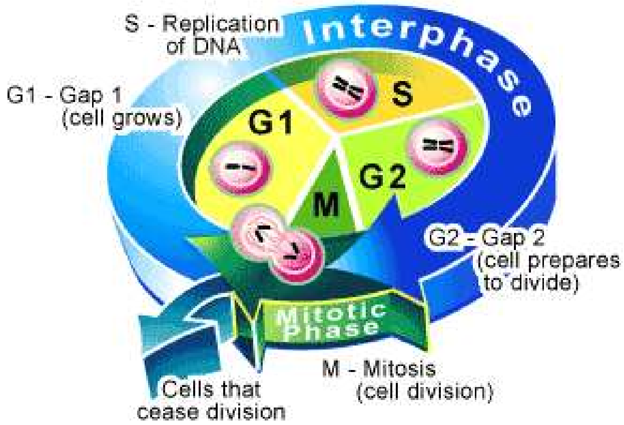


FIGURE 34.3. The cycle of cell division

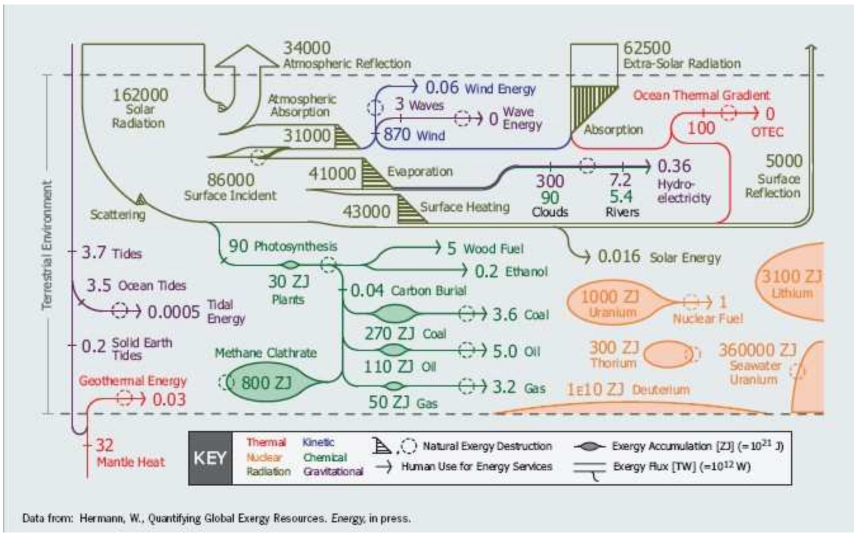


FIGURE 34.4. Global metabolism

34.5 The Universe: Brahma and Shiva

In hinduism Brahma is the God of Creation and Shiva the God od Destruction thus playing the roles of anabolism and catabolism in the metabolism of the Universe.

34.6 Gardening

To create a garden you have to put seeds to grow, but you also have to destroy weeds, and destroying weeds requires work, which you can view as a necessary loss to make to give room for the new plants. Nobody has seen a garden which does not require elimination of weeds one way or the other.

34.7 Rudolf Arnheim

The fundamental process of creating-releasing tension has been studied by Rudolph Arnheim (1904-) in art, film and perceptual psychology.

This is in direct opposition to Boltzmann's conception of entropy as disorder with increasing entropy characterizing a process towards equilibrium. When confronted with Arnheim's view of equilibrium as order, not disorder, Boltzmann would say that, yes the macrostate of equilibrium could be viewed to be ordered, but definitely not the microstate which he would argue is fully disordered, in order to defend his claim that Nature seeks disordered microstates. Arnheim would then say that it is more constructive and illuminating to view an approach to equilibrium as a process towards order, than a process towards disorder. We agree with Arnheim.

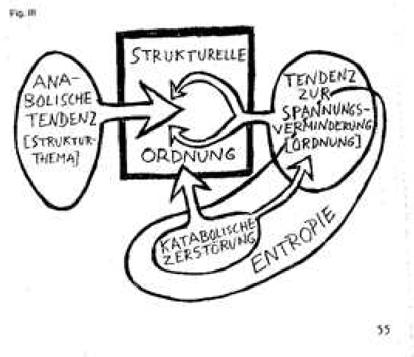


FIGURE 34.5. Order as tension release.

35
Chemical Reactions

35.1 Mixing-Unmixing

Both the catabolism and anabolism of the metabolism of life are based on chemical reactions. Catabolism typically involves a process of *mixing*, which means destruction of macroscopic difference/order and correspondingly anabolism involves a process of *unmixing*, or creation of macroscopic difference/order. Mixing does not require high precision, just stir, while unmixing requires care and precision.

In the chemical reaction of a catabolic process, the reactants are mixed so that they can meet and react, see Fig. (**??**). Mixing increases microscopic difference, but decreases macroscopic difference. In the chemical reaction of an anabolic process resulting in macroscopic order, the reactants are not mixed and the reaction typically takes place at a reaction front, see Fig. (**??**).

The area of the active reaction front can be much larger if the reactants are mixed, and thus catabolic reactions can be quicker than anabolic, which explains why creation is slow, while destruction may be fast, see Fig. (35.3).

Because of the different requirements of precision, numixing cannot quickly be achieved simply by reversing the quick process of mixing. Therefore a catabolic process of mixing defines an Arrow, and unmixing cannot only be realized in a slow anabolic process.

FIGURE 35.1. Mixing of ingredients to make a cake.

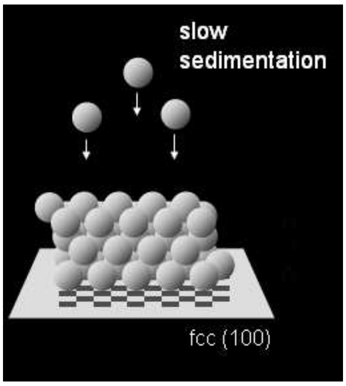


FIGURE 35.2. Slow growth of a crystal by sedimentation.

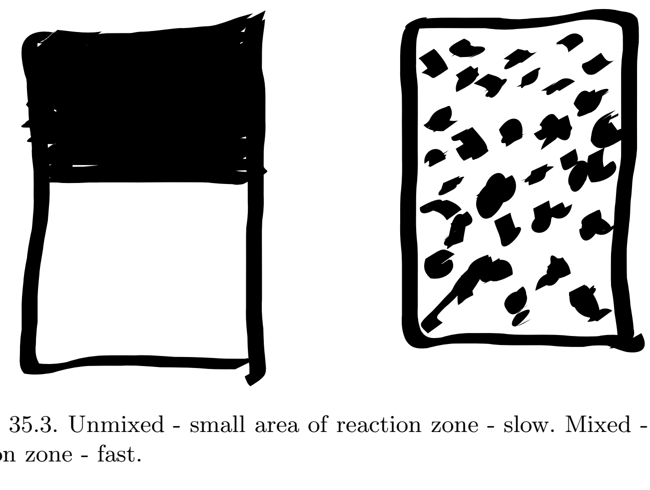


FIGURE 35.3. Unmixed - small area of reaction zone - slow. Mixed - large area of reaction zone - fast.

35.2 Mixing-Unmixing and Precision

We summarize by noting that a process of mixing

(m1) decreases macroscopic difference,

(m2) increases microscopic difference,

while a process of unmixing

(u1) increases macroscopic difference,

(u2) decreases microscopic difference.

We understand that both (m1) and (m2) and also (u1) may be performed with low precision, while (u2) requires high precision on microscopic scales for *identification* and *separation*, which is a slow process.

35.3 Centrifugation

In industrial processes separation can be performed by *centrifugation*, which in principle is a sedimentation process as in Fig. (35.2), with an effective gravitational force caused by the rotation of the centrifuge. With a fast centrifuge the separation can be made quickly, but biological processes do not use this principle, except possible when a dog gets rid of the water after a swim by shaking.

35.4 Selection and Separation

Why is separation sometimes a slow process? Well, it needs to be discriminating and somehow select what is to be separated, and then do it. There are many selection processes in society, like choosing a new president, and we know that these processes are very slow and complicated and they need to be precise. So selection may take time and care because high precision search is needed, but also the very separation process may take long time, as when a child separates itself from the parents, or a sediment settles.

There are other forms of separation, which can go fast like ripping a paper into pieces. Such processes are difficult to reverse, because a a careful serach and selection will have to be done to find the pieces which match.

35.5 Darwin and Selection

Darwin's principle of *natural selection* has been a very slow process requiring 100 millions of year for life to develop, because no centrifuge has been available for quick selection of the fittest.

36
Information Theory

36.1 Shannon

It is natural to view any process as some form of *information processing*. In particular, it is natural to expect a connection between thermodynamics and information theory. This idea was pursued by Claude Shannon (1916-2001) when forming a theortical basis for *information theory* in his *Mathematical Theory of Communication* from 1948. Shannon gave the concept of entropy in thermodynamics an interpretation as a measure of disorder of a string of information to be communicated. Information with a lot of entropy would then require more effort to communicate in terms of signal band-width and/or time.

Of course, Shannons information theory used the notion of *finite precision of digital information* directly measured by the number of digits in digital representation (like the number of pixels in an image), with a direct connection to the cost of communication.

36.2 Landauer

The physicist Rolf Landauer (1927-1999) stressed the necessity of erasing finite precision digital information, in order not to get drowned by digits, and made an interpretation of the erasure of information as an irreversible increase of entropy. We all know that without erasure, our hard disk will get full, so we understand that Landauer said something important. If you erease information it is will not be possible to recover, so be careful with this operation. But is it really necessary to erase information. Can't you just get a bigger hard disk?

FIGURE 36.1. The irreversible process of a wave breaking on the shore.

36.3 Beyond Landauer

We shall below connect to Landauer's approach below, but modify by bringing in the aspect of stability. We shall see that an aspect of an interesting process, which we said is process on the border between stability and instablity, is that

(i) *small-scale information* is necessarily produced,

(ii) small-scale information has to get erased.

The novelty is the inevitable production of small-scale information, which reflects the weak stability of an interesting system. This reflects our mantra of "finite precision computation and stability". And small scale information is costly to store because it requires many digits because of the small scales. Get the idea?

We know that there are many interesting processes in Nature, and according to our mantra such processes will have to involve erasure of small-scale information in order not to get bogged down and simply stop functioning: The show must go on and cannot be stopped by petty details.

36.4 The Braking Wave

The braking of a wave on a shore illustrates both (i) and (ii): When a big beautifully shaped wave approaches a shore, it gets steeper and steeper until it finally tips over, and breaks into turbulent mess of small vorticies which “disappear” as the wave recedes.

36.5 Life and Waste

Every living creature creates waste, a household produces waste, a society produces a lot of waste, and all this seems impossible to avoid. Life produces waste, and waste consists of small-scale pieces of junk. You have to throw old newspapers not to get drowned in paper, or use them to heat your house, and when you do that you destroy information, irreversibly. Life is an irreversible process because it creates information by destroying information. That is the 2nd Law.

In Plato’s perfect society, no waste is produced, but this society does not exist. Only the existing society exists, and cannot exist without producing waste. This is an existential question.

FIGURE 36.2. Recycling of waste

37
Turbulence

> Turbulence is one of the principal unsolved problems of physics today. ....The real challenge, it seems to us, is that no adequate model for turbulence exists today.... The equations of motion have been analyzed in great detail, but it is still next to impossible to make accurate quantitative predictions without relying heavily on empirical data. (Tennekes and Lumley in A First Course in Turbulence, 1994).

37.1 An Irreversible Process

Turbulent flow is a fundamental irreversible process, which we will study in more detail below.

The flow of a slightly viscous flow always becomes turbulent, except in the trivial fully uniform case with all fluid particles moving with the same velocity. Large vorticies generate smaller vortices by mixing fluid particles of different velocities in a cascade from large scale kinetic energy to smallest scale kinetic energy percieved as heat energy, with the smallest scale being proportional to the square-root of the viscosity.

In Fig. (49.2) we plot a snap-shot of the flow pattern (and isosurface os the vorticity) of a slightly viscous gas like air around a sphere. We notice the unsymmetric pattern with a turbulent *wake* to the right the sphere (or behind the sphere in the direction of the flow). The flow is irreversible: Changing the flow direction changes the flow pattern completely putting the wake now to the left.

The irreversibility is expressed by the transformation of large scale kinetic energy to small scale heat energy, in a fluid dynamics analogy to the heating a stone by dropping it to the ground.

37.2 Turbulent Mixing

For a chemical reaction to take place, reactants must meet in space and we noted above that this process is enhanced by mixing the reactants with the objective of increasing the area of active reaction zones. The many vortices of various size in turbulent flow causes strong mixing, and thus reactions can go faster in turbulent flow than in laminar flow with little mixing.

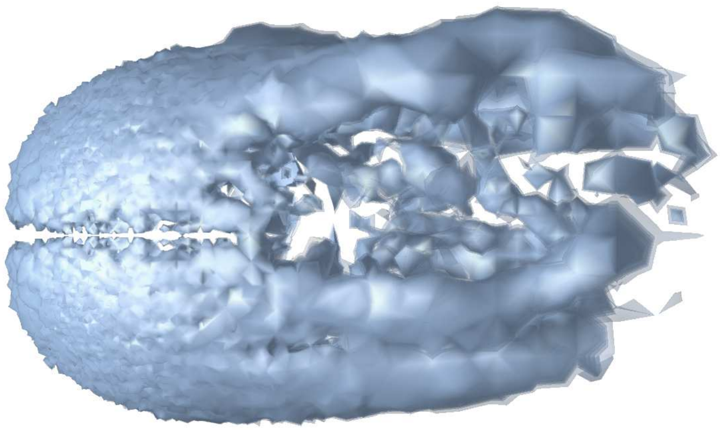


FIGURE 37.1. Turbulent air flow around a sphere. Notice the unsymmetric flow pattern with the wake *behind* the sphere. (isosurface of vorticity).

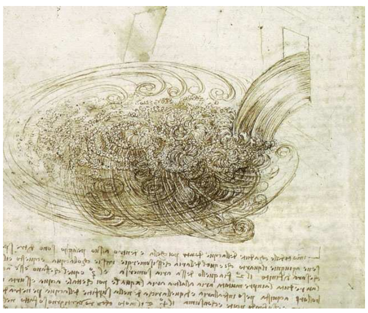


FIGURE 37.2. Mixing and emergence of organized structures in turbulent flow according to Leonardo da Vinci.

38
Clocks and Navigation

38.1 John Harrison

John Harrison (1693-1776) was an English clockmaker who revolutionised and extended the possibility of safe long distance sea travel in the Age of Sail by inventing a long-sought and critically-needed key piece in the problem of accurately establishing the East-West position, or longitude, of a ship at sea. The problem was so intractable that the English Parliament offered a huge fortune for the day roughly $12 million in current terms for a solution.

After steadfastly pursuing various methods during thirty years of experimentation, Harrison finally designed and built the world's first successful chronometers, a highly accurate maritime time-keeping instrument which for the first time allowed a navigator to accurately assess his ship's position in longitude. This is so because the earth is constantly rotating, and therefore knowing the time whilst making an altitude measurement to a known heavenly body such as the sun, provided critical data for a ship's position east-west, a necessary capability for re-approaching land after voyages over medium and long distances. On such voyages, cumulative errors in dead reckoning frequently led to shipwrecks and lost lives.

38.2 GPS

Today navigation is done using the *Global Positioning System GPS* based on the 1983 SI standard. GPS defines a system of absolute time and space around the Globe. At the press of a button on your GPS-receiver (now often in your mobile

FIGURE 38.1. John Harrison with his clock.

telephone), you get the GPS-coordinates of your present position as well as your velocity and standard GPS-time.

A GPS receiver receives radio wave signals from at least 4 out of 24 satellites orbiting the Earth with 12 hour periodicity. Each satellite signal has encoded the time of transmission from the satellite, which allows the GPS-receiver to compute the time lag (time for a light signal to pass from satellite to receiver) and thus the distance to the satellite (in lightseconds), and from 4 signals determine its position including synchronization of its own clock to standard GPS-time needed to determine the time lag. The satellites have all identical cesium clocks synchronized to a GPS-time at launch.

39
Politics

The invention of science have overcome the great difficulties of time and space which were thought to make separation almost a necessity, and we now feel that we can look forward, not to the isolated independence of England's childreen, but to their being united to one another with the mother country, in a permanent family union. (W. E. Forster)

40
Walt Whitman

To Think of Time
To think of time – of all that retrospection,

To think of to-day, and the ages continued henceforward.
Have you guess'd you yourself would not continue?
Have you dreaded these earth-beetles?
Have you fear'd the future would be nothing to you?
Is to-day nothing? is the beginningless past nothing?
If the future is nothing, they are just as surely nothing.
.... It is not to diffuse you that you were born of your mother

and father, it is to identify you,
It is not that you should be undecided, but that you should
be decided,
Something long preparing and fromless is arrived and
form'd in you
You are henceforth secure, whatever comes and goes.
The threads that were spun are gather'd, the weft crosses the
warp, the pattern is systematic.

41
Disneyland and Simulation

Baudrillard writes:

- *Disneyland is a perfect model of all the entangled orders of simulation. To begin with it is a play of illusions and phantasms: pirates, the frontier, future world, etc. This imaginary world is supposed to be what makes the operation successful. But, what draws the crowds is undoubtedly much more the social microcosm, the miniaturized and religious revelling in real America, in its delights and drawbacks. You park outside, queue up inside, and are totally abandoned at the exit. In this imaginary world the only phantasmagoria is in the inherent warmth and affection of the crowd, and in that aufficiently excessive number of gadgets used there to specifically maintain the multitudinous affect. The contrast with the absolute solitude of the parking lot - a veritable concentration camp - is total. Or rather: inside, a whole range of gadgets magnetize the crowd into direct flows; outside, solitude is directed onto a single gadget: the automobile. By an extraordinary coincidence (one that undoubtedly belongs to the peculiar enchantment of this universe), this deep-frozen infantile world happens to have been conceived and realized by a man who is himself now cryogenized; Walt Disney, who awaits his resurrection at minus 180 degrees centigrade.*

- *The objective profile of the United States, then, may be traced throughout Disneyland, even down to the morphology of individuals and the crowd. All its values are exalted here, in miniature and comic-strip* *form. Embalmed and pactfied. Whence the possibility of an ideological analysis of Disneyland (L. Marin does it well in Utopies, jeux d'espaces): digest of the American way of life, panegyric to American values, idealized transposition of a contradictory reality. To be sure. But this conceals something else, and that "ideological" blanket exactly serves to cover over a third-order simulation: Disneyland is there to conceal the fact that it is the "real" country, all of "real" America, which is Disneyland (just as prisons are there to conceal the fact that it is the social in its entirety, in its banal omnipresence, which is carceral). Disneyland is presented as imaginary in order to make us believe that the rest is real, when in fact all of Los Angeles and the America surrounding it are no longer real, but of the order of the hyperreal and of simulation. It is no longer a question of a false representation of reality (ideology), but of concealing the fact that the real is no longer real, and thus of saving the reality principle.*

- *The Disneyland imaginary is neither true nor false: it is a deterrence machine set up in order to rejuvenate in reverse the fiction of the real. Whence the debility, the infantile degeneration of this imaginary. It s meant to be an infantile world, in order to make us believe that the adults are elsewhere, in the "real" world, and to conceal the fact that real childishness is everywhere, particularly among those adults who go there to act the child in order to foster illusions of their real childishness.*

- *Moreover, Disneyland is not the only one. Enchanted Village, Magic Mountain, Marine World: Los Angeles is encircled by these "imaginary stations" which feed reality, reality-energy, to a town whose mystery is precisely that it is nothing more than a network of endless, unreal circulation: a town of fabulous proportions, but without space or dimensions. As much as electrical and nuclear power stations, as much as film studios, this town, which is nothing more than an immense script and a perpetual motion picture, needs this old imaginary made up of childhood signals and faked phantasms for its sympathetic nervous system.*

42
Reichenbach

> He was convinced that he had achieved a solution of the problem of the direction of time. (Maria Reichenbach in the Preface to *The Direction of Time* by her husband.)

42.1 A Leading Philosopher

Hans Reichenbach (1891-1953) was a leading philosopher of science, educator, proponent of logical empiricism and founder of the Berlin Circle: Society of Empirical Philosophy. He gained notice for his methods of teaching. Specifically, he was easily approached and his courses were open to discussion and debate, highly unusual in his time. In 1930 he and Rudolf Carnap began editing the journal Erkenntnis ("Knowledge").

In 1933, when Adolf Hitler became Chancellor of Germany, Reichenbach emigrated to Turkey, where he headed the Department of Philosophy at the University of Istanbul. He introduced interdisciplinary seminars and courses on scientific subjects, and in 1935 he published *The Theory of Probability.*

In 1938, with the help of Charles Morris, he moved to the United States to take up a professorship at the University of California, Los Angeles. His work on the philosophical foundations of quantum mechanics was published in 1944, followed by *Elements of Symbolic Logic* and *The Rise of Scientific Philosophy.*

He died on April 9, 1953 in Los Angeles while working on problems in the philosophy of time and on the nature of scientific laws published posthumously as *The Direction of Time.* We cite from this book:

- *The problem of time has always baffled the human mind.*
- *The study of time is a problem of physics.*
- *Einstein's and Minkowski's timeless universe is a four-dimensional Parmenidian Being, in which nothing happens, "complete, immovable, without end...; is is all at once, a continuous one". Time flow is an illusion, Becoming is an illusion; it is the way we human beings experience time, but there is nothing in nature which corresponds to this experience.*
- *It is a hopeless enterprise to search for the nature of time without studying physics. If there is a solution to the philosophical problem of time, it is written in the equations of mathematical physics.*
- *The direction of time is thus explained as a statistical trend; the act of Becoming is the transition from the improbable to probable configurations of molecules*
- *Transitions to lower entropy are as frequent as those to higher entropy; and this is the statement of the reversibility objection.*

Reichenbach correctly identifies the weakness of the position of the Eliatic school of Parmenides and Zeno that change is impossible, as well as Kant's subjective time, and he also raises the reversibility objection to Boltzmann's statistics.

42.2 The Reversibility Objection

The gist of *The Direction of Time* is to come to grips with the reversibility objection, and thus rationalize once and for all Boltzmann's statistical mechanics. However, the manuscript was left unfinished on his desk at the time of his sudden death in 1953, indicating that a life time was not enough to find a solution... by statistics.

43
Destruction

Every act of creation is first of all an act of destruction. (Pablo Picasso)

Free nations are peaceful nations. Free nations don't develop weapons of mass destruction. (George W. Bush)

Religions that teach brotherly love have been used as an excuse for persecution, and our profoundest scientific insight is made into a means of mass destruction. (Bertrand Russell)

Nobel was a genuine friend of peace. He even went so far as to believe that he had invented a tool of destruction, dynamite, which would make war so senseless that it would become impossible. He was wrong. (Alva Myrdal)

44
Tragedy vs Comedy

> Death is always and under all circumtances a tragedy, for if it is not, then it means that life itself has become one. (Theodore Roosevelt (1858 - 1919)).

44.1 Tragedy

The word *tragedy* is a contraction of the Greek words *tragos* (goat) and *aedein* (to sing) and refers to the tragic song proverbially sung by a goat before being led to the altar for sacrifice in ancient Greek religious ceremony. In tragedy the hero is similarly led to catastrophy by inevitable logic, just as we all are led to inevitable death by the logic of life. Tragedy thus can be seen as an aspect of Principe Perfeito. The dynamics of a tragedy is the inevitable march towards death of the individual, without possibility of repetion: When the hero is dead, he is dead.

The individuality of the the hero is essential, which reflects the individuality of each human life: Everybody is ultimately alone on the road to precipice.

44.2 Comedy

We recall that according to Bergson [1], *comedy* arises from breaking the spell of tragedy leading the individual towards inevitable death, by allowing

(i) change of identity and (ii) repetion. In a comedy, persons change identity (by changing clothes) and things get repeted (words or scences), and both (i) and (ii) seem funny and bring laughter. One way of coping with the tragedy of life, thus seesm to be to pretend for a while that the laws of tragedy can be broken, and and handle the contradiction of knowing that this impossible, by laughing.

FIGURE 44.1. Masks of comedy and tragedy.

Part V

Mathematics of Time

45
The Euler Equations

> However sublime are the researches on fluids which we owe to Messrs Bernoulli, Clairaut and d'Alembert, they flow so naturally from my two general formulae that one cannot sufficiently admire this accord of their profound meditations with the simplicity of the principles from which I have drawn my equations ...(Euler 1752)

> The 2nd Law cannot be derived from purely mechanical laws. It carries the stamp of the essentially statitical nature of heat. (Bergman in Basic Theories of Physics 1951)

> The total energy of the universe is constant; the total entropy is continually increasing. (Rudolf Clausius)

45.1 Thermodynamics and the Arrow

We know that thermodynamics has an Arrow of Time, so if we can understand thermodynamics, then we can understand the Arrow. Recalling Newton's enormous success with his theory of gravitation, of course we would like to study thermodynamics using mathematics.

This looks really promising, because there are mathematical equations describing thermodynamics consisting of Newton's equation $ma = f$ expressing *conservation of momentum*, plus equations expressing *conservation of mass and energy*, plus a *state equation* describing how the pressure depends on density and temperature.

That is all, and these equations are called the *Euler equations*. As soon as Calculus was developed, they could be formulated and also were, first by

Euler in 17??. They can be combined into the 1st Law of Thermodynamics expressing conservation of mass, momentum and total energy. Let's take a look and see what they look like in mathematical notation. In principle they form a *system of partial differential equations* of the form $\dot{u} = f(u)$, that we met in Chapter 4, with a specific choice of $f(u)$ involving derivatives in space.

45.2 Conservation of Mass, Momentum and Energy

We formulate the Euler equations for an *ideal* gas (or fluid) enclosed in a fixed volume Ω in three-dimensional space $\mathbb{R}^3$ with boundary Γ over a time interval $[0, T]$ with intial time zero and final time T. An ideal gas is a model of a gas (or fluid) with very small viscosity and heat conductivity, like air (or water).

We seek the *density* ρ, *momentum* $m = \rho u$ with $u = (u_1, u_2, u_3)$ the *velocity*, and the *total energy* ϵ as functions of $x \in \Omega \cup \Gamma$ and $t \in I$, where $x = (x_1, x_2, x_3)$ denotes the coordinates in $\mathbb{R}^3$ and u_i is the velocity in the x_i-direction. The Euler equations for the unknown functions ρ, m and ϵ read with $Q = \Omega \times I$,

$$\begin{aligned} \dot{\rho} + \nabla \cdot (\rho u) &= 0 && \text{in } Q, \\ \dot{m}_i + \nabla \cdot (m_i u) + p_{,i} &= 0 && \text{in } Q, \quad i = 1, 2, 3, \\ \dot{\epsilon} + \nabla \cdot (\epsilon u + p u) &= 0 && \text{in } Q, \\ u \cdot n &= 0 && \text{on } \Gamma \times I, \end{aligned} \tag{45.1}$$

together with an initial condition, where $p = p(x, t)$ is the *pressure* of the gas, $v_{,i} = \frac{\partial v}{\partial x_i}$ is the partial derivative with respect to x_i, $\dot{v} = \frac{\partial v}{\partial t}$ is the partial derivative with respect to time t, n denotes the outward unit normal to Γ, Further, the total energy $\epsilon = k + e$, where

$$k = \frac{\rho |u|^2}{2}$$

is the *kinetic energy*, and

$$e = \rho \tau$$

is the *internal energy* with τ the *temperature*, assuming the heat capacity is equal to one. The boundary condition is a *slip* boundary condition requiring the normal velocity $u \cdot n$ to vanish corresponding to an inpenetrable boundary with zero friction. One may also consider other boundary conditions including inflow and outflow conditions and non-zero friction. Of course, $\nabla \cdot v = \sum_i v_{i,i}$ denotes the divergence of $v = (v_1, v_2, v_3)$ and $\nabla w = (w_{,1}, w_{,2}, w_{,3})$ the gradient.

There are five equations in the Euler system (**??**), while the number of unknowns including the pressure is six, and so we need one more equation, which is the *state equation* and which for a *perfect gas* takes the form of *Boyle's law*:

$$p = (\gamma - 1)\rho T \tag{45.2}$$

with $\gamma > 1$ the gas constant or *adiabatic index* equal to the ratio c_p/c_v of the specific heat under constant pressure c_p and constant volume c_v.

The Euler equations (45.1) with zero right hand sides, model a closed system with no interaction with the environment. You can extend the model to interaction or include the environment obtaining again a closed system.

45.3 The Euler Equations in Compact Form

The Euler equations take the following general form: Find $u(t)$ susch that

$$\dot{u}(t) = f(u(t)) \quad \text{for } t > 0, \quad u(0) = u^0, \tag{45.3}$$

where $u = (\rho, m, \epsilon)$ is the vector of *conserved quantities* and $f(u)$ is a vector representing the *flux rate* of these quantities. The system (45.1) or (45.3) models thermodynamics in very compact form. The system (45.3) can be solved by time-stepping, just like the pendulum equation:

$$u(t + dt) \approx u(t) + f(u(t))dt,$$

and thus allows computational modeling of a wealth of problems in thermodynamics all involving turbulent flow. The Joule-Thompson simulation in Chapter 14 is representative.

45.4 The Beauty of the Euler Equations

The Euler equations look like an very useful model for thermodynamics, because it has *just one parameter*, which is the constant γ in the state equation, which can easily be determined experimentally measuring the pressure at some density and temperature.

Why does it seem to be useful? Because if you know γ and the initial state, then you can predict the state of the system at any later time, simply by solving Euler's equations. This is what we did above when repeating the Joule-Thompson experiment in our litte PC lab, and thereby came to understand what was going on. Very useful, indeed!!

But before cashing in, we will have to come over a (minor) disappointment and put it behind us.

45.5 Non-Existence of Stable Exact Solutions

The Euler equations have no physically meaningful solutions exact solutions. This is because exact solutions are unstable and thus cannot be materialized and observed.

45.6 Approximate Solution Is Enough: EG2

Does this mean that we simply have to throw away the beautiful Euler equations and look for something better? But what? The only thing we know about thermodynamics is the 1st Law and the Euler equations express the 1st Law, and we cannot throw away the only thing we know. What to do? Is there a way out of the dilemma? Can we use the Euler equations without being able to solve them exactly?

You understand that we are in the same situation as James Madison when writing down the American Constitution, and realizing that no society will be able to follow it exactly. Should he trow away the Constitution?

No, you should not throw away the Constitution, because then you have nothing, and you should keep the Euler equations and just solve theem approximately using time stepping. After all the Euler equations have the form $\dot{u} = f(u)$ and we know how to time-step such an equation using $u(t + dt) \approx u(t) + f(u(t))dt$. If you have a computer you can do that,and you have seen results of such computational simulations above.

We take some care when we can solve the Euler equations, knowing that we cannot satisfy them exactly, and that is to by paying a certain price or fine for violating the laws. We call this method to solve the Euler equations *EG2*, which is a General Galerkin finite element method for the Euler equations. You can freely download the computer code from www.fenics.org and try on your PC.

We do not need to go into the details of EG2 here, it suffices to know that EG2 solves the Euler equations approximately on a *computational mesh* with *finite mesh size* h. Typical meshes have a mesh size of 10^{-2} on the unit cube with altogether 10^6 mesh points. The mesh size would represent the microscopic scale of the computation and and coarser resolvable scales would represent macroscales. A gas has about 10^{24} molecules per mole, and thus the values of density, momentum and energy at each mesh point represent mean values of about 10^{18} molecules, and thus the microscopic computational scales represent macroscopic physical scales.

A computational *particle model* of a gas accounting for the position and velocity of each of the 10^{24} particles in each mole, with full resolution dwon to physical scales, is impossible on any today conceivable computer.

EG2 puts a cost for not being able to fulfill the Euler equations at every point in space and time, and the total cost per unit of time at time t is

$$D(t) = \int hR^2 \, dx \tag{45.4}$$

where $R(x,t)$ is the *residual* or the discrepancy of satisfaction of the Euler equations at the point x at the time t. For a a turbulent solution $D(t)$ is not small, which requires $R(x,t)$ to be large pointwise. Thus turbulent solutions heavily violate the conservation laws pointwise in space-time, which you would expect to prevent them to be meaningful. But by the Galerkin feature of EG2, mean-values in space-time of $R(x,t)$ turns out to ber small, and thus EG2 solutions satsify the Euler equations in a mean-value sense, or *weak* sense. EG2 solutions are weak solutions of the Euler equations with a certain control of the pointwise residual enforced by the cost $D(t)$, which is neither small nor large, thus not neglible but affordable.

45.7 EG2 as a Finite Precision Clock

With EG2 we stay within a deterministic framework and only add a restriction of finite precision computation coming from the finite mesh size of the computational mesh. We are thus led to a model of thermodynamics as a giant *Finite Precision Clock*, replacing the classical Laplace Clock with infinite precision, which cannot be constructed and thus cannot be used. The Finite Precision Clock is deterministic and does not involve any microscopic games of roulette.

45.8 The 2nd Law for EG2

A remarkable property of EG2 solutions is to automatically satisfy a form of the 2nd Law, which is not the classical concerning entropy, but a simpler and more useful form without any entropy. The new 2nd Law takes the following *global form*:

$$\begin{aligned} \dot{K} &= W - D, \\ \dot{E} &= -W + D, \end{aligned} \tag{45.5}$$

where

- $K(t) = \int_\Omega k \, dx$ is the total (integrated) kinetic energy at time t,
- $E(t) = E = \int_\Omega e \, dx$ is the total heat energy at time t,
- $W(t) = \int_\Omega p \nabla \cdot u \, dx$ is the total work rate by expansion/compression,

and $D > 0$ for turbulent solutions.

45.9 What Does the 2nd Law Say?

Now we come to the great moment of interpreting the 2nd Law (45.5). What do we see? Well, since $D > 0$, we see two basic facts:

(i) transfer of energy from kinetic energy K to heat energy E,

(ii) K grows by expansion only,

(iii) E grows by compression.

Here we have the basic facts of thermodynamics neatly condensed: (i) states that we always have to pay a fine of converting kinetic energy into heat energy, which we cannot get back. (ii) states that a gas can be put into motion under expansion, and (iii) states that compression of a gas heats the gas.

By (iii) we understand that in the Joule-Thompson experiment, the gas will have no incentive to compress itself back to the initial state from the final spread out state, so it will not do that. To understand this basic fact we do not need to invoke any notion of entropy, with all its difficulties. It is enough to take a look at (45.5). Which explanation would you prefer?

45.10 Irreversibility from Principe Perfeito

Irreversibility comes from (i): the kinetic energy converted to heat energy in turbulent dissipation, it is “lost” into “internal energy” for ever and cannot be recovered. This is like the parking fine you have paid for breaking the law, which you cannot get back.

We sum up by saying that the 2nd Law (45.5) expresses as a Principe Perfeito in precise mathematical form, the irreversibility in thermodynamics, using only the classical concepts of kinetic energy, heat energy and work, without any mentioning of entropy.

This amounts to a considerable rationalization of thermodynamics, relieving scientists from the hopeless task of defining what entropy is and how to measure it and guarantee that it cannot decrease. Of what you cannot speak, you have to be quite.

You can view Principe Perfeito as a deterministic form of the 2nd Law, which can replace statistical formulations of the 2nd Law. The finite precision of Principe Perfeito replaces the microscopical games of roulette of statistical mechanics, and thus simiplifies thermodynamics.

46
Mathematics of Edge Stability

The forces in capitalist society, if left unchecked, tend to make the rich richer and the poor poorer. (Jawaharlal Nehru (1889-1964), Indian Premier Minister)

The inherent vice of capitalism is the unequal sharing of blessings; the inherent virtue of socialism is the equal sharing of miseries. (Winston Churchill (1874-1965))

The importance of money flows from it being a link from the present to the future. (John Maynard Keynes)

Entrepreneurs and their small enterprises are responsible for almost all the economic growth in the United States. (Ronald Reagan)

46.1 Exponential Growth or Decay

We now study the mathematical concept of edge stability in a couple of elementary models. We start with the following model: Find the function $u(t)$ satisfying

$$\begin{aligned} \dot{u} &= \alpha u \quad \text{for } t > 0, \\ u(0) &= u_0, \end{aligned} \tag{46.1}$$

where α is a constant and we assume that $u_0 > 0$. This is the basic model for an economy or a population with $u(t)$ represent its size at time t. The equation $\dot{u} = \alpha u$ expresses that the rate of change of $u(t)$ is proportional to $u(t)$ itself, with the constant of proportionality α. For example, with $\alpha = 1$ the equation

$\dot{u} = u(t)$ expresses that the bigger $u(t)$ is the faster will it grow. You understand that this could lead to instability; the bigger you get the faster you will grow...

The solution is the *exponential function*

$$u(t) = \exp(\alpha t)u_0. \tag{46.2}$$

This is an *exponetially increasing* function as t increases, if $\alpha > 0$, and *exponentially decreasing* if $\alpha < 0$. If we *perturb* the initial data u_0 to instead $u_0 + \Delta u_0$ with Δu_0 the perturbation, then the solution changes by $\exp(\alpha t)\Delta u_0$ with the same feature of exponential growth/decay depending on the sign of α.

We thus may naturally define the model (46.1) to be *exponentially unstable* if $\alpha > 0$ and *exponentially stable* if $\alpha < 0$. If $\alpha > 0$ then perturbations grow exponentially and if $\alpha < 0$ then perturbations decay exponentially.

Now, we are interested in systesm which are neither very stable nor very unstable. Exponentially stable systems do not have interesting dynamics and exponentially unstable systems collapse. This leads us to choose $\alpha = 0$. The solution is then simply $u(t) = u_0$, that is nothing changes, and that is not interesting either. The model (46.1) is to simple to show any aspect of edge stability of interest.

46.2 An Edge Stable System

To get an interesting edge stable system we have to go to a *system of equations*. The simplest system expressing a basic feature of edge stability is the following: Find the *pair* of functions $u(t)$ and $v(t)$ such that

$$\begin{aligned} \dot{u} - \epsilon v &= 0, \\ \dot{v} &= 0, \\ u(0) = u_0, &\quad v(0) = v_0, \end{aligned} \tag{46.3}$$

where ϵ is a *positive* constant, and we assume that also u_0 and v_0 are positive. This system corresponds to the case $\alpha = 0$ in (46.1) since there is no u-term in the firrst equation and no v-term in the second equation. It is thus system which is neither exponentially stable nor unstable. It is on the border between stability and instability, but it is not the trivial system $\dot{u} = 0$ and $\dot{v} = 0$.

We can easily solve (46.3) to find that

$$u(t) = \epsilon v_0 t, \quad v(t) = v_0. \tag{46.4}$$

Very simple, but not without interest as we will see. Apparently, the component $u(t)$ *grows* linearly in time, while $v(t)$ stays constant. The quotient $q(t) = \frac{u(t)}{v(t)}$ also grows linearly of course

$$q(t) = \epsilon t \tag{46.5}$$

46.3 An Economical Interpretation

We now interprete the model (46.3) in economical terms as follows: Consider an inventive person P with a small one-person consulting business, in say web page design. P operates from a difference in knowledge of web page design: P knows some tricks that the customer does not know, and the bigger the difference is the more need there is for consulting. The difference in knowledge between consultant and customer is expressed by the (positive) coefficient ϵ.

Let us now view $u(t)$ to be the *total income* of the consulting business at time t and let $v(t) = v_0$ measure the effort P spends on his business in hours per week. We can then view $q(t)$ as a measure of the *total payoff* (as income/effort), and we know that

$$q(t) = \epsilon v_0 t,$$

which expresses that the total pay-off is proportional to the difference in knowledge measured by ϵ and the effort of P, and to time of course. The pay-off per unit time step is $\dot{q} = \epsilon v_0$. This is what we expect. The bigger the difference in knowledge is and the more effort P puts in the bigger is the pay-off.

Since $u(t)$ is growing with time, P will get richer and richer, and will be able to expand his business into a (big) consulting company increasing the difference between the top knowledge of the company and the customer. But this opens the possibility for some people at the company to split off and set up one-person companies operating on some aspect of the total difference like a special feature of the design of a web page, like color or special buttons. The process can now start over again.

46.4 Essence of Capitalism and Turbulence

What we see is that difference feeds difference, or more precisely, large scale difference opens the possibility of smaller scale difference which opens the possibility to smaller scale difference... Therefore a big company is surrounded by a range of of smaller companies all the way down to one-person companies, with each company feeding on the next bigger company on the scale. This is the way a capitalitic economy functions, and we shall see that this is how vortices in turbulent fluid feed on each other.

An essential aspect is the appearance of smaller scales, which with finite precision has to come to an end, which in the economic model is the one-person company. There must be a cost, like an interest rate or tax, penalizing further differentiation. Without this cost the one person in the one-person company would have an incentive to become schizofrenic and would go out of business. In the case of turbulent flow the cost is production of heat energy from kinetic energy, which cannot be retrived and thus acts like a viscous brake on the fluid motion. Without the brake the flow could not exist. Without a stabilizing transaction cost, the flow of money in a stock market will become unstable and the market will collapse, cf. Fig. (46.1).

FIGURE 46.1. Turbulence on the stock market on October 24 1929

47
Two Basic Models

47.1 Spreading Information

As two basic mathematical models of very similar mathematical form but very different nature, we shall consider a *wave equation* describing the phenomenon of *wave propagation* or *convection*, together with a *heat equation* describing the process of *diffusion of heat*. We thus will consider the simplest mathematical models for the basic physical phenomena of convection and diffusion.

As a concrete model we may think of a line of people where each person may communicate with the two nearest neighbors, in a succession of time steps, once every minute say. Convection corresponds to a rumour being transmitted in one direction along the line from one person to the next starting at one end of the line. In this case there is a good chance that the message at the end is reasonably close to the initial one.

Diffusion corresponds to spreading the rumour instead from the middle of the line with each person taking the mean value of the rumour from the two neighbors in each time setp. In this case the details of the message will be lost during the transmission by the repeated mean value operations. We can see this effect in Fig. (47.2) where we show the initial image with details and the same image after a sequence of diffusion steps taking mean values over grey shades resulting in an image with “soft” shades without details. We see that diffusion destroys information.

We shall now discover these effects in mathmatical form in the wave and the heat equation.

47.2 The Wave Equation

As a basic mathematical model we shall consider the following *initial value problem* for the *wave equation*: Find the function $u(x,t)$ of two real variables x and t satisfying:

$$\dot{u} + u' = 0 \quad \text{for all } x \quad \text{and } t > 0,$$
$$u(x,0) = u_0(x) \quad \text{for all } x,$$

where the prime indicates differentiation with respect to the variable x, the dot as above indicates differentiation with respect to the variable t and the function $u_0(x)$ is a given *initial value*.

We consider t to represent time, and we consider x to represent a space consisting of a horisontal line (directed to the right). The variable t is identified as a time variable, because of the nature of the initial condition: The variable specified to be zero in the initial condition is the time variable! Note that without the initial condition, the t and x variable in the wave equation cannot be distinguished, but with the initial condition they can!

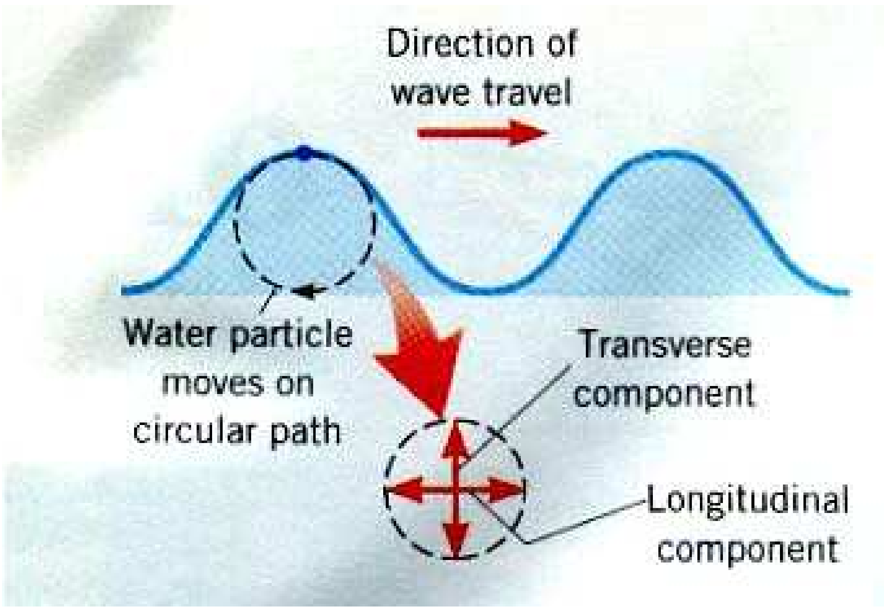


FIGURE 47.1. A water wave is generated by circular motion of the water molecules. The wave can propagate to right or left without loosing its form.

We notice that the initial wave form $u0(x)$ represents coexistence in Leibniz sense. A wave form is necessarily a smooth differentiable function of x representing coexistence. A wave is not just a delta-function of x representing a "particle" but an entity with extension in space with the values $u(x,t)$ for different x but the same t in coexistence.

The wave equation models the propagation of a wave along the x-axis in the positive direction with speed 1. The solution is given by the simple formula

$$u(x,t) = u_0(x-t),$$

showing that the initial wave form u_0 is translated to the right with speed 1.

The wave equation is reversible: Changing the direction of both t and x leaves the equation invariant into the same wave equation modeling wave propagation to the left with speed 1 (both the term u_t and u_x changes with a minus sign leaving the equation $u_t + u_x = 0$ intact or invariant).

The wave equation models a reversible world where a wave being propagated to the right (without distortion of form) can be reversed by propagation to the left running time backwards, making the wave return to its initial condition. The net result is that time in the wave equation does not have a direction. In other words, there is no Arrow of Time in wave equation. Any wave propagation can be reversed.

In particular the wave equation allows cyclic phenomena such as a wave bouncing back and forth for ever under repeated reversals of time as a form of perpetuum mobile. In such periodic phenomena time would be periodic, and not linear always moving forward to new event

It is common to connect perception of time as being periodic with female psychology reflecting cyclic process of seasons and life and death in Nature, while the time perception of a male is supposed to be linear goal-orientated towards some final (remarkable) result. Of course, these are stereotypes.

If your life was governed by the wave equation, then you would be able to reverse time and go back to your birth and start over again (in an endless cyclic process). But you know that this is not possible so your individual life cannot be modeled by the reversible wave equation with periodic solutions, while societies of many individuals of course may show periodicity.

47.3 The Heat Equation

A basic mathematical model with fundamentally different properties from the wave equation is the *heat equation*: Find the function $u(x,t)$ satisfying

$$\begin{aligned} &\dot{u} - u'' = 0 \quad \text{for all } x \quad \text{and all } t > 0, \\ &u(x,0) = u_0(x) \quad \text{for all } x, \end{aligned}$$

with now the second derivative in space u'' instead of the first derivative u' occuring in the wave equation. A subtle difference which changes everyting!

If we change the direction of time in the heat equation we get the equation

$$\dot{u} + u'' = 0$$

with a plus sign in front of u'' instead of a minus sign appearing in the heat equation. What kind of an equation is this? Is it another heat equation? No, it is an equation, which we refer to as the *inverse heat equation*, with completely different properties than the heat equation as concerns the effect of little perturbations:

FIGURE 47.2. Picture of Leibniz teaching philosophy of time to Queen Sophie Charlotte von Brandenburg before and after smoothing by the heat equation.

In the heat equation perturbations quickly get damped as time moves forward, while they in the equation $\dot{u}+u''=0$ quickly get amplified and drown the solution. The heat equation acts like blurring a sharp picture into an almost uniformly grey image. The equation $\dot{u}+u''=0$ would represent the reverse process of *unblurring* a blurred image, or unmixing the cream in your coffe after mixing by stirring. It would be practically impossible because the slightest little unavoidable error would ruin the reversal. It is clear that you cannot recover the initial image from the blurred in Fig. (47.2). We show an attempt in Fig. (47.3).

You can make the experiment in Photoshop yourself: Try to unblur an image which you have blurred and see that you cannot do that, even if you are an expert on Photoshop. The blurring has removed some details which are impossible to recover.

FIGURE 47.3. Picture of Leibniz teaching philosophy of time to Queen Sophie Charlotte von Brandenburg after an attempt to recovery by solving the inverse heat equation.

47.4 Summing Up

To smooth or mix (or smash a piece of expensive china) does not require much of precision, while the reverse process of sharpening or unmixing (or assembling the smashed vase) would require an incredibly high precision which cannot be achieved.

Mixing is easy. Unmixing is impossible. In other words: Time reversal in the heat equation is impossible. In a process governed by the heat equation, time can only moved forward. The heat equation has an Arrow of Time.

If your life is described by the heat equation, then time can only go forward and you can only get older (and smoother) with time until you are so smooth that you cease to exist.

Fair enough, but from where does the smoothing or diffusion come, which in the heat equation is modeled by the term $-u''$ (with the minus sign!). We can also view this term to model a process of friction in which mechanical or kinetic work is transformed into heat energy: By rubbing your hands, they get warm.

So, if there is some friction in your life, then necessarily there will be an Arrow of Time, but from where does friction come? Is it possible to get rid of the friction, and allow time reversal?

47.5 Turbulent Flow

The answer is NO! It is not possible to get rid of the friction, no matter how smart you are. And this insight is a new (and highly non-trivial) main result of the book. The reason is that if you consider a fluid with small viscosity, then the flow always becomes turbulent, and turbulence acts like friction transforming kinetic energy into heat energy in an irreversible process.

Why does the flow become turbulent? The reason is that the laminar flow that would have been reversible if it had existed, is unstable and thus does not exist. Turbulence can be seen as reaction to an impossibility of maintaining a laminar reversible flow: Facing an impossible situtation the flow goes turbulent. This is like smashing china in a living marriage confronting a necessarily arising impossibility. The slightly viscous flow cannot stay laminar and thus turns turbulent. And turbulent dissipation is irreversible. Information is destroyed and cannot be recovered.

Facing in your life the necessity to go on and the impossibility to satisfy all requirements exactly, the only way out is to decide to destroy some information (like old hang-ups) and that makes your life irreversible with an Arrow of Time.

In mathematical terms the The Arrow of Time arises because the inviscid Euler equations do not admit stable exact solutions, but turbulent approximate solutions with meanvalue outputs which are stable. Thus stable physical processes can be realized by paying the price of turbulent dissipation and irreversibility.

Life must be irreversible! Reversible life is unstable and cannot exist. Irreversibility is the price you will have to pay in order to exist. There is no alternative but no existence at all. What do you choose?

48
A Dynamical System with Memory

Music is the art which is most nigh to tears and memory. (Oscar Wilde)

I have always been amazed at the way an ordinary observer lends so much more credence and attaches so much more importance to waking events than to those occurring in dreams... Man... is above all the plaything of his memory. (Andre Breton)

The light that radiates from the great novels time can never dim, for human existence is perpetually being forgotten by man and thus the novelists discoveries, however old they may be, will never cease to astonish. (Milan Kundera)

Happiness is the longing for repetition. (Milan Kundera)

The struggle of man against power is the struggle of memory against forgetting. (Milan Kundera)

Without the meditative background that is criticism, works become isolated gestures, historical accidents, soon forgotten. (Milan Kundera)

48.1 Time Dependence Without Memory

Let us consider the concept of memory in the context of a dynamical system of the general form: Find $u(t)$ such that

$$\dot{u}(t) = f(u(t)) \quad \text{for } t > 0, \quad u(0) = u^0, \tag{48.1}$$

where $u(t)$ describes the state of the system at time t, $f(u)$ is a given function of u and u^0 is a given initial value. Such a system formally has *no memory*: The values of the state function $u(s)$ for $s < 0$ do not enter into the formulation (48.2), only the initial value $u(0) = u^0$.

More generally, the present state $u(t)$ at some time $t > 0$ determines $u(s)$ for any later time $s > t$. The influence of the previous states $u(s)$ with $s < t$ is channeled to later states $u(s)$ with $s > t$ through the "window of the now": $u(t)$.

48.2 Modeling Memory

A dynamical system *with memory* may take the form

$$\dot{u}(t) = f(u(t) + \int_0^t g(t, s, u(s))\, ds \quad \text{for } t > 0, \quad u(0) = u^0, \tag{48.2}$$

where $g(t, s, u)$ is a given function, and the integral

$$\int_0^t g(t, s, u(s))\, ds \tag{48.3}$$

represents the accumuluated influence on the current rate $\dot{u}(t)$ of all the previous states $u(s)$ with $s < t$. In this case $u(t)$ does not serve as the only channel to later states, but also previous states $u(s)$ with $s < t$ influence the future as memories remembered at the current time t. Depending on the function $g(t, s, u)$ the memory can be short, long, fading or have some other quality. What is important is that in order to take a time step from t to $t + dt$, it is necessary to have access to all the values of the state $u(s)$ for $s < t$ which enter into the integral (48.3), which thus need to be stored or memorized. Each value $u(s)$ then represents a "frozen moment" from time s which is stored in memory until "evaluation" at time $t > s$. A stored memory $u(s)$ is then "reused" for all $t > s$ for which the integral $\int_0^t g(t, s, u(s))\, ds$ contains the value $u(s)$.

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[9] Max Planck, Acht Vorlesungen über Theoretische Physik, Berlin, 1909: Es braucht kaum hervorgeben zu werden, dass diese neue Affassung des Zeitbegriffs an die Abstraktionsfähigkeit und an die Einbildungskraft des Physikers die allerhöchsten Anforderungen stellt. Sie übertrifft an Kühnheit wohl alles, was bisher in der spekulativen Naturforschung, ja in der philosophischen Erkenntnistheorie geleistet wurde; die nicheuklidische Geometrie ist Kinderspiel dagegen.

[10] Euler 1755

[11] J. Loschmidt, Sitzungsber. Kais. Akad. Wiss. Wien, Math. Naturwiss. Classe 73, 128-142, (1876).

[12] L. Boltzmann, Lectures on Gas Theory, Dover, 1964.

[13] J. Hoffman and C. Johnson, Is the World a Clock with Finite Precision?, Finite Element Center Preprint, 2006.

[14] J. Hoffman and C. Johnson, Computational Turbulent Incompressible Flow, Applied Mathematics Body and Soul Vol 4, Springer, 2006.

[15] J. Hoffman and C. Johnson, Computational Black-Body Radiation, to appear.

[16] W. Thomson, On the dynamical theory of heat; with numerical results deduced from Mr. Joule's equivalent of a thermal unit and M. Regnault's observations on steam, Math. and Phys. Papers vol.1, p.179, 1851.

[17] Sadi Carnot, Reflections of the motive power of fire and on machines fitted to develop that power, 1824.

[18] Einstein: Neither Herr Boltzmann nor Herr Planck has given a definition of W.

[19] Einstein: Usually W is put equal to the number of complexions. In order to calculate W, one needs a *complete* (molecular-mechanical) theory of the system under consideration. Therefore it is dubious whether the Boltzmann principle has any meaning without a *complete* molecular-mechanical theory or some other theory which describes the elementary processes (and such a theory is missing).

[20] Dijkstra: Originallly I viewed it as the function of the abstract machine to provide a truthful picture of the physical reality. Later, however, I learned to consider the abstract machine as the *true* one, because that is the only one we can *think*; it is the physical machine's purpose to supply a *working model*, a (hopefully) sufficiently accurate physical simulation of the true, abstract machine.

[21] William Ockham (1285-1349): Entia non sunt multiplicanda praeter necessitatem (Entities should not be multiplied unnecessarily).

[22] C. E. Shannon, A mathematical theory of communication, The Bell System Technical Journal, Vol. 27, pp 379-423, 623-656, July, Oct, 1948.

[23] Planck: Either the quantum of action was a fictional quantity, then the whole deduction of the radiation law was essentially an illusion representing only an empty play on formulas of no significance, or the derivation of the radiation law was based on sound physical conception.

[24] Planck: Mechanically, the task seems impossible, and we will just have to get used to it (quanta) (Planck 1909).

[25] Einstein to Born 1944: You believe in the God who plays dice, and I in complete law and order in a world which objectively exists, and which I, in a wild speculative way, am tryin to capture. I hope that someone will discover a more realistic way, or rather a more tangible basis than it has been my lot to find. Even the great initial success of Quantum Theory does not make me believe in the fundamental dice-game, although I am well aware that younger collegues interpret this as a consequence of senility. No doubt the day will come when we will see those instictive attitude was the correct one.

[26] Einstein: Some physicists. among them myself, cannot believe that we must abandon, actually and forever, the idea of direct representation of physical reality in space and time; or that we must accept then the view that events in nature are analogous to a game of chance. (On Quantum Physics, 1954)

[27] Born: If God has made the world a perfect mechanism, He has at least conceded so much to our imperfect intellects that in order to predict little parts of it, we need not solve inumerable differential equations, but can use dice with fair success. (Quantum Physics)

[28] Einstein: The theory (quantum mechanics) yields a lot, but it hardly brings us closer to the secret of the Old One. In any case I am convinced that *He* does not throw dice. (to Born 1926)

[29] Dirac: Shut up and calculate. (on quantum mechanics)

[30] Tolstoy I know that most men, including those at ease with problems of the highest complexity, can seldom accept even the simplest and most obvious truth if it be such as would oblige them to admit the falsity of conclusions which they have delighted in explaining to colleagues, which they have proudly taught to others, and which they have woven, thread by thread, into the fabric of their lives. (Tolstoy)

[31] Einstein: The more success the quantum theory has, the sillier it looks.

[32] Karl Popper, The Logic of Scientific Discovery, 1949.

[33] Schrodinger, The Interpretation of Quantum Physics. Ox Bow Press, Woodbridge, CN, 1995:"What we observe as material bodies and forces are nothing but shapes and variations in the structure of space. Particles are just schaumkommen (appearances). ... Let me say at the outset, that in this discourse, I am opposing not a few special statements of quantum physics held today (1950s), I am opposing as it were the whole of it, I am opposing its basic views that have been shaped 25 years ago,

when Max Born put forward his probability interpretation, which was accepted by almost everybody.

[34] "I don't like it, and I'm sorry I ever had anything to do with it". (Erwin Schrodinger talking about Quantum Physics)

[35] Fritjof Kapra, 1975: "A careful analysis of the process of observation in atomic physics has shown that the subatomic particles have no meaning as isolated entities, but can only be understood as interconnections between the preparation of an experiment and the subsequent measurement. Quantum physics thus reveals a basic oneness of the universe. The mathematical framework of quantum theory has passed countless successful tests and is now universally accepted as a consistent and accurate description of all atomic phenomena. The verbal interpretation, on the other hand, i.e. the metaphysics of quantum physics, is on far less solid ground. In fact, in more than forty years physicists have not been able to provide a clear metaphysical model".

[36] Stephen Hawking, 1988: "But maybe that is our mistake: maybe there are no particle positions and velocities, but only waves. It is just that we try to fit the waves to our preconceived ideas of positions and velocities. The resulting mismatch is the cause of the apparent unpredictability.

[37] Arthur C. Clarke:"If a scientist says that something is possible he is almost certainly right, but if he says that it is impossible he is probably wrong".

[38] E. Schrödinger, Die gegenwärtige Situation in der Quantenmechanik, Naturwissenschaften 23, 1935: I hope later to make clear that the reigning doctrine is born of distress.

[39] "Schrödinger's point of view is the simplest; he thought that by his develpoment of de Broglie's wave mechanics the whole pardoxical problem of the quanta had been settled: there are no particles, no 'quantum jumps'– there are only waves with their well-known vibrations, characterized by integral numbers. The particles are narrow wave-packets. The objection is that one generally needs waves in spaces of many diemnsions, which are something entirely different from the waves of classical physics, and impossible to visualize" (Born in the Born-Einstein Letters)

[40] Schrödinger was, to say the least, as stubborn as Einstein in his conservative attitude towards quantum mechanics; indeed, he not only rejected the statistical interpretation but insisted that his wave mechanics meant a return to a classical way of thinking. He would not accept any objection to it, not even the most weighty one, which is that a wave in $3n$-dimensional space, such as needed to describe the n, is not a classical concept and cannot be visualized. (Born in the Born-Einstein Letters)

[41] "What wanted to say was just this: In the present circumstances the only profession I would choose would be one where earning a living had nothing to do with the search for knowledge". (Einstein's last letter to Born Jan 17 1955 shortly before his death on the 18th of April, probably referring to Born's statistical interpretation of quantum mechanics).

[42] "De Broglie, the creator of wave mechanics, accepted the results of quantum mechanics just as Schrödinger did, but not the statistical interpretation." (Born in the Born-Einstein Letters)

[43] "I cannot understand how you can combine an entirely mechanistic universe with the freedom of the ethical will". (Born in the Born-Einstein Letters)

[44] "At any moment, the knowledge of the objective world is only a crude approximation from which, by applying certain rules such as the probability of quantum mechanics, we can predict unknown (e.g. future) conditions" (Born in the Born-Einstein Letters)

[45] It seems to me that the concept of probability is terribly mishandled these days. A probabilistic assertion presupposes the full reality of its subject. No reasonable person would express a conjecture as to whether Caesar rolled a five with his dice at the Rubicon. But the quantum mechanics people sometimes act as if probabilistic statements were to be applied *just* to events whose reality is vague. (Schrödinger in a letter to Einstein 1950)

[46] ... those who have talked of 'chance' are the inheritors of antique superstition and ignorance...whose minds have never been illuminated by a ray of scientific thought. (T. H. Huxley)

[47] "Therefore I feel that the Heisenberg-Bohr (Copenhagen) interpretation of quantum mechanics is dead". (H.D. Zeh, in The problem of conscious observation in quantum mechanical description, ArXiv Quant-Phy June 2000.

[48] Max Tegmark, The Interpretation of Quantum Mechanics: Many Worlds or Many Words?, in Fundamental Problems in Quantum Theory, eds. Rubin and Shih.

[49] Stephen Hawking, 1988: "But maybe that is our mistake: maybe there are no particle positions and velocities, but only waves. It is just that we try to fit the waves to our preconceived ideas of positions and velocities. The resulting mismatch is the cause of the apparent unpredictability.

[50] Robert Laughlin, A Different Universe, 2005.

[51] Walter Kohn, Electronic Struture of Matter - Wave Functions and Density Functionals, Nobel Lecture, 1998.

[52] David Warsh, Knowledge and the Wealth of Nations, W.W. Norton & Company, 2006.

Part VI

Appendix

49
Sustainable Society

49.1 The Vision of the Cave Man

The early cave man probably understood very well that creation and life cannot exist without destruction and death. Most of the cells of a human body get replaced over a month, and the members of a society get born, live their lives and die away, while the society continues to exist, for a while.

49.2 The Vision of the Modern Man

Somewhere along the line, somebody came up with the idea of *eternal life*, which became a dream to many. The dream of eternal life for individuals has remained a dream, but today there is a growing hope of a *sustainable society*, a society that will never die. The idea is that if we recycle enough, then human civilization can nicely continue for ever: It will be sustainable. All politicians speak about *sustainability*, and they have to do that to remain credible.

But is it credible? Can a sustainable society be realized, or is it just a dream? What does the 2nd Law say? We will return to this below.

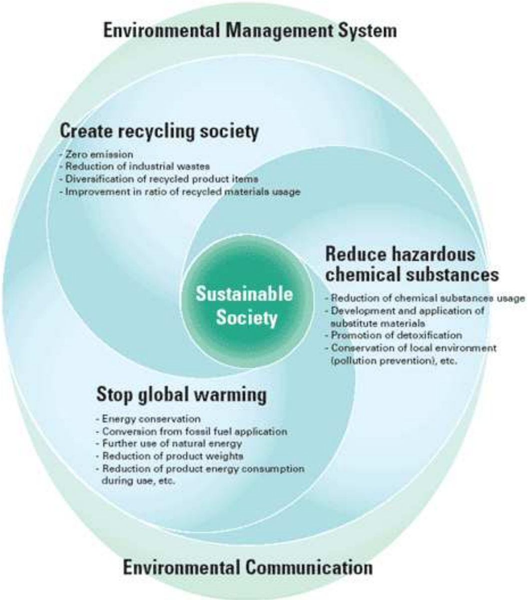

FIGURE 49.1. Model of a sustainable zero emission society.

FIGURE 49.2. Recycling of shoes