A Matter of Time

Arto Annila
A former professor of biophysics
at the University of Helsinki[*]

Abstract: In the spirit of ancient atomism, the quantum of light was renamed the photon, the fundamental element of everything. Since the photon carries energy on its period of time, a flux of photons embodies a flow of time. The flows of quanta naturally select optimal paths, i.e., geodesics, to level off energy differences in the least time. While the flow equation can be written, it cannot be solved because the flows affect their driving forces, which in turn affect the flows, and so on. Since the forces, i.e., causes, and motions, i.e., consequences, cannot be separated, the future remains unpredictable. Similarly, when a computation affects its own course, it remains uncomputable. And a problem remains undecidable when time does not advance, as the flows of quanta, instead of finishing up, get caught up in circulating.

The mother of wisdom

We experience time passing, but the experience itself lacks a theoretical formulation. This shortage points to an enormous blind spot in our scientific worldview since every process involves a passage of time. For us to see why the future is unpredictable, why a function is uncomputable, and why a problem is undecidable, the flow of time should be brought into the form of a natural law.

We readily use notions of time: just in time; time flies; only time will tell. Yet we have a devil of a time to define time itself. We use time to relate events to one another, but we are not quite able to relate the concept itself to anything. Why is time instinctively felt on the one hand, but beyond our ken on the other?

Heraclitus' well-known verse conveys the ancient ideas about time: "Everything changes and nothing stands still." The philosopher phrased the irreversible passage of time: "No man ever steps in the same river twice, for it's not the same river and he's not the same man." This remark that nothing can change, unless everything else changes, is both plain and profound.

As experience is the mother of wisdom, we should express our intuitive experience of time in terms of physics. By this method, Galileo structured observations as mathematical laws.[1]

A problem of physics

Although one of the most mundane matters, time is a big problem for physics. While we experience time to have a direction, the laws of physics, as we know them today, do not make a difference whether time flows from the past to the future or from the future to the past. So, "Where does the arrow of time come from?", asked Arthur Eddington.

Theoretically speaking, everybody in the universe is immersed in space-time, and yet general relativity neither explains the substance of space nor the flow of time. So there is a serious lacuna

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[*] *Contact: artoannila.com*

in our learning, given that history is on display everywhere. "Of all obstacles to a thoroughly penetrating account of existence, none looms up more dismayingly than 'time'," [2] wrote John Wheeler, a great figure of the golden age of general relativity.

Time is expressly a problem of physics, as Ray Monk, a professor of philosophy, pointed out in his review of Lee Smolin's book *Time Reborn* (2013):

> "The problem here is that the philosophical view, for which Smolin is arguing, is not one that many non-physicists would find particularly controversial. It is that time is real, a position that Smolin describes as a 'revolutionary view', but which, for most people, is just common sense. Of course, time is real! For most of us, casting anxious glances at the mirror as the effects of time reveal themselves in the aging process, it is all too real. To understand why this unexceptional, common sense assertion is regarded as revolutionary, one must, to some extent at least, understand how the world looks to modern physicists." [3]

Let us first clarify the nature of this problem for physicists and then focus on expressing our unproblematic everyday experience of time using the concepts of physics.

In general relativity, as well as in quantum mechanics, the flow of time is without cause, so there are no consequences either. Bodies move along their optimal paths; the planets orbit the Sun one cycle after the other; comets come and go. Within modern physics, it does not even make sense to ask why things happen. We have a hard time comprehending these theories that correspond to but do not explain data. Even worse, says Sean Carroll, physicists don't seem to want to understand the theories they use.[4]

We don't grasp any effect without some cause. Einstein's famous criticism of quantum theory, "God does not play dice," captures the foolishness of a belief that any consequence could be the result of mere chance without any proximate cause. A phenomenon may appear random, but there is no guarantee that this is truly the case. Science does not have criteria for proving a phenomenon to be arbitrary, as its central tenet is that every single phenomenon in the universe can be shown to have a natural cause. Since the flow of time is a natural phenomenon, it seems reasonable that it, too, should be shown to have a natural cause. If a field of science stops looking for causes, it stops advancing.

Erwin Schrödinger lectured once that the equation named after him does not outline alternative events but rather all possible events superposed. But we do not have any personal experience of all imaginable versions of the present being entangled with one another. This is why quantum mechanics goes beyond our comprehension. It does not seem real.

As physicists and philosophers know, there is no experimental proof of entanglement or superposition existing in Nature itself. Quantum mechanics, like any other theory, provides only a framework for the interpretation of data. Are the prevailing interpretations true? Assessing the truth of the relationship between theory and observations is difficult, as the argument is circular: scientists interpret the experimental data based on the theory, and they design new experiments based on the interpretation. Since we cannot free ourselves of this hermeneutic circle, we must be skeptical about all observations, experiments, and theories.

Take it or leave it

The mystery of time has only deepened since the early 20th century. Quantum entanglement is not bounded by the microcosm of particles but leads logically to the existence of parallel cosmoses. Take it or leave it.

If you take quantum theory seriously, then your worldview is inevitably remote from the reality we know from our own experience. However, we cannot present any evidence of a parallel reality. If the theory cannot be put to the test, does it qualify as science? On the other hand, if you abandon quantum mechanics as absurd, how would you then calculate the results of some simple experiments? Be it as it may, we cannot just high-handedly label one outcome of modern physics as suitable, such as an accurately calculated atomic spectrum, and another as unsuitable, such as the multiverse.

We experience vividly that the past is irreversibly distinct from the future. Even so, textbook physics states that in the world of particles, the laws of physics are independent of time. However, it is a thin line between the microscopic and the macroscopic. Even though our senses cover only a narrow band of the Scala Naturae, ranging from elementary particles to enormous galaxies, we haven't spotted any fracture in the unity of Nature. So, could it be that so long as nothing is happening, time just doesn't point anywhere? Have we simply defined the laws of physics to be independent of time in order to attain maximum precision? In other words, when quantities stay put, measurements are precise.

In contemporary physics, time is instrumental, insubstantial, incomprehensible, whereas it should be concrete, causal, comprehensible. That is why we need to go back to reality and once again bring Galileo's method to bear.

The quintessence of time

A clear, frosty night under a starry sky is a great experience – except that with time it feels cold. Heat does not escape by itself but together *with time*. The observation is obvious, but that is precisely why it is precious. Can we thus infer that the passing of time always associates with a flow of energy? What *is* it that moves when energy and time flow?

This trivial reasoning about the quintessence of time may seem quite amateurish. How could it possibly lead to a breakthrough? After all, the nature of time is a world-class mystery. It is good to become aware of succumbing to prejudices, though even then, it is almost impossible to avoid their influence. It is also good to know about the first physics, Galileo's method, about mathematizing experiences in the form of natural law. Drawing understanding from experience does not mean discarding the achievements of physics but rather making sense of them.

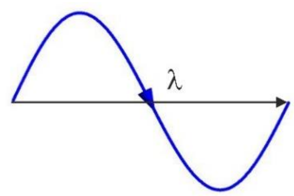
What *is* time? It is an open question. Can we face it with an open mind? We have measured, and we have theorized, but we have not figured out what time *is*. Therefore, the manner in which we sense reality is a prudent starting point for grasping the substance of time.

Under the starry firmament, one feels cold because heat escapes from the warm skin to cold space. This experience exhibits causality. The difference in temperature is the cause, i.e., force, and the loss of heat is the effect, i.e., motion.

The photon carries energy. *But does the photon carry time too?*

Energy and period are inseparable properties of the photon, as Max Planck exposed in 1900. The photon energy, $E = hf$, can be calculated by multiplying the frequency of oscillation, f, corresponding to the color of light, by Planck's constant, h. What does the equation mean?

The frequency indicates how many periods fit in one second. The period of visible light is so short that there are a hundred trillion periods in one second. The period, t, is very short, but not nought. Time is real. It is a property of the photon like energy.[5]



The photon is a wavelet that carries energy on its period. So, as the photon propagates, time and energy move. The speed of light $c = \lambda/t$ for all wavelengths, λ, and periods, t.

Time *is* the period of the light quantum. This is a new viewpoint, not a new finding. In fact, the second is *defined* as 9 192 631 770 multiples of the period of the photon, whose energy makes the cesium-133 atom oscillate. Time is tangible, even visible; the period of a red photon is longer than that of a blue one.

Time comprises periods as a trek comprises legs. This seemingly trivial conclusion about the essence of time will lead to a significant change in worldview, as envisioned by Ludwig Wittgenstein: "The problems are solved, not by giving new information, but by arranging what we have always known."[6] According to the new view, time is not an illusion, but a concrete quality of the quantum, just as energy. As the quanta move, both energy and time flow.

Planck's constant is equal to energy multiplied by time, $h = Et$. This rearranged form is mathematically equivalent to the one in the textbook, but the meaning is different. Planck's constant is not just a coefficient of proportionality but the measure of the photon, the quantum of action, the fundamental element of Nature. Indeed, Planck's constant occurs in many contexts and appears in many equations.

> We have now identified the agent of causality. It is the quantum. The cause, i.e., the motive force of occurrence, is an imbalance, and the consequence, i.e., the motion, is the flow of quanta that carry both energy and time.

Since we see and sense the quanta of light, we know them through experience. According to Bertrand Russell, the underlying elements of reality must be objects that are known through experience.[7] The philosopher said that it is wise to eschew impenetrable concepts that have no connection to our experience as meaningless.

Planck's constant means that the quantum is an indivisible and eternal constituent. The massless photon does not decay. However, two may combine out-of-phase, not to vanish, but to become part of the invisible void.[5] The vacuum, as has been detected, is both the source and the sink of particles and antiparticles, and hence fundamentally of the same substance as matter. In conversions, reactions, changes of any kind, quanta move from one form of substance to another.

The universe could not evolve unless everything comprises the same fundamental elements. Newton queried after this atomistic axiom in his book of Opticks, “Are not gross bodies and light convertible into one another?” Unlike a malleable model, which merely matches up with data, this tenable tenet is based on a falsifiable axiom. For one thing, the tenet would trivially turn out false if a photon were to split up, and for another, if energy were found to stay constant in an event.

Galileo founded physics as a method for mathematizing experiential knowledge into a universal law. This is what we have done. The experience of heat escaping from the skin with time renders the concepts of energy and time complementary properties of the quantum. Rather than through such an experience, Planck found the constant by interlacing two equations together. While covering the whole spectrum of light, Planck’s law of radiation does not actually explain the light. Planck was, therefore, blind to the essence of light.

The order of time

The idea that the fundamental element of time is the period of a quantum is perhaps surprising in its simplicity but only logical. By contrast, it would be confusing to consider this period and time as different concepts. They have the same unit of measure as well. Paraphrasing Leibniz: if we do not have the means to distinguish between two things, we must regard them as identical. There is thus no more of a mystery hidden in time than in energy.

Since time and energy, as well as momentum and wavelength, are complementary properties, the steps in a sequence of events are not interchangeable; mathematically speaking, they are noncommutative. The result depends on the order in which the measurements are made because no observation will leave its object intact by either extracting out of it or granting it at least one quantum. The order of time thus follows from the order in which the quanta move.

Time and energy are complementary properties, as the founder of quantum mechanics, Niels Bohr, said. One cannot be without the other. When the energy of the photon decreases, the period increases. Nonetheless, the light quantum maintains its size per Planck’s constant.

It is pivotal that the photon is open to change because the universe could not be expanding unless the photon period was increasing and energy was decreasing. The light that departed from the blazing early universe and arrived at the cold present of our time has extended so much that our eyes cannot detect it. But as our body can still feel it, even the earliest events in the universe are not altogether beyond our range of experience. We live amidst all the history that exists. To date, the photon periods sum up to about 14 billion years from the present to the past.

Evolution as a unique process renders the universe asymmetrical in its details,[8] whereas truly symmetrical distributions of random processes are found nowhere in Nature. Even so, the steady state is held to be the norm of physics. That is why stationarity is known in precisely defined terms, such as equilibrium, conserved, commutative, computable, linear, Euclidean, and deterministic, whereas the full range of processes is referred to by vaguely understood antonyms, such as nonequilibrium, nonconserved, noncommutative, noncomputable, nonlinear, non-Euclidean, and nondeterministic. Constraints of symmetry, i.e., stationarity, rather than comprehension of the evolving reality, have guided theoretical physics since the mid-18th century.[9] This is both the source of the success and the cause of the crisis that physics finds itself in today.

The ideal of science

The ideal of science is that when one thing changes, other things remain intact. However, this *ceteris paribus* principle, a background-dependent model, an effective theory, does not hold. Consequences give rise to new causes because the flow of quanta from one system to another changes both, as well as their positions relative to other systems. Mathematically speaking, the limits of integration change over integration.

Undeniably, a stone rolling down from a hilltop has kinetic energy, as understood. However, as the stone rolls, the landscape also moves. Initially, the stone, which is part of the landscape, is on top of the hill, and finally, it is at the bottom of the valley. Along with a stone's downward motion, the height difference, the cause of the rolling, decreases. Failing to note this, one will be led astray.

Gottfried Leibniz and Johann Bernoulli knew of the general formula for kinetic energy, mv^2, which the Dutch mathematician and natural philosopher Willem 's Gravesande confirmed by experiments in the early 18th century and Émilie du Châtelet made widely known by her books and translations. It was only later when the factor ½, familiar from school books, was placed in front of the formula to make it solvable but then flawed.

The Newtonian worldview is perceived as deterministic, computable, but it is we who have defined it as such. The familiar formula, $\mathbf{F} = m\mathbf{a}$, is about the equilibrium because we have dropped out the change in mass from Newton's original law of motion, where the force, $\mathbf{F} = d_t\mathbf{p} = m\mathbf{a} + \mathbf{v}d_tm$, equals the change, d_t, in momentum, $\mathbf{p} = m\mathbf{v}$. The change in mass, d_tm, is, for example, heat from nuclear reactions. Also, chemical reactions release heat. There is no change without a change in energy, $\mathbf{v}\cdot\mathbf{F}$. Since quanta move from the system to its surroundings or vice versa, no system evolves unless its background changes too. Nonetheless, the desire to predict by fixing the background in theories of physics excludes the fundamentally unpredictable aspects of reality.

Why is time relative?

Although realizing that time is relative, Einstein did not clue us in to what time *is*. Clocks do run at different rates at different places, but why? General relativity, as an effective theory, does not explain why the clock up in the attic runs faster than the one in the basement; it only reproduces the data.

Surroundings do not only affect the rate of a clock but also other processes. For example, in winter, our house will cool down quickly if someone has left the front door wide open, whereas, in summer, there is not much drag because indoors and outdoors are equally warm. Thermodynamic balance is attained in the least time so that the higher the temperature difference, the faster the energy flows. In a perfect balance, nothing happens, time does not pass because no force drives the quanta out to the surroundings or into the system.

Since quanta carry both time and energy, we understand the rate of a running clock in the same way we do the rate of heat flow. As the gravitational field decreases upwards, the passage of time in the attic is faster than in the basement because up there the energy difference, the imbalance between the clock and the surroundings, is bigger than that in the basement.

This experience-based comprehension of the passage of time is mathematically consistent with general relativity.[10] The calculation is just as it should be; only our interpretations are revised. The higher the energy difference, the faster the flow.[11] Since energy is relative to the surroundings, so is time.

The optimum of time and energy is the same because time and energy are inseparable properties of the quantum. For example, the slightly flattened form of the rotating Earth is energetically optimal, having the least-time shape: a clock runs as fast at the North Pole as at the Equator. On the one hand, the clock would run faster at the Equator than at the pole because the distance to the center of Earth is longer, and hence gravity is weaker. On the other hand, at the Equator, the clock would be running slower due to Earth's rotation. These two opposing effects precisely cancel each other.

Why does time move forward?

The preconceived idea that ever-increasing disorder is what directs the arrow of time is deeply rooted in contemporary physics. Our own experience is that also ordering takes time. For example, we see that order increases when water freezes, and we see that disorder increases when the ice melts. Order, just as disorder, will emerge as the energy difference between the environment and the system evens out. It is, therefore, not an increasing disorder but an imbalance that directs the arrow of time.

When a film is played backward, the course of events looks unreal. Shards of glass on the floor just cannot merge into a solid vase and rise back onto the table. For that to happen, work needs to be done, but we see no one doing it. Time does not step all by itself but by forces, i.e., free energy. It is the forces at present that point to the future and transform the present into the past.

It is only natural that the universe expands everywhere in every direction, a stone falls straight down, a plant grows toward light, and you go for the best price. In this way, balance is pursued in the shortest time. The maxim is, in a sense, a self-evident truth. When this quest for balance in the least-time is understood as *natural selection*, that is, Nature selects, then evolution encompasses not just the living but everything. Temperature difference forces hot tea to cool down, just as food powers the growth of a population. These phenomena involve different mechanisms but the same underlying principle. That is why the data, irrespective of scale and scope, display the same patterns: skewed distributions, sigmoid growth curves, power laws, oscillations, and even chaos.[12]

The equation of time, Maupertuis' principle of least action,[11] where momentum $\mathbf{p}$ is integrated over a path $\mathbf{x}$, i.e., $\int \mathbf{p} \cdot d\mathbf{x}$, can be derived from the statistical mechanics of open systems.[12] Boltzmann sought for this equation of motion. He was impressed by Darwin's proposal for evolution by natural selection but did not see the need to make a fundamental distinction between the living and the non-living and hence envisioned evolution of any kind to follow the same principle. Paradoxically Boltzmann failed to discern the dynamic as he knew the end state from deriving the expression for the balance of gas molecules. However, that equation does not have any trace of the forces that brought about the thermodynamic balance because, at the balance, nothing happens when the sum of forces is zero.

The root of the problem was noted by Boltzmann's friend Josef Loschmidt. The professor of physical chemistry wondered how an equation that is symmetric with respect to time could possibly describe the flow of time. Furthermore, the German mathematician Ernst Zermelo remarked that, according to Boltzmann's equation, a system that has once been in a state of imbalance would return to the same state of imbalance. Such things do not happen. The issues raised by Loschmidt and Zermelo concern likewise other equations in which energy is constant. Such equations do not explain the leveling of imbalance but only model the condition of balance.

Still quite true, disorder increases invariably when coherent flows of quanta fan out of sync in interactions with incoherent surroundings – conversely, synchronous surroundings force order in the system.

Why is the future unpredictable?

At first glance, one might suppose that if one only knew a system's initial state exactly, say that of a traveling salesman, then also the future could be worked out precisely. However, an event, such as the salesman arriving in a city, will alter the driving forces, say, travel costs, which in turn will change the future course, and so forth. Hence there is no effective algorithm for figuring out the least-expensive travel plan, but at worst, every possible path must be evaluated. Such a computational task is intractable, i.e., noncomputable.[13]

Noncomputability is thus not about complexity since even problems involving only three bodies are unsolvable because the motion of one body, say, the Earth affects the forces that act on the other two, say, the Moon and the Sun, and vice versa. The source of intractability isn't either the inherent indeterminism in knowing things, as maintained by quantum mechanics, but nondeterminism follows from the fact that both the system and its observer (background), change upon interacting, i.e., through flows of quanta. When quanta make up everything, everything depends on everything else.

Chaos and dramatic effects do not follow from subtle differences at the onset but from the tremendous forces engaged along the way, i.e., history.[12] The flap of a butterfly's wings in Brazil does not cause a tornado in Texas but the temperature difference between the warm ocean and the cold upper atmosphere does.

The physical rationale behind the halting problem, or an undecidable problem in general, is that everything hinges on everything else. It is, therefore, impossible to know a priori without executing, i.e., unleashing a flow of quanta, whether a process, such as a program with input, will finish up with output or get caught up in circulating forever.[13]

While the calculation of a stationary system, such as a closed orbit, can be precise, it is not a prediction about the future but a disclosure of the unknown because, in such a system, time does not advance but circulates on and on. The outcome is a paradox: the equation of motion has the elements of the explanation, but at the point of balance, where nothing happens, there are no causes or consequences to be explained. The inevitable conclusion is that the future is genuinely unpredictable, yet bounded by free energy. In other words, not just anything can happen, only something for which there are forces, say, resources.

Something rather than nothing

When we say that quanta embody everything, we assert a worldview that includes everything. Yet it is incomplete. According to the incompleteness theorems of Kurt Gödel, a foremost logician and philosopher, it is possible to pose questions about the universe that have no answers.

We may ask why there is something rather than nothing, but we know nothing about nothing. We cannot know anything beyond the universe. For instance, as the photons are all there is,[14] how could the expansion possibly exceed the speed of light, that is, to go beyond the unity of everything? Since space stems from matter, there is no fuel to power ever-faster expansion.[5,15] So, we may abandon the assumption that the universe could billow out ever more rapidly by dark energy. Instead, the rate of expansion, the Hubble parameter, $H = 1/t$, is decreasing $d_tH = -1/t^2$, as time, t, is increasing.[10] Parmenides' idea of the eternal element of everything limits thus interpretations of the data on the universe's evolution more sharply than many a contemporary model of the cosmos.

Likewise, asking what preceded the beginning, we wonder where the quanta came from. But our experience only tells us that they exist. This contradiction exposes our inability to comprehend below the quantum and beyond the universe. We cannot prove the truth or falsity of statements that are beyond our deductive system. The universe is the realm of our reality.

Time occupied the minds of both Newton and Einstein. Now the issue is neither about absolute nor relative time but about tangible time – the quantum is the matter of time.

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