

## CHAPTER 6

# Time and Aging: A Physicist's Look at Gerontology

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To enter as a physicist into the field of gerontology brings along certain dangers. I will presumably fall into pitfalls of misunderstanding or step on some other booby traps, which those who are familiar with the terrain have learned to avoid. This danger is probably even greater since the so-called science wars and the Sokal affair have sensitized the relation between the physics community and those working in the humanities and social sciences in general.

To be sure, unlike Sokal's (1996) contribution, my chapter is not a hoax. But like him, my intention will be more or less skeptical and aimed at toning down overrated and uncritical expectations of the benefit of importing physical concepts into other fields of research. I will argue that, although modern physics has lots of interesting things to say about time, it has very little to say about aging. Moreover, the little it has to say about aging has no practical relevance for gerontology.

I will avoid trying to define aging. I take it that aging is a phenomenon that is familiar to every one who has looked into a mirror more than once. The field of gerontology aims to study the physiological, social, and psychological aspects of human aging. There are, *prima facie*, two good reasons to expect that this field might have some interesting relationships with physics.

The first reason is that both fields share a common interest: the concept of time. I will try to describe in this chapter some aspects of time in modern theoretical physics and address the question whether they shed light on the topic of aging. The second reason is that aging and its ultimate consequence, death, is a universal phenomenon. One of the few certainties that humans have is that they cannot remain young forever and will eventually die. The inevitability of this fate strikes us with such force that one might suspect this to be due to a general law of nature. Since physics is traditionally regarded as the discipline most intimately conversant

with laws of nature, it is natural to turn to physics in order to see whether there is such a law. Some authors claim it is the Second Law of Thermodynamics. They argue that all living beings evolve toward death because of the universal tendency toward ever-increasing entropy implied by this law.

The chapter is organized as follows. First, I will review some aspects of the notion of time that usually arise in discussions of this topic in physics and the foundations of physics literature. After that I shall give a description of the well-known Twin Paradox of relativity theory, which is arguably the result most relevant to aging in modern physics, followed by a discussion of some themes connected with the “arrow” of time and the Second Law of Thermodynamics. Finally, I shall debate some recent claims in the gerontology literature about the relevance of physical theory for the understanding of time and aging.

### TIME IN CLASSICAL (PRERELATIVISTIC) PHYSICS

Time is a central notion in physics. And although theoretical physics has developed exact ways to deal with this notion and experimental physics has devised accurate instruments to measure times, it is not easy to say what it is. If you ask a “physicist on the street” what is meant by time, the most likely answer will be “time is simply that quantity which is measured by a clock.” This answer is not very helpful for two reasons. First, the obvious objection is that one can define a clock, in turn, as an instrument designed to measure time. Thus, the answer is in danger of circularity. Second, it only addresses the quantitative aspect of how time is measured and not the meaning of the term.

In fact, I think it is fair to admit that physics simply does not have the wherewithal to specify the meaning of time or to define time in terms of more fundamental, nontemporal notions. The meaning of time is a problem belonging to metaphysics or, more generally, to the philosophy of physics. If we resist the temptation to dive into metaphysics, at least for the moment, one can only say that even in theoretical physics the meaning of time still has to be grasped on the basis of our common everyday language. In some sense this is embarrassing, because in our everyday speech time can mean many things. For example, on some occasions we speak of it as if it were a commodity: it is something we can spend, or save, waste or share. Here, it seems to be almost synonymous with effort or attention or, as the saying goes: money. This is clearly not the meaning intended in physics.

The intended meaning of time is more closely approached by the idea that all events can be ordered in an organized whole, by means of the primitive temporal relations “earlier than,” “later than,” or “simultaneous with.” To be more precise, let us denote the relation that event  $E$  is earlier than, later than, or simultaneous with event  $F$  as

$$E < F, E > F, \text{ and } E \sim F.$$

It is customary in classical physics to assume that these relations interlock in such a way to provide a complete, continuous, and linear ordering. This means that we postulate several properties of this ordering (which I won't spell out here). The upshot from these postulates is that one can derive the result that the ordering can be represented by means of a continuous parameter  $t$ . That is to say, we can attribute a real number  $t(E)$  to every instantaneous event  $E$ , such that

$$\begin{aligned} t(E) < t(F) &\text{ if and only if } E < F, \\ t(E) > t(F) &\text{ if and only if } E > F, \text{ and} \\ t(E) = t(F) &\text{ if and only if } E \sim F. \end{aligned}$$

An equivalent view is to represent the events geometrically as ordered along a straight line.

But even if we focus on this intended meaning, it is remarkable how underdeveloped our vocabulary for temporal concepts really is. Consider the analogy with space. In this case too, we can start with primitive spatial relations like “ $E$  is to the left of  $F$ ” etc., and build up spatial geometry from them. Once we have the geometry, we will readily distinguish various further spatial notions, for example, location, region, and distance. These terms are so familiar that no one would confuse them. Now, it is not hard to find temporal analogs for these fine-tuned distinctions. For example, we could use the terms instant, duration, and lapse to refer to temporal location, temporal region, and temporal distance. However, such specialized terminology has never become popular. Instead, one usually speaks of the “time of birth” when we refer to an instant, “the time of the Crusades” when we mean a temporal region, or an athlete’s “time” for the 100-meter race, when we consider the lapse between start and finish. Apparently, common language favors equivocation between distinct temporal notions. Below we will encounter further examples of this lack of precision in our temporal vocabulary.

The quantitative representation of time by a parameter  $t$  immediately raises a further problem. Once we have found one such parameter, we have many of them because every transformation, say from  $t$  to  $t' = f(t)$ , with  $f$  a monotonic continuous function, provides us with another parameter that represents the temporal ordering just as well. The choice of a unique parameter is obtained by introducing a standard time scale; it is fixed by the choice of a standard clock.

It is not easy to give criteria for the choice of such a clock; that is, to specify in what sense one particular clock is “better” than any other. The most compelling criterion one can come up with is the idea that this choice should make the physical laws of motion look simple. That is to say, one identifies certain physical systems, which we have good reason to believe are relatively free from external disturbances, and for which physical theory predicts that, if undisturbed, their evolution should be regular (e.g., periodic). Then, the best standard clock is one that makes their motion indeed come out perfectly regular. Thus, in the final analysis it is the theory that dictates the choice of an appropriate time scale and not the other way around.

This procedure might look a bit like cheating: the validity of our laws of motion seems to be guaranteed from the outset. Doesn't this mean that the validity of the laws of motion becomes a pure, empty convention? No. After all, in principle, it could very well be that there are no such clocks. It is an empirical fact, and not a conventional choice, that one can actually find clocks that make the laws of motion true (at least to excellent approximation) for all physical systems.

An obvious standard clock, which has served very well for centuries, is given by the various rotations in the solar system, from which we derive the units of the day, the month, and the year. But it is well known that these rotations are not completely regular, neither with respect to each other, nor with respect to clocks constructed by other means. Hence, by the seventeenth century, astronomers had replaced a solar-based year by the sidereal year, which is measured with respect to the "fixed stars." But then the fixed stars are also not really fixed. So, keeping up with the progress in observation and instrumentation, new and different standards have been devised. The most accurate standard currently accepted is the International Atomic Time (TAI), obtained from a statistical average over a large number of atomic clocks (see e.g., <http://tycho.usno.navy.mil/systime.html>).

Even after a standard clock system has been fixed, we are still left with the choice of a unit and a zero (origin) of the scale. Here we have nothing but convention and pragmatic reasons to guide us. The customary choice is to define the unit (the second) in such a way as to most closely correspond to existing practice. The choice of a zero is fixed by reference to some arbitrary event such as high noon in Greenwich England.

Note that the choice of a particular time scale is often called "Time." Thus, one refers to the various scales in common use as atomic time, sidereal time, Greenwich Mean Time, Central European time, summer time (or Daylight Saving), etc. This might easily suggest that by changing time scale, we are in fact adopting a completely new concept of time. It should be clear that this is not the case. The underlying concept is still given by the same qualitative temporal ordering, which is unaffected by the choice of scale. The choice of a scale is a pragmatic one. In fact, the habit of referring to different scales as different times again points to the paucity of common language regarding temporal notions. The analogous questions concerning space (e.g., the choice between miles and kilometers etc.) would never be considered to involve different notions of length, let alone different concepts of "space."

Perhaps the above remarks are already so obvious that some readers wonder why I mention them at all. The reason is that some authors in gerontology claim that the notion of time in classical physics is characterized by "reification," that is, by an identification of the notion of time with its measurement by a clock. And indeed, one must grant that the "physicist on the street" tends to confirm this view. It is therefore not entirely trivial to point out that classical physics does not support such a naïve identification. The choice of a clock is a subtle issue, settled by the

current state of the art in instrumentation and by considerations about simplicity and convention. But it does not bear on the underlying nature of physical time.

In order to prepare for later discussions, I will briefly discuss the question how one could attribute an age to physical systems in classical physics. Of course classical mechanics envisions systems as being composed of classical particles: immutable, nondestructible grains of matter, that cannot be subject to any aging. But another meaningful question is whether there is some quantity we can ascribe to the system that keeps track of the passage of time. Hilgevoord (1996) calls them *clock variables*.

For many simple systems there are such quantities. For a free moving particle, it is just the distance covered; for a harmonic oscillator, it is the phase; for a free-falling body in a uniform gravitational field, it is its velocity. Not surprisingly, the question is closely related to that of finding a good clock. Indeed, the systems just mentioned are all reasonable candidates to act as a standard clock.

However, there are good reasons why the study of such clock variables, which can be seen as measuring the age of the system, is not a prominent feature in theoretical physics. Usually, their analytical treatment is notoriously obstreperous. This is due, among other things, to the fact that in general a system may pass through the same state at different stages of its evolution. A clock variable, which is a function of state, will then become ambiguous.

It is often convenient to join the time parameter  $t$  of an event with its spatial coordinates. In that case, we end up with a four-dimensional space-time picture, in which every instantaneous and extensionless event in our universe is represented by four coordinates, specifying when and where it occurs. In doing so, however, an important implicit assumption of the classical time concept in classical physics becomes explicit. This is the idea that the temporal ordering applies universally, without regard for spatial locations. For example, it is assumed that one can always specify exactly whether or not two events are simultaneous, regardless of how distant they are from each other in space. This four-dimensional space-time picture provides a method to represent or order events and physical processes, which, in most cases, suffices for the purpose of physics. But it leaves many interesting issues untouched.

The first of these is the metaphysical problem of what time *is*. One of the best-documented issues in this problem is the debate between the so-called absolute and relational views on time (and space). The question here is whether time (or space) exists as an entity independent of events and processes, or whether it is no more than an abstraction derived from the spatiotemporal relations between such events. The debate between these two views has a long history, starting with Aristotle and culminating in the seventeenth century in a clash between Newton (leading the absolutist camp) and Huygens and Leibniz in the relationist camp.

The contrast between these two views can be illustrated by imagining a world in which there are no changes; a world which is completely dead and still. The two views give very different answers to the question whether there would be

time in such a world. According to the relationist, the notion of time is dependent on change, and therefore, in such an imaginary universe the notion of time ceases to exist. But from the point of view of the absolutist, time and space are conceived of as an arena or stage on which events are enacted. So even if there are no such events, the empty stage still continues to exist, and it remains meaningful to distinguish different instants and durations, even though there would be no instrument to measure them.

This debate on metaphysical issues is often coupled with issues from epistemology. Thus, relationism is often, but not necessarily, accompanied by the epistemological point of view (empiricism) that the meaning of scientific concepts has to be specified in terms of empirical observations. Since a universe without change clearly does not contain clocks to measure time, it is natural from this perspective to conclude that the very notion of time becomes meaningless. By contrast, the absolutist viewpoint seems more congenial to the epistemological view (realism) that science aims to describe an independently existing reality. Of course, we gain information about such entities by means of observation. But in this view, observation does not exhaust the meaning of our concepts. Their meaning is to be judged in terms of how they represent reality. So even if there are no means for measuring time, the notion itself can still be meaningful.

Apart from the above metaphysical problem, another question is how adequate the classical picture of time is. One can easily imagine other structures that differ more or less from the linear continuum. For example, one might assume that on a very small scale, time is not continuous but discrete. That is, one might drop the assumption that for any two distinct instants  $t_1$  and  $t_2$ , there exists a third instant  $t_3$ , which lies between them. Indeed, many modern physicists expect that at a scale of  $10^{-43}$  seconds (the so-called Planck time), the present theories of physics will collapse and have to be replaced by some theory as yet unknown.

Another issue is the question whether time extends linearly to plus and minus infinity. It is possible to imagine the ordering of time to be cyclic rather than linear: in other words, one might assume that events are recurrent after a long period. This would mean that instead of considering the space-time manifold as a flat infinite sheet, it would be curled up as a cylinder. Of course this entails that the relation of "earlier than" and "later than" do not define a global ordering. However, if the radius of that cylinder is large, it will be locally indistinguishable from the flat plane, just as the surface of the earth appears on a small scale as a horizontal plane. However, our evidence suggests that the history of the universe is not recurrent for at least  $10^{10}$  years.

Above, we have mentioned some issues that come up, time and again, in the physical and philosophical literature on time. Are any of such issues relevant to gerontology; that is, to an understanding of human aging? I do not believe so. The choice between, say, a Solar Year and the Sidereal Year might have occupied astronomers in the seventeenth century, but on a human scale the difference is so minute that it is not noticeable at all. Similarly, the debate on the relational and

absolute nature of space and time only becomes relevant in a universe that is devoid of change or contains only three or fewer objects. The universe in which we live is not of that kind. Finally, doubts about the continuity or linearity of the time ordering appear only at scales so small or so large that again they are irrelevant to any gerontology that is concerned with human affairs. We can conclude that the relevance of these problems for gerontology is therefore negligible.

### TIME IN RELATIVITY THEORY

The advent of the theory of relativity has brought radical changes to our conception of time and space. In particular, it brought about a whole new episode in the debate between the absolutist and the relationist views of time and space. Einstein struggled with the question how to unite certain aspects from the theory of mechanics with the theory of electromagnetism, developed in the nineteenth century by Maxwell and Lorentz. The details of his work are not important here, and so I merely mention that a crucial point in Einstein's reasoning was the recognition that we have no *a priori* way of assessing whether or not two distant events are simultaneous. This can only be accomplished by means of a synchronization procedure. Einstein proposed a natural procedure (synchronization by means of the exchange of light signals). This weaves the properties of light into the fabric of space and time. Given his further postulates about the behavior of light (its speed being independent of the source, and the relativity principle), he was able to show that the Newtonian notions of absolute space and absolute time had to be abandoned. In particular, the notion of simultaneity between distant events became dependent on the state of motion of the observer.

It is commonly believed that Einstein's theory of relativity favors the relationist viewpoint above the absolutist one. There are several reasons for this belief. The first is of course Einstein's rejection of absolute space and absolute time as such. The second reason is that his argument adopted an empiricist strategy, by analyzing how different observers, equipped with standard clocks and rods, would go about measuring space and time intervals. As mentioned before, this point of view is traditionally associated with relationism. The third and worst reason is that sometimes the close etymological resemblance between relativity and relationism leads to a conflation of the two.

However, it later became clear that this belief is not tenable. The special theory of relativity replaces the notions of absolute Newtonian space and time by a more elaborate structure, usually called Minkowski space-time. However this new structure is just as absolute as its two separate predecessors. The most striking distinction is that Minkowski space-time does not possess a notion of absolute simultaneity. More precisely, it is not meaningful in this structure to ask whether two distant events are simultaneous or not. However, Minkowski space-time does acknowledge a notion of "space-time interval," or a "metric" as it is often called, which is every bit as absolute as the structures of Newtonian space and time. In

particular, the metrical properties of Minkowski space-time are independent of, and not reducible to, events or processes.

The issue becomes more complicated when we pass from the special to the general theory of relativity. In this theory, the metrical properties are influenced by the presence of matter. I will not go into this topic. Suffice it to say that even in this case, there is no prospect for the claim that these metrical properties can be reduced to the spatiotemporal relations of matter (Hofer, 1998). The project of designing a fully relationist theory of space-time thus remains an elusive one, although work on this topic is still being pursued; for example, in Julian Barbour's recent book, entitled (somewhat misleadingly) *The End of Time*.

### The Twin Paradox

Perhaps the most straightforward case in which modern physics has relevance for aging is the particular consequence of the relativity theory known as the Twin Paradox. In special relativity, the rate of a clock depends on its state of motion. Consider two clocks, which are constructed in an identical fashion; and assume they are moving uniformly with respect to each other. That is, their relative motion is at constant speed and in a constant direction. For simplicity, let's adopt a frame of reference in which one of them, say *A*, is at rest. The theory of relativity predicts that, judged from this frame of reference, the moving clock *B* will run *slower* when compared with the rate of the resting clock *A*. This is the famous time dilation effect.

But now consider the case where one of the clocks makes a round trip and returns to the one that remains at home. From the point of view of clock *A*, the moving clock runs slow during both legs of the journey. So when it returns, it is lagging behind the resting clock. This is not a relative effect: it is a definite fact that, at the point where both clocks can be compared locally, the one that has travelled indicates an earlier time than the one that remained at rest. In general, the time indicated by a standard clock is now called its *proper time*  $\tau$ . The rate depends on the velocity of the clock through

$$d\tau = \sqrt{1 - (v/c)^2} dt$$

where  $c$  denotes the speed of light.

One can add some human interest to the story by replacing the clocks by a twin. Imagine that one of two twin sisters departs on a trip in a fast spaceship. After a long journey, in which she roamed the depths of the galaxies, she returns to earth. On her arrival, her sister is there to greet her. But when they meet, the space voyager is still in the prime of life; for her, the expedition has lasted only a year. Her stay-at-home sister, however, is already old and grey, because by earthly reckoning 50 years have passed. So, these twin sisters experience differential aging, even though both were born at the very same time.

This conclusion has been regarded as so paradoxical that it has been called the Twin Paradox. Many authors hasten to declare that it is not a real paradox

at all, since it does not involve a contradiction. But it has been appropriately named, in the original sense of the term paradox, meaning contrary to common sense. Needless to say, the above story is, of course, only a thought experiment. In actual fact, the velocities needed to achieve even the smallest difference in aging are enormous, and it seems unlikely that a spaceship with the required specifications will ever be built. However, there is no doubt about the validity of the Twin Paradox, since the effect has been observed for elementary particles, which are easier than humans to accelerate to speeds near that of light.

One question that has often been raised about the Twin Paradox is whether it is reasonable to assume that the relativistic time-dilation effect should affect humans in the same way as it affects physical clocks. Of course, generally speaking, physics has little to say about how humans perceive time durations. This issue falls under the province of "Psychological Time." It is an acknowledged fact of human experience that an hour spent in boredom, waiting for a delayed airplane, for example, is perceived as longer than an hour spent in pleasant company and entertaining conversation. There is no reason to doubt that this distinction between psychological and physical time will apply in space travel as it does in a terrestrial environment. Thus, whether the journey will be perceived as long or short will depend on whether the traveller is bored and lonely or not (whether NASA will provide entertaining company, on board movies, etc.) and not on the theory of relativity.

But apart from our mental perception of time, there are also physiological processes involved in aging: our metabolism, our hair and nails growing, the formation of wrinkles, etc. Again, it is well known that the rate at which some of these processes take place varies from individual to individual and is influenced by nonphysical factors. A well-known series of portraits of Jimmy Carter, taken at different stages during his four-year presidency of the United States, provides a telling example of how stress can speed up physiological aging. Again, there is every reason to expect that such factors will influence the aging of a space traveller in the same fashion as it does on earth.

But even if we acknowledge such effects, it seems reasonable to say that they represent relatively small variations on an underlying trend: roughly, humans do age proportionally to chronological time. Moreover, the relativistic time-dilation effect can be made as large as one pleases by increasing the speed to be arbitrarily close to that of light. In principle, it is possible to make the space traveller return to earth thousands of years after her sister died, while by her own clock the journey took less than an hour. No amount of boredom or psychological stress can compensate for such drastic differences. Hence, human beings are not essentially different from other physical systems or clocks, albeit very irregular ones, and the predictions of relativity will apply to them. So, regardless of whether the journey is boring, exciting, or stressful, the traveller will experience less aging than the earthbound twin sister.

So the theory of relativity has some impact on gerontology. If high-speed space travel someday becomes available to the common household, our perspective on aging will change dramatically, and the theoretical concepts to describe it will have to be modified. For example, one would no longer be entitled to assume that persons born at the same time belong to a single cohort. Still, I would argue that, until that day, one may safely conclude that the impact of this aspect of relativity theory on the problems of gerontology is negligible. The only lesson is this: if it is your dream to travel to the future and see what life on earth looks like in the twenty-fourth century, and if you happen to be a multimillionaire who can afford to build the required spacecraft, then, according to the theory of relativity, it is possible to realize your dream. (Although I would recommend cryogenics as a cheaper and more promising alternative.)

### THE ARROW OF TIME

The geometric representation of time, employed in both Newtonian and relativistic space-time, however, leaves out some aspects that are very deep-rooted in our experience of time, as well as in certain macroscopic physical phenomena. I am referring to what is often called "Time's Arrow." Eddington coined this phrase in a popular but very influential book of 1929. It was Eddington's aim to point out that physics systematically turns a blind eye to a certain "one-way property of time" that has no analogy in space. Exactly what that property is, is not so clear from Eddington's writing. It could stand for the idea that time goes on, the asymmetry between past and future, the distinction between being and becoming, and the irrevocable nature of certain physical processes. Again, there are quite a number of separate issues at stake here, conveniently but confusingly packed into a single phrase. Let's try to disentangle them.

One important aspect of time that is involved here is the idea of a *flow* or passage of time. Human experience includes the sensation that time moves on and that the present is forever shifting toward the future and away from the past. This idea is often illustrated by means of the famous two scales of McTaggart. Scale B is a one-dimensional continuum in which all events are ordered by means of a date. Scale A is a similar one-dimensional continuous ordering for the same events, employing terms like "now," "yesterday," "next week," etc. This scale shifts along scale B as on a slide rule.

Another common way of picturing this aspect is by attributing a different ontological status to the events in the past, present, and future. Present events are the only ones which are "real" or "actual." The past is not actual: it is gone and forever fixed. The future is no more actual than the past but still "open," etc. The flow of time is then regarded as a special ontological transition: the creation or actualization of events. This process is often called *becoming*. In short, this viewpoint holds that grammatical temporal tenses have counterparts in reality.

Is this idea of a flow of time related to physics? Many authors (e.g. Eddington, 1929; Prigogine, 1980; Reichenbach, 1971) have indeed claimed that the Second Law of Thermodynamics provides a physical foundation for this aspect of our experience. But according to contemporary understanding, this view is untenable (Grünbaum, 1967; Kroes, 1985). In fact the concept of time flow hardly ever enters in any physical theory. Newton's conception of absolute time that "flows equably and of itself" seems the only exception. But there is no evidence, as far as I know, that Newton's flow was the above idea of becoming. In a physical description of a process, it never makes any difference whether it occurs in the past, present, or future. Thus, scale B is always sufficient for the formulation of physical theory, and the above-mentioned ontological distinctions play only a metaphysical role.

It seems clear that tenses cannot be defined in physical terms, and that if they are to be used at all in a physical description, they have to be imposed or motivated from some external source. This is not to say, however, that these distinctions are illusions or only subjective. In fact I think there are two plausible viewpoints on the relation between tenses and physics. The first, a physicalistic viewpoint, is that we should take the physical conception of reality as (a provisional proposal for) a literally true description of reality. This point of view, and the fact that no physical theory yet has ever provided clues on how to ground tenses in physical reality, provides an argument in favor of the nonreality of tenses.

On the other hand, one might also argue that physics is an enterprise that, by its very nature and purpose, is limited and abstract. It considers only those aspects of reality that can be connected to or expressed in terms of general laws and repeatable events. This aim of physics naturally leads it to discard all aspects of reality that are accidental, nonrepeatable, and specifically tied to a unique "here-now." According to this point of view, the fact that physics finds no evidence for the concept of tense is not an argument that it is unreal, but just indicates that physics persistently ignores this aspect of reality.

A second theme, which is more relevant to physics, is that of *symmetry* under time reversal (Horwich, 1987). Suppose we record some process on film and play it backwards. Does the inverted sequence look the same? If it does, for example, a full period of a harmonic oscillator, we call the process time symmetric. But such processes are not in themselves very remarkable. A more interesting question concerns physical laws or theories. We call a theory or law time symmetric if the class of processes that it allows is time-symmetric. This does not mean that all allowed processes have a palindromic form like the harmonic oscillator, but rather that a censor, charged with the task of banning all films containing scenes that violate the theory or law, issues a verdict that is the same for either direction of playing the film.

Note that the term "time reversal" here is not meant literally. That is to say, we are considering a reversal of processes that is or is not allowed by some physical theory, not the underlying time ordering. Note also that in this

conception, time (a)symmetry is a property of the theory and not of the processes. That is to say, it is very well conceivable that one and the same process is characterized by some theory as time symmetric, while another theory judges it to be time asymmetric.

In many cases, the reversal of physical processes looks rather strange. Maxwell writes in 1868:

. . . if every motion great & small were accurately reversed, and the world left to itself again, everything would happen backwards. The fresh water would collect out of the sea and run up the rivers and finally up to the clouds in drops which would extract heat from the air and evaporate, and afterwards, in condensing, would shoot out rays of light to the sun and so on. Of course all living things would regrede [sic] from the grave to the cradle and we should have memory of the future but not of the past (Maxwell, 1995, pp. 187-188).

This image of a time-reversed world has been used by many novelists to exploit its weird and amusing consequences.

But it is hard to say whether a hypothetical censor would ban such a world as being in conflict with physical laws. It is a remarkable fact that on the microscopic scale, all fundamental physical theories are time symmetric. Thus, judged from those theories' point of view, the world described by Maxwell is just as physically possible as our own. However, many macroscopic physical laws are not time symmetric. Examples are the diffusion equation, Fourier's heat equation, etc. The most famous example is the Second Law of Thermodynamics. The question how this can be so, especially if one wishes to see the macroscopic equations as reducible to the microscopic ones, is a vexed question.

Another main theme in discussions on the arrow of time is irreversibility. A process is called irreversible if it cannot be fully undone. Once it has taken place, the original state cannot be completely restored, even with the help of the most sophisticated auxiliary apparatus imaginable. Examples of such processes are erosion, corruption, decay, and of course, aging. Planck famously argued that all processes in the real world are irreversible. He also claimed that this was a consequence of the Second Law of Thermodynamics.

It is not a trivial matter to state what the Second Law of Thermodynamics actually says (cf. Uffink, 2001). There are, as Bridgman (1961) conservatively estimated, as many formulations as there have been discussions of it! A relatively safe formulation is the statement that according to thermodynamics, all systems in an equilibrium state are characterized by a quantity called entropy, and that in all transitions that a system can go through during adiabatic isolation, ending in another equilibrium state, this quantity can never decrease.

However, the confusion surrounding the Second Law of Thermodynamics is not confined to classical thermodynamics, the theory developed by Clausius, Kelvin, Gibbs, and Planck. During the twentieth century, many modifications of the theory have been proposed, in order to make it applicable to more general types

of systems and situations. This has resulted in a plethora of theories, calling themselves “generalized” thermodynamics, “extended” or “rational” thermodynamics, thermodynamics of irreversible processes, nonequilibrium thermodynamics, continuum thermodynamics, etc. On some occasions, the same name is even claimed by rather different theories.

One of the best known of these approaches is probably the theory of Prigogine (1955) and De Groot (1951) which deals with open dissipative systems, generally assumed to be in nonequilibrium. Here it is assumed that such systems can still be characterized by an entropy function  $S$ . Changes in the entropy are supposed to be governed by two factors: an internal entropy production,  $d_i S$ , and an exchange of entropy,  $d_e S$ , with the environment. In other words:

$$(1) dS = d_i S + d_e S.$$

It is postulated that the internal entropy production is never negative

$$(2) d_i S \geq 0.$$

While this theory has scored a number of successes, in particular after the incorporation of the so-called Onsager relations, and in special cases where the adoption of a minimum entropy production principle was helpful, its status in physics has remained controversial and contested.

For example, it is always possible to resolve a change of entropy as a sum of two terms. In fact, this can be done in an infinite number of ways, even under the condition that the first term be positive. In order to obtain a unique identification of the entropy production and the entropy exchange, a more stringent definition of these terms is needed. Secondly, the justification usually offered for the assumption that the internal entropy production should be positive is the old second law of (orthodox) thermodynamics. But since orthodox thermodynamics is not applicable to nonequilibrium systems, one would expect some independent and more general arguments to be given in support of this extension to general systems.

Finally, Truesdell (1980) has severely criticized this and other theories for their rather liberal use of the differential calculus. He points out, among other objections, that in ordinary differential calculus there can be no meaningful differential inequalities.

In this section I have sketched various aspects involved in the notion of the arrow of time. The question how, if at all, these themes relate to gerontology is much more difficult than it was for the themes of the previous sections. Notions like the passage of time or becoming do have a strong connotation with our human experience of time and arise also in studies of psychological time. They are clearly relevant in gerontology. The main difficulty is rather that their relationship with physics, if any, remains unclear and controversial. Time asymmetry remains a major and unresolved issue in the debate on the foundations of physics. Irreversibility is perceived to be essential to the Second Law of

Thermodynamics, but again the issue is controversial. The question whether this second law, properly construed, has an impact on gerontology is the subject of the next section.

### IS AGING DUE TO A FUNDAMENTAL LAW OF PHYSICS?

Up until now, my effort has been devoted to a discussion of those aspects of time that capture the attention of physicists and philosophers of physics. In the present section I will reverse my approach. Instead of taking the physics literature as my point of departure, I will now start from the work by some gerontologists who argue that theoretical physics provides an important clue to the understanding of aging. This view is advocated particularly by Yates (1988) and also by Schroots and Birren (1988). The work by Schroots and Birren provides a convenient starting point, since it reviews much earlier work on the nature of time and aging in gerontology.

Of course the first question to be asked is what is meant by the distinction between time and age. The basic definition of age, mentioned by Schroots and Birren (1988), is that age is the time elapsed since birth. This is called chronological age. However, this concept is not all there is to age. We are all familiar with the expression that someone is young (old) for his or her age. A central quest of theoretical gerontology seems to be to give a scientific meaning to such locutions. Obviously, the intended notion of age here is not the chronological age; rather, one has to think of it as a quantity that characterizes a certain stage of development of an individual. The problem is whether one can find some objective markers from which an alternative to chronological age can be constructed. Depending on where the ingredients are drawn from, such constructs are called biological, psychological, or social age. The process of aging itself; that is, the increase of age, taken in these three distinct senses is called senescing, geronting, and eldering.

From the biological perspective, much research has been devoted to the various physiological phenomena that exhibit oscillatory behavior; for example, the heart beat, breathing, the sleep/wake cycle, etc. Indeed, in this research, the human organism has been likened to a clock shop, with complicated mutual hierarchical relations between them (master and slave clocks). Several such biological functions have been studied as indicators of biological age: maximum heart rate, lung capacity, hearing sensitivity to high frequencies, etc. Still, Schroots and Birren (1988) are not impressed by the results of such investigations. They conclude that “measures of functional or biological age were considered useless” and “Until now, there is no evidence of a better predictor of length of life, residual life-span, time until death, residual longevity or nearness to death than plain chronological age” (p. 7).

Schroots and Birren provide a similar overview for the topic of psychological time and its components, such as the notions of time experience, time perspective, and temporal awareness. Again, they reach rather pessimistic conclusions about

the prospects for this research. In particular, the problem seems to be that the variability of psychological time notions is observed to increase with age. They summarize the implications of this investigation drily as “every older man is in certain respects (a) like all older man (b) like some older man and © like no other older man, with strong emphasis on ©” (p. 15). Their conclusion is that “the idea of a new psychological age variable can be dismissed immediately.”

Their discussion on social time mentions, among other things, the concept of *eldering* or social aging, which is defined as the process of social role change and behavior in mature adults in a direction expected and displayed by others in a society. An important difference from the previous notions is of course that an analysis of social aging involves a strong reliance on normative concepts. But again, Schroots and Birren are not happy with what they find in this literature. They observe that “the fundamental criticism of the concepts of biological age and psychological age also applies to social age, which is scaled on a physical time-scale, and is consequently measured in units of calendar or chronological time” (p. 16). In conclusion, “the quest for social time has merely resulted in *tautologies*, implicitly or explicitly” (p. 19).

Clearly, previous work in gerontology has failed to provide a proper analysis of aging, according to Schroots and Birren. Yates (1988) expresses similar complaints about the lack of coherent theory building in gerontology. Together, they advocate a new approach, which Schroots and Birren term “gerodynamics.” Generally speaking, there are three main characteristics of this approach. First, it regards humans as instantiations of a general species of “living” or “biological” systems, to be described by thermodynamics of irreversible processes. A second characteristic is the claim that aging is to be seen as an accumulation of entropy in the system, due to the Second Law of Thermodynamics. Third, it involves the introduction of another concept of time, called “intrinsic time.” I will expound and comment on these three points below.

### HUMANS AS LIVING SYSTEMS

Schroots and Birren provide a clear description of the conception of human beings in gerodynamics. According to this viewpoint,

... humans are regarded primarily as living systems, hierarchically organized from many subsystems, such as cells, cell tissues, organs, and so on, according to levels of complexity. As a system, humans can be conceived of as part of an even more complex larger system—for example, the physical and social environment. From a thermodynamic or energetic point of view, a living system of any sort is *open*.

That is to say, a current of energy passes through the hierarchically organized (sub)systems in a chain of reactions. This flow of energy starts with the sun as solar energy and gets transformed into chemical energy via plants and animals, which are our food. Metabolism introduces further

*transformations*, in which food with a relatively high energy level is converted into waste products such as carbon dioxide and water, with low energy levels of biological systems (p. 22).

While this quotation greatly emphasizes the role of physical concepts, the fact that Schroots and Birren include the social environment in their scheme shows that their approach is not exclusively physical and allows for nonphysical factors.

By contrast, Yates is more outspoken in his physicalist outlook. His stated aim is to provide “the physical foundation for a general gerontological theory” (Yates, 1988, p. 91) and indeed a full “epistemological reduction of biology to physics” (p. 94). Succinctly, his goal is

... to close the gap between biology and physics so that we can make some progress toward a comprehensive scientific theory of the aging of biological systems. In that physical theory aging will be seen as a progressive loss of dynamical stability dependent on changing constraints. That alteration of constraints is the touch of the Second Law [of thermodynamics] in biochemical networks. The theory will also require that there are two kinds of time for biological organisms” (p. 97).

Strangely, Yates (p. 91) accompanies this stated goal by an admission that his point of view is anthropocentric; that is, concerned with humans only. This seems to me incoherent with the quest for a comprehensive and general theory.

### THE SECOND LAW OF THERMODYNAMICS

As is apparent from the last quotation, a second main theme in the approach advocated by Yates as well as Schroots and Birren is the role of the Second Law in the explanation of aging. The main idea is that living organisms are to be regarded as open thermodynamical systems in a steady state. As mentioned above, this means that we associate an entropy  $S$  to such a system, whose change is governed by an internal entropy production and exchange with the environment. In order to maintain a steady state, in which the entropy of the system remains constant, these two terms should compensate each other.

$$(3) dS = d_i S + d_e S = 0.$$

In other words, in a steady state, the internal entropy production is compensated by an equal amount of entropy exportation to the environment.

But Yates claims that the Second Law also has another interpretation; namely “Constraints shall not last!” (p. 99). He argues that an organism cannot maintain a steady state indefinitely, because “the internal thermodynamical engine cycles are not perfect, being themselves subject to the Second Law” (p. 102). The result is that

$$(4) d_i S > d_e S,$$

which implies  $dS > 0$ . Hence, by the continual loosening of internal constraints, there will be an entropy accumulation in the system. It is this accumulation that “drives senescence,” according to both Yates and Schroots and Birren. Indeed, as the latter argue

Generally speaking, one might then say that each living system moves toward maximum disorder or entropy, in short toward death. In terms of general systems theory from a thermodynamic perspective aging can now be defined as the process of increasing entropy with age (p. 22).

There are several remarks and objections to be made. First, Yates’ interpretation of the Second Law is rather unorthodox. The version of the Second Law of Thermodynamics proposed by Prigogine implies nothing more than  $d_i S > 0$ . The inequality (4) does not follow from this and cannot be said to be an expression of this law. Of course, this is not to say that this relation is generally false. In many systems, whether living or not, we do see a loosening of constraints as time goes on (by wear and tear, etc.), and they are often accompanied by an increase of entropy. But in many other cases, the passage of time will not loosen constraints but merely change them, or indeed even impose additional new constraints. All this is entirely compatible with thermodynamics as commonly understood. Therefore, Yates’ reinterpretation of its Second Law has no lawlike validity within thermodynamics.

Further, even if one admits that living systems are in many circumstances truly characterized by an accumulation of entropy, it is not thereby established that one can *define* aging as the accumulation of entropy. An obvious counterexample is obtained by considering an experiment in which one avoids internal entropy accumulation by increasing its exchange with the environment. If you lock me in a freezer cell for several hours without protective clothing, the entropy production of my body will not keep up with the heat that it loses to the environment. So here we have

$$(5) d_i S < d_e S,$$

and my total entropy  $S$  will decrease. Note that in spite of the violation of (4), this is not at all in conflict with the Second Law. But still, my losing entropy does not mean that I will become younger. Instead, I will die from cold. Incidentally, the example also shows that death cannot be equated with a state of maximum entropy. Indeed, it seems likely that in many cases, dying is not accompanied by any change of entropy in the organism at all and hence is a thermodynamically rather insignificant event. A development toward maximal entropy occurs only during the subsequent process of decay or cremation. Clearly then, it is too naïve to expect that a complex phenomenon such as human aging can sensibly be reduced to the increase or decrease of a one-dimensional physical quantity.

As noted before, Schroots and Birren allow for a role of the social environment in their conception of living systems. They envisage that this role can be included

in the general scheme by means of a concept of “social entropy.” But this seems hardly a viable option. Social entropy is at best a dubious metaphor, which has lost all relationship to thermodynamics. It does not and cannot appear as a term in the entropy balance of an open thermodynamical system simply because this relation applies equally to cars and stars and microwave ovens as it does to living organisms. If one wishes to pursue this idea seriously, then the whole evocation of the thermodynamical formalism becomes nothing but a speculative metaphor rather than a physical foundation for a theory of aging. As an aside, I note that the introduction of social entropy (interpreted by Schroots and Birren as a form of information) is not favored by Yates. He regards information as a “toxic juice,” which ought to be wrung out from gerontological theory (Yates, 1988, p. 97).

### INTRINSIC TIME

Another main ingredient of gerodynamics is the proposal of a new notion of time, called “intrinsic time.” This notion is supposed to stand in contrast to the ordinary (chronological) concept of time, which is henceforth also called “external time.” It is claimed that intrinsic time is relevant for the explication of aging. Thus Yates writes

External . . . time gives us the clock time by which we measure chronological age, *but it does not necessarily give us intrinsic human age*, which is determined by internal process time as described below. . . . Intrinsic time is created by biological processes as an emergent property of their non-linear dissipative dynamics, leading to the result . . . that the intrinsic biological significance of a unit of external time cannot be itself constant but must change with chronological age (p. 98).<sup>1</sup>

Schroots and Birren argue similarly, but are more explicit about what to understand by intrinsic time:

Paraphrasing Richardson and Rosen, it may be stated that any given dynamics of any given system will generate its own *intrinsic time* scale. That is, intrinsic time is created by physical, biological, psychological and social processes as an emergent property of their dynamics. As already known, any dynamical process can serve as a clock, time being measured by monitoring one of the variables undergoing change. The dimensional unit of this intrinsic time is simply the unit of the state variable chosen for observation” (p. 24).

They illustrate this concept by the example of a burning candle. Here, one can consider the length of the candle as the state variable undergoing change and indicating the intrinsic time of this process.

A number of questions may be raised about this notion of intrinsic time. The most important one, in my opinion, is that this discussion of intrinsic time seems to

<sup>1</sup> Amusingly, he presents this as “the simplest view consistent with Einsteinian locality.”

suffer from a pervasive confusion. What is really meant by this concept? From the texts available to me, I think there are two ways in which one can understand it. The straightforward, literal, way would be to read these authors as proposing a different time *scale* or unit for measurement of time. But this proposal immediately runs into difficulties. As we have seen before, the question of the choice of scale is one that is settled largely by considerations of convenience. Nothing substantial is at stake in this issue, as long as we do not upset the underlying temporal ordering relation. It is hard to see how one particular scaling convention would possess more explanatory power than any other, or would in some other way provide an essential element in the analysis of aging. Indeed, it seems that once more, the poverty of our language concerning temporal concepts lures one into the misconception that by choosing another scaling convention, we have actually created a different concept of time altogether. This confusion also appears in Schroots and Birren's "fundamental criticism," mentioned above, against previous notions of time; namely, that they rely on a scale measured in chronological time.

However, there is a second way of reading the proposal. One can understand the vague claim that intrinsic time "is created as an emergent property of the dynamics" as intending to say that it is a variable of the dynamical state of a system. In this sense, the notion of intrinsic time would be analogous to the proper time of special relativity theory, which depends on the velocity of a system. Indeed, if the purpose is to provide a basis for the idea that different individuals age at different rates, this should be the type of concept we are after. One only has to assume that some other dynamics than that of relativity could produce a similar differential effect on at least some variables of the system.

It is to be noted that in this second reading, intrinsic time is an attribute of a system, and hence, there can be as many different intrinsic times as there are systems. But it has nothing to do with a choice of a scale. (Although one can, of course, choose some intrinsic time as a standard scale.) Indeed, in the Twin Paradox we only arrive at the definite result that the two sisters age differently because we apply the same scale (i.e., the same standard clock) to both of them. If one could say that one sister has aged 50 units in one scale and the other only one unit of a different scale, then we have no basis to compare them: it might be that the former units are weeks and the latter years.

Now in spite of these misgivings, it should be clear that the desire for a time scale that fits the study of aging is a perfectly natural and legitimate enterprise. We have seen before that in physics, the choice of a time scale is largely a conventional issue. It is picked out by the desire to make the laws of motion look simple. And just like physicists, gerontologists may also wish to design a scale in which gerodynamical laws (if there are such things) take their simplest form. Ideally, one would like to obtain a scale that reflects the fact that the human life at certain stages goes through rapid transformation and more or less

tranquil periods at other stages. In other words, such a scale should be proportional to the transformational rate rather than chronological time.

In fact it is not hard to find such scales. The main problem for the prospect of using an intrinsic time scale is that there appear to be so many choices for such a scale. For example, Yates considers an intrinsic time determined by mortality rate. That is to say if  $t$  represents the ordinary chronological time scale and  $f(t) dt$  represents the probability that an organism dies between  $t$  and  $t+dt$ , then

$$d\sigma = f(t) dt$$

defines a time scale  $\sigma$  in which the mortality rate is constant.

An advantage of this scale is that it is readily obtainable from demographic data. Moreover it has the appealing feature that it depicts humans as aging faster at those stages in which mortality is higher (i.e., during infancy and old age) and relatively slower in between. (It would, however, give less prominence to early adolescence, a stage that, although arguably the scene of important transformations, does not appear to be accompanied by high mortality.)

However, this choice of time scale also has disadvantages. Obviously, the mortality rate is, strictly speaking, a property of the population as a whole rather than of an individual. It is well known that the mortality rate is highly dependent on the social environment. A person living in an industrialized and peaceful society has a higher life expectancy than one who is born into a poor or combative society. Moreover, a society can itself witness transition from poverty to affluence, from peace to war or back again, in just a couple of years or decades. This means that, as a measure of intrinsic age, the mortality rate suffers from the same problem as measuring money by its nominal value: it may show considerable inflation or deflation within an average life span.

Another proposal for the definition of intrinsic time scale, discussed by Schroots and Birren, is the rate of metabolism. They refer to Hershey and Wang (1980), who report work on the metabolic rate, as calculated from respirational data on mammals, and were subsequently able to obtain a metabolic age for human subjects. This is a time scale whose increments are proportional to the metabolic rate. An advantage of this scale is that it is more explicitly internal and tied to the individual organism itself.

Both Yates and Schroots and Birren express the hope that a general connection between intrinsic time and thermodynamics can be obtained. This hope seems to be based on a paper by Richardson and Rosen (1979), which claims to derive an entropic metric for intrinsic time in a certain class of dissipative processes.

Their paper makes it clear that it is not concerned with the choice of a particular time scale, but with the second alternative mentioned above; namely, the introduction of a quantity determined by the state of the system, which can be used to calibrate its age. Unfortunately, I doubt very much whether this hope will come to fruition. When dealing with open systems, one has to give up the idea of intrinsic dynamics. The fate and evolution of an open system depends, not

only on its own initial state and constitution, but also on its environment and its modes of interaction with its environment. The notion of intrinsic time is therefore anything but intrinsic to the system.

Although Richardson and Rosen claim that they have obtained an intrinsic time in a certain class of dissipative processes in terms of an entropy metric, their actual results are much more modest. The intrinsic times they consider can only be compared to systems of the same dynamical class (e.g., one may compare two candles with each other, and two harmonic oscillators to each other, but one cannot compare the intrinsic time of a candle with that of an oscillator). Given the fact that every human will in some sense undergo its own unique dynamics (“every old man is like no other old man”), this means one has no basis for comparing intrinsic ages of different individuals. This is enough to shatter any prospect of a general gerodynamical science. Secondly, their claim to have derived an entropic metric for the intrinsic time in certain dissipative processes is not substantiated. Indeed, the concept of entropy never occurs in their treatment of intrinsic time, and its metric; that is, its relation to ordinary time is always determined completely by the constitutive parameters of the system. Thirdly, their approach only works straightforwardly for a single variable. The generalization they offer (and characterize as “immediate”) to treat more than one variable, which is in fact mathematically flawed.<sup>2</sup>

Yates (1988) goes even further in his claims about a physical underpinning of intrinsic time. He claims that “the origin of intrinsic time is quantized action” (p. 99). This last term is meant to refer to Bohr’s postulate that certain action integrals of atomic orbits are only allowed to assume integer multiples of Planck’s constant. This postulate forms part of a precursor of quantum mechanics, nowadays called “old quantum theory” or Bohr-Sommerfeld theory. He claims that the quantization of action assumed by Bohr’s theory also applies to macroscopic processes such as metabolism, and leads to a natural time scale. He also claims that the discretization of action arises out of the general dynamics of complex systems.

This is an astonishing set of claims, and frankly, I believe not a single one of them is true. First, in physics Bohr’s quantization of action has long been discarded in favor of the “new” quantum mechanics, created in 1925–1926 by Heisenberg, Born, Jordan, Dirac, and Schrödinger. Second, it is certainly not a consequence of general dynamics, nor does it involve complex systems.

<sup>2</sup>Technically speaking, they argue that in this case, several intrinsic times can be defined, one for each variable separately. They show that in the case of coupled linear transport equations, the substitution of these into the differential equations results in a sum that formally resembles the expression of a distance in terms of a metrical tensor. But the metric is given here by the coupling coefficients in the transport equations, not by entropy. Moreover, Richardson and Rosen do not address the question whether the various intrinsic times are mutually independent. Without an answer to this issue, the partial derivatives in terms of those that they use are not well defined.

Finally, quantization of action does not lead to a natural time scale; in the Bohr-Sommerfeld theory, it is used to obtain stationary states in which no change occurs.

## CONCLUSIONS

Does theoretical physics have anything to contribute to gerontology? In the first part of this chapter, I have taken a short tour around some topics in the study of time that capture the interest of physicists and philosophers of physics. Generally speaking, one can say that there is little here that should arouse the attention of gerontology.

In the second part, I have looked at the work of some gerontologists who turn to physics for the development of a general theory of aging. Again, the main findings here are disappointing. The view of a human as a physical system is a valuable point of departure. Of course, this is not to deny that humans also have complex psychological and social relationships. In fact, many will argue that it is these relationships that define who we are as human beings. But notwithstanding that fact, a scientific account of humans as physical systems, rather than disembodied rational agents, is certainly needed to get a comprehensive account of aging.

There is also no doubt that the human organism is subject to the laws of thermodynamics and, in this respect, is not essentially different from other, less complex, open thermodynamic systems, such as microbes or combustion engines. However, we do not age in the same way as microbes or combustion engines or even other mammals. It seems unlikely to me that the vocabulary of nonequilibrium thermodynamics, or any other general physical theory, is rich enough to account for this distinction. Hence, a proper explanatory account of aging cannot be conducted in terms of general physical concepts; it must relate to some very special aspects of our physical and biological make-up, and presumably our psychology and social make-up as well.

So does physics have anything useful to teach gerontology? When I started writing this chapter, I was convinced the answer would be no. But now, looking back, I think there is maybe one lesson. In physics one can draw a sharp distinction between the choice of a time scale and the conception of age as a dynamical variable of the system. Perhaps this example may help gerontologists to draw a similar distinction in their study of human aging.

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## CHAPTER 8

# Whence an Emergence of Biological Time?

*Jos Uffink*

In Chapter 6 I have discussed the role that modern theoretical physics might play in our understanding of those aspects of time and aging that are prominent in gerontology. My main purpose was, frankly, didactical. I pointed out that many discussions of these issues suffer from confusion by using the same words to denote different concepts. My overall conclusion was that the help of theoretical physics in the problems of gerontology can only be very limited. I also took the opportunity to criticize some authors who argue that the theoretical framework of gerontology should be grounded in the laws of physics. In particular, I have criticized Yates (1988) for his fanciful interpretation of the Second Law of Thermodynamics, his claim that a notion of “intrinsic time” would follow from Bohr’s quantum postulate, and the curious inconsistency between his self-professed aim to develop a general, physics-based biology and the admission that his approach is anthropocentric and thus applicable to human beings only.

Now Yates has responded to my essay in the foregoing chapter. His response does not touch upon any of my critical comments mentioned above, so my present rejoinder will mostly consist of some general observations about his response. I will postpone a discussion of the single point on which Yates does criticize my previous chapter to Section 5.

### FROM PHYSICS TO BIOLOGY?

The theme of Yates’ reply is the “emergence of biological time.” It is clear that the main topics characteristic of Yates’ conception of biological time are its flow, its direction, and its alleged irreversibility. Note that the concept of aging (or the more specialized concept of senescence) is not mentioned here, nor are they addressed elsewhere in his chapter. Neither is the distinction between intrinsic and

extrinsic time, which appeared to be such a crucial ingredient in his previous work. Accordingly, I will not return to my criticism on these issues either. The central topic of Yates' reply is the question whether and how biological time might emerge from physics. This question, of course, is intimately connected with the wider problem of the relationship between biology and physics in general. In fact, it is this general problem that occupies the main part of his chapter.

The most striking point in the chapter is that it involves a complete withdrawal of the view Yates espoused previously on this relation. His earlier chapter advocated a thoroughly reductionist view of the relation between physics and biology, as can be seen from the following quotations:

Life obeys all the known laws of physics. No new fundamental postulates are needed to explain the dynamics of life (Yates, 1988, p. 106).

and

To me the issue is: Can we strengthen biology through epistemological reductions to physics? I see no chance for expunging intellectually pernicious or vapid vitalism, entelechy, *élan vital*, and "Just So" stories from biology unless we strive for that reduction, at least in principle (Yates, 1988, p. 94).

Yates' present manuscript, however, advocates a diametrically opposed view. It argues that physics is just incompetent to deal with complex systems, such as living beings, and claims

Because it is abundantly clear that conventional physics cannot do the job of illuminating biological time, we biologists need a fresh approach (Yates, this volume, p. 163).

Moreover,

as physics abandons time to our illusions, it disqualifies itself as a basis for a hoped-for strategic physical biology . . . revealing that even at its best, physics is nongeneric. . . . *The only truly generic science is biology!* (Yates, this volume, p. 166).

Clearly, Yates has given up all of his previous hope for a reduction of biology to (conventional) physics. Instead, he now argues that physics should be extended by various new postulates in order to explain the dynamics of life. One naturally wonders what may have caused such a radical change of mind. Could my previous chapter have convinced Yates to revise his previous views? If so, I would of course welcome this as a silent compliment. But, in fact, I doubt that my chapter deserves such credit. The reason is that I never criticized Yates for his previous reductionist outlook. Indeed, I am more sympathetic to his previous views on the relation between physics and biology than to those adopted in his present chapter.

Let me explain this in more detail by stating my own view of this relation (for which I obviously do not claim any originality). I fully agree with Yates' previous view that living beings are physical systems, and that physics needs no extension,

in the form of new fundamental postulates or otherwise, to describe life. That is to say, I adhere to reductionism on the ontological level.

However I am skeptical about reductionism on the epistemological level. I do not expect that biological concepts and theories will be derived from the laws of physics by means of mere correlative definitions or bridge principles and the application of certain special conditions. In short I do not believe that a “theory reduction” is feasible. My skepticism on this point is based on two considerations. First of all, the ideal of a successful theory reduction has proved to be very hard to come by. Even those cases that were previously thought to be paradigmatic successes of theory reduction (such as the relation between thermodynamics and statistical mechanics) turn out to be much more obstreperous upon closer analysis. In fact, there seems to be hardly any example of successful theory reduction within physical science. But then, since epistemological reduction is already so difficult to attain, even for theories such as thermodynamics and statistical mechanics, which are relatively close to each other in their conceptual apparatus, it seems implausible that it will be obtained between more distant sciences like physics and chemistry, let alone physics and biology. A second point is that theory reduction presupposes that both theories involved are formulated in terms of a formal calculus or in terms of set-theoretical predicates. It is, however, obvious that biology as yet does not adhere to this format.

Now, it may seem that the above point of view on the relation between physics and biology (ontological reduction yes; epistemological reduction no) is somewhat disappointing. Surely, one might argue, if one admits that living organisms are physical systems, one ought to expect some kind of intertheoretical relationship between their descriptions in physics and in biology. A flat rejection of epistemological reduction might easily seem like a denial of such a relationship. My response would be that the requirement of some intertheoretical relationship is indeed natural, but that it need not take the special form of theory reduction, or, for that matter, the form of “emergence.” My own expectation is that some form of the notion of “supervenience,” which is currently receiving much attention in the philosophy of science literature, is most likely to account for this relationship (cf. Kim, 1984). But it would take us too far afield here to argue for this in detail.

To end this section, allow me to make one final comment on Yates’ claim that, in contrast to physics, biology is the only truly generic theory. I think this remark is inconsiderate. With all due respect for the immense progress that biology has achieved in the last century and a half, it seems fair to say that we have no clue whether even the most celebrated results of biology (e.g., the theory of evolution or the determination of the genetic code) have any validity outside of planet Earth. For all we know, biology depends essentially on highly contingent and very special conditions of our local cosmic environment. To claim that biology is generic and physics is not is to mock the meaning of the word.

### THE “FAILURES” OF CONVENTIONAL PHYSICS

Having explained my own views on the relation between physics and biology, I now return to a discussion of Yates’ chapter. He claims that conventional physics suffers from limitations, which ought to be acknowledged before any progress can be made. He lists a total of five such flaws, but for brevity, I will comment on only two of them.

His first point is that physics is unable to deal with complex systems. It is somewhat hard to discuss the merits of such a claim without a definition of the term “complex systems.” What does one mean by a complex system? Is it one with a huge number of degrees of freedom? Is it a system whose dynamics are complicated and unstable? Must it be an open system? Is it far from equilibrium in the thermodynamic sense? Is it necessary that it should have an active interior, displaying periodic or almost periodic cyclic processes or processes that are nearly cyclic? There are passages in Yates’ chapter that suggest he regards each of these criteria as essential, but no clear-cut definition is provided that would help to sharpen the discussion on this issue.

Nevertheless, it is not too difficult to rebut the claim. Whatever criterion used to define a complex system, it seems to me that the sun qualifies on all counts. It consists of a huge number of particles; it is far from in thermodynamic equilibrium with its environment; it is open (emitting radiation into empty space) and possesses a very active interior, producing solar protuberances on a scale of hundreds of thousands of kilometers, and a stable internal cycle of sunspot activity of about 11 years. But is physics incompetent to describe the sun? Visit the section of any university library devoted to solar physics and one will be convinced of the absurdity of such a claim.

A second claim laid down by Yates is that

Living systems carry their histories with them. . . . In contrast, physical systems are predominantly ahistorical—just responding to the fields in which they are embedded . . . (Yates, this volume p. 164).

This view of physical systems is plainly false. Obvious counterexamples are the phenomena of magnetic hysteresis, and the “form memory” displayed by certain metals, or the hard disc of any personal computer. My impression is that Yates confuses the general idea of a physical system with that of an elementary particle, and mistakenly assumes that physics is only interested in the latter.

Now it is true, of course, that our physical understanding of complex systems in general, and of living organisms in particular, still leaves much to be desired. Most of our theories concerning macroscopic systems are still semiphenomenological and do not depart from “first principles.” But that is no surprise. In general, the study of complex systems is also complicated, and it is quite natural that progress on this topic is slow and involves a lot of hard work. The fact that our

understanding of macroscopic and complex systems within conventional physics is still incomplete is, in my opinion, no indication that physics is flawed or in need of repair.

### A FIX FOR THE “FAILURES” OF PHYSICS

However, Yates’ conclusion is a different one. He argues that the flaws mentioned in the previous section need to be “fixed” in order to obtain a new, extended physics, for which he has coined the name of “homeodynamics.” This new theory is allegedly capable of dealing with complexity and the emergence of biological time. Of course I welcome every effort to improve or extend physics and wish this new theory every bit of success. But the stakes in this game are high: every proposal of a new theory will be judged by comparing its success with that of its predecessors and competitors, in particular the conventional physics that Yates wishes to leave behind.

Thus, we have the right to ask how homeodynamics competes with conventional physics. In particular, one might ask whether homeodynamics meets the standards of Yates’ own “ultraconservative position” (Yates, this volume p. \_\_\_), which requires any useful physical theory to be formalizable in set-theoretical terms and to specify predictive theoretical models that can be tested against empirical data. Unfortunately, no such formalization of homeodynamics is offered. Indeed, from the list of 10 assumptions provided by Yates, I cannot make out much of the content of his new theory. His description is no more than a set of slogans.

Be that as it may, it is apparent that Yates has high expectations of the role of fluid mechanics in his new theory, and of the Navier-Stokes equation in particular. This strikes me as odd, because fluid mechanics and the Navier-Stokes equation have been part and parcel of conventional physics for more than a century and a half. Yates’ proposal to “extend” physics by incorporating this equation is thus, at best, a little late.

What is more, the conception of time employed in fluid mechanics is really the same as in Newtonian theory. Since Yates considers the latter to be incompatible with biological time, one wonders how biological time is going to emerge in homeodynamics. What Yates offers in support of this claim is surprisingly little. It consists merely of the exclamation that “Homeodynamical processes do not occur in time—they *make* their time” (Yates, this volume, p. 166). There is, however, no argument whatsoever about how this metaphysical claim would follow from the listed elements of homeodynamics. Nor does Yates explain how the kind of “time,” allegedly generated by homeodynamical processes would lead to “biological time”; that is, how it obtains direction, flow, and irreversibility. Finally, if one really believes that such processes do not occur in time, one faces the onus of explaining what the variable  $t$ , figuring so prominently in the Navier-Stokes equation, refers to.

### INTRINSIC DYNAMICS VERSUS INTERNAL GENES

Let me finally also comment on the one occasion where Yates addresses a point I raised in my previous chapter, and that is my claim that the dynamics of an open system are anything but intrinsic to that system. To me this is just a point of simple logic: an open system is one that can interact with its environment. Dynamics is the common name for the equations that determine the evolution of a system. For an open system, these equations will have to refer to parameters of the particular state of its environment. Consequently, these equations are not intrinsic to the system. However, Yates thinks that my remark is astonishing and reveals “that he [i.e., me] is not sufficiently acquainted with the extensive literature on biological clocks” (this volume, p. 163).

He quotes the example that in many organisms the circadian rhythm persists even when the system is isolated from all environmental time clues. This example is beside the point. To say that a system is isolated from time cues does not mean that it is isolated in a physical sense. It would be more relevant if the circadian rhythm could be shown to persist in organisms deprived of food and oxygen. And although genes are internal to the organism, they remain material bodies, whereas dynamics are a set of equations. They belong to different categories. Even if internal genes explain the behavior of biological clocks, the dynamical equations describing this behavior will still depend on the characteristics of the environment of the organism. To state that dynamics itself are internal, as Yates does, is as strange to me as it would be to say that the law of gravity is internal to a falling stone.

### FINAL REMARKS

I agree with Professor Yates that differences between our perspectives remain, and that it would overstretch the patience of readers to continue discussion.

So let me just sum up. Yates’ present position is that standard physics fails because it does not provide adequate models for human life. He believes that physics needs radical revision and extension, and he offers the theory of homeodynamics to fulfil this need. I have argued that in order to be considered as an alternative candidate to standard physics, homeodynamics would have to be judged by the same criteria of exactness and empirical content. There is no way in which Yates’ theory passes such a test. As it stands, homeodynamics is little more than an incoherent collection of slogans.

Yates complains that I have nothing to offer in comparison. But I actually did present my own views on the subject. In my opinion, the standard body of physical theories is working just fine. Of course, there are relatively unexplored fields, even in classical physics, and new insights are still being developed every day. That just shows how rich the conceptual structure of physical theory is, and that

the enterprise is in healthy shape. There is no need for a radical departure from ordinary physics in order to achieve compatibility with biology.

Instead, we need a more sophisticated view of intertheoretical relations. If one hopes to find a complete and strict reduction of biology or social science to physics or, as Yates calls it, an “analytical derivation” of models of human life from the fundamental principles of physics, one is bound to be disappointed. The idea of theory reduction is not going to work; there is no way a useful or interesting description of human life can be derived analytically from physics. Attempts at analytical derivation have already failed in other cases where the intertheoretical relationships are much simpler, such as between the theories of thermodynamics and statistical mechanics or between chemistry and physics. It would be naïve to expect that such attempts will succeed in the case of biology and physics.

But we need not go in this direction. It seems to be more fruitful to analyze the relationship between biology and physics in the form of “supervenience” relations. Quite roughly, one says that X is supervenient on Y, just in case there can be no change in X without a change in Y. Thus, taking X to be any biological or social condition of a human being and Y a complete physical description of the state of his or her body and its environment, supervenience of biology from physics implies that any change of biological conditions corresponds to a change in the physical state. This view thus allows for the underlying idea that, ontologically, a human being (or any living organism), is really just a particular kind of physical system. At the same time, it allows for autonomy in theoretical description. Supervenience of biology or social science from physics does not pretend that the most meaningful notions in human life, notions like happiness, pain, love, senescence, aging, etc., can even be defined in the vocabulary of fundamental physics.

To be sure, much more work would be necessary to analyze the supervenience relation in detail. Nevertheless, it seems to me that this approach holds more promise than Yates’ desperate attempt to discard physics for the flimsy framework of homeodynamics.

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