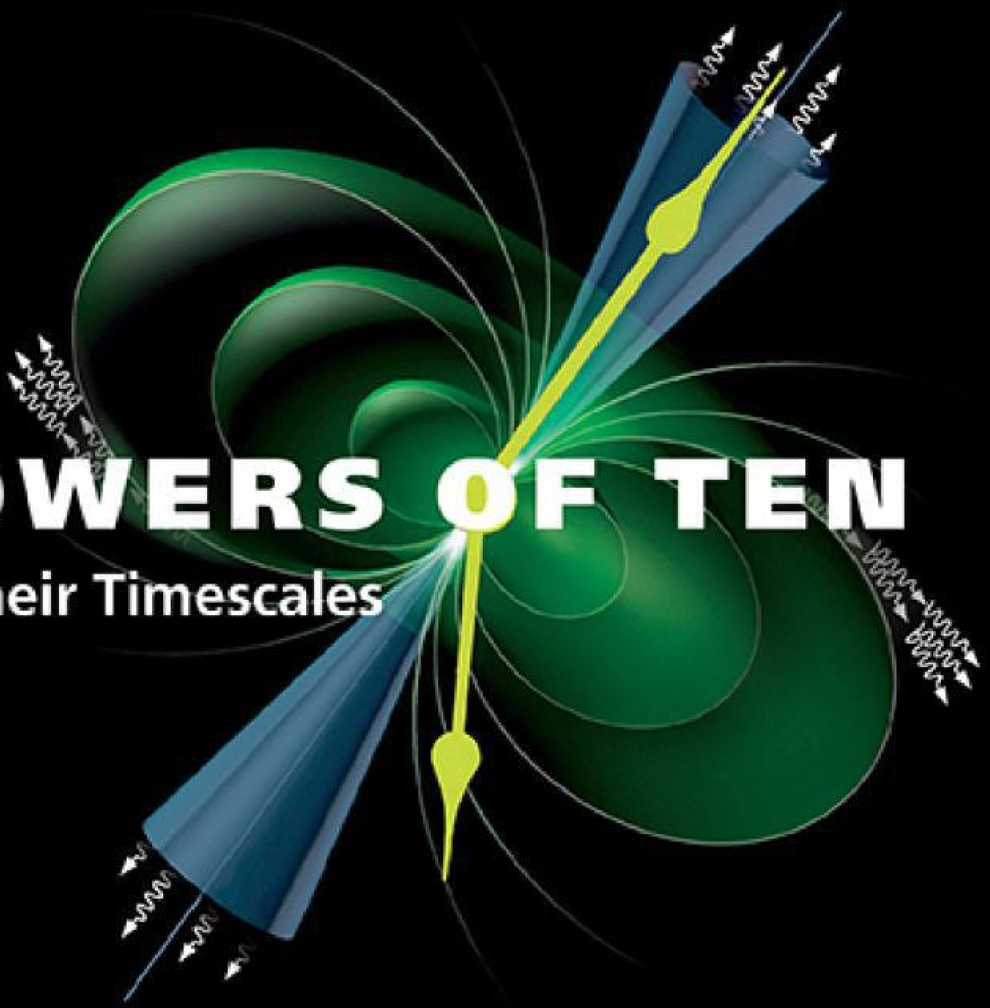
Gerard 't Hooft · Stefan Vandoren

Translated by Saskia A. Eisberg-'t Hooft



TIME IN POWERS OF TEN

Natural Phenomena and Their Timescales

With a Foreword by Steven Weinberg

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Natural Phenomena and Their Timescales
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Foreword

by Steven Weinberg

Ordinary human experience spans a range of times from seconds to decades, the longest intervals of time a mere billion or so times longer than the shortest. But the progress of science has been marked by the scientist's growing familiarity with time intervals that are very much longer, or very much shorter, than those that are experienced in our lives.

Around 150 BC the Greek astronomer Hipparchus observed that the position of the Sun at the time of the autumnal equinox was gradually changing, at a rate that would take the equinoctal Sun completely around the zodiac in about 27,000 years. Newton later explained this precession of the equinoxes as an effect of a slow wobble of the Earth's axis of rotation, caused by the gravitational attraction of the Sun and Moon for the equatorial bulge of the Earth. The Earth's axis is now known to make a complete turn in 25,727 years. Hipparchus had done the first serious scientific calculation of a time interval very much longer than a human lifetime, and found a result that was off by only about 5 percent.

In this century we have become used to much longer intervals of time. From the relative abundance of isotopes of uranium we can infer that the material of which the solar system is made was formed in an exploding star about 6.6 billion years ago. Looking farther back, by observing the way that galaxies now rush apart we can infer that 13.8 billion years ago the matter of the universe was so compressed that there were no galaxies or stars or even atoms, only a hot thick gas of elementary particles.

The extension of our experience to very short time intervals has been even more dramatic. By observing phenomena like diffraction that are associated with the wave nature of light, it became known early in the nineteenth century that a typical wavelength of visible light is about 0.3 ten-thousandths of a centimeter. Light was already known to travel at a speed of about 300,000 kilometers per second, so the period of the light wave, the time it takes light to travel one wavelength, was known to be about 10^{-15} seconds (a quadrillionth of a second). This is not very different from the time (to the extent that a classical description is relevant) that it takes electrons in atoms to make one complete circuit of their orbits.

Modern elementary particle physics deals with time intervals that are very much shorter. The lifetime of the W particle (the heavy charged particle responsible for the weak force that allows neutrons to turn into protons in radioactive nuclei) is only 3.16×10^{-25} seconds, not long enough for a W particle traveling near the speed of light to cross the diameter of an atomic nucleus.

What I find truly remarkable is not just that scientists have come to confront these very long and very short intervals of time. It seems to me even more amazing that our experiments and theories have become sufficiently reliable so that we can now give precise figures, like 13.8 billion years and 3.16×10^{-25} seconds, with some confidence that we know what we are talking about.

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We would also like to thank Christiaan Eisberg for reading the text and providing us with useful comments.

A number of people have contributed their expertise or opinions regarding specific subjects of the book. We would like to express our gratitude to Prof. Dr. J. J. Bredée for his assistance with the text about the heartbeat, to Dr. Tatiana Boiko and Dr. Elena Battaglioli for discussions about timescales in biology and specifically about the working of neurons, and to Annemarie Kleinert for the etymology of the German word *stunde*. We also thank Burchard Mansvelt Beck for his numerous remarks on the calendar and related issues enabling us to greatly improve our discussions on these themes.

Finally, we would like to acknowledge our colleagues at the Institute for Theoretical Physics in Utrecht, the Netherlands, for their keen participation in discussions, and many of our friends and family members for their encouragement and support in bringing this book to a successful conclusion.

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Natural Phenomena and Their Timescales

Introduction

Time is of the essence. In natural sciences, time is an indispensable parameter. With the word 'time' we might mean to express a 'point in time', the exact moment an event takes place, or a 'time span', the period during which an event takes place. This time span could be long or short — our world is filled with such a diverse range of amazing natural phenomena, that the variances in time spans during which they take place often far exceed our imagination. On the one hand, computers nowadays are able to compute millions, sometimes billions of calculations in a second; while on the other hand, there are natural phenomena occurring on our planet that have taken millions of years to evolve. For example, the evolution of many living organisms takes place so slowly that its almost imperceptible progress is difficult for us to fathom.

But modern natural sciences show us phenomena that take things a lot farther in both directions than the two examples above. The smallest matter mankind has studied moves considerably faster than the quickest computing processes of the most expeditious machine; while on the other side of the timescale we see planets, stars and entire galaxies of unimaginably old age, some of billions of years. Scientists believe they know almost exactly how old the universe is, but even its seemingly eternal lifetime does not constitute a limit for physicists' research.

Structure of the Book

The objective of this book is to illustrate the various timescales we observe in the world around us, each of which is unique. We will start with the unit of one second — the timescale we are probably all most familiar with; the timescale that is also most widely used as a fundamental unit in modern science. From there we march onwards, with each step jumping to the next scale by a factor of 10. In the first part of our book we will look at increasingly larger timescales, examining phenomena that last for exactly 10 seconds, 100 seconds, 1000 seconds and so forth. These phenomena will be laid out and illustrated page by page, until we reach the age of the universe — and we won't stop there, as there are processes that take longer than the evolution of the universe itself!

At the other end of the scale, many events last less than a second. In the middle of this book — after we have covered the longest lasting periods that feel like eternities — we jump to the smallest units of time, to the natural phenomena that are completed in the fastest possible times. We then increase these time spans by a factor of 10 with each step, until we get to the end of the book and reach one second once again.

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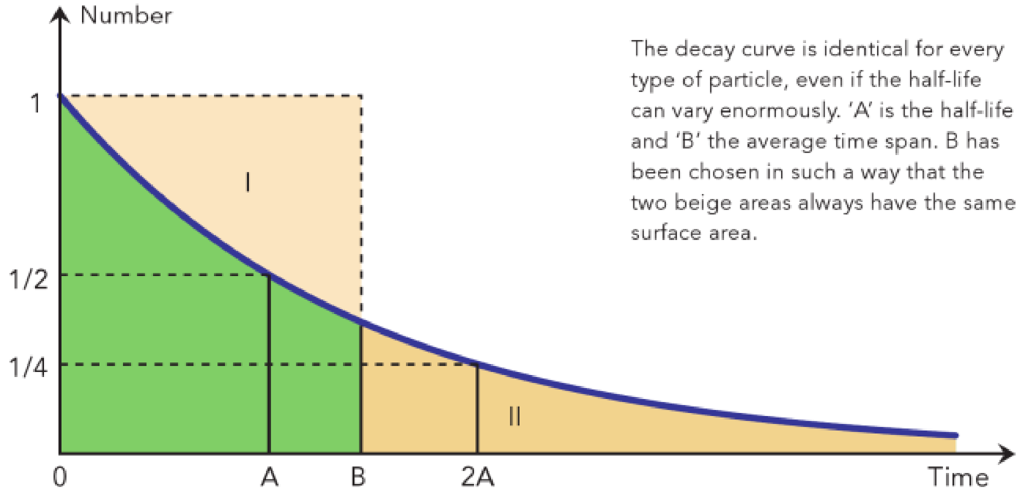
This may seem like a rather unusual layout, but we believe this to be the most lighthearted; this creation should really be regarded as a coffee table book, something to browse through at your leisure. Start wherever you like, hop and skip through the various pages, from one segment that piques your curiosity to the next. We would like you to discover our world as we see it: fascinating and remarkable at every conceivable timescale. Every unit of time is unique. Every level showcases enthralling phenomena. In other words, our book comprises a series of independent short portrayals and illustrations of phenomena that manifest themselves across various periods of time, from the blink of an eye to a blue moon.

Process

When we were contemplating writing this book, we did not know exactly what subjects we would come across and a lot of research was required to compile its contents. This led us to fall from one amazement into another, discovering awesome details that we are excited to share with you. For example, did you know that there are phenomena that leave a trace at virtually all time spans? A case in point is atoms and subatomic particles. These can disintegrate as a result of natural forces called 'radioactivity'. But radioactivity can be the consequence of various types of natural forces, meaning that it exhibits varying characteristics depending on its catalyst. Sometimes a particle or atom must complete a complicated process to disintegrate. In our professional jargon we refer to this as a 'tunneling process': a particle must dig a tunnel, right through a high potential barrier. This digging can take a very long time, or be over in an instant, depending on the length and depth of the particular tunnel.

Radioactive decay is described by the concept of 'half-life': the average time it takes for the number of radioactive particles of a given kind to decrease by half. This is not the same as the average lifetime of a particle. The average lifetime of a particular radioactive particle is always 1.442695 times its half-life (see graph below). At least, this is the case for particles of which the disintegration follows an exponential curve; with a few exceptions (such as the K-particle), this is always the case.

Some atomic nuclei and other particles disintegrate so quickly that it is very difficult to prove scientifically that these particles exist, while others take so long to decay that it is complicated to prove they are actually



The decay curve is identical for every type of particle, even if the half-life can vary enormously. 'A' is the half-life and 'B' the average time span. B has been chosen in such a way that the two beige areas always have the same surface area.

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disintegrating. We have chosen the most interesting of these particles, and those whose disintegration times, measured in seconds, also come closest to a power of 10. Information about disintegration times can be recognized by boxes with pink borders. Similarly, other recurring themes have also been color-coded.

Recurring Themes

Pink Boxes

As described above, facts and figures about decay times have been placed within pink side bars.

Blue Boxes

In the world of stars, planets, moons and comets, orbital and rotation periods prove to vary wildly. Because of their enormous variation, these times have also resulted in a recurring theme within the book. We have placed such events within a blue border.

Yellow Boxes

Periodical signals — such as electromagnetic waves — also comprise a theme. Depending on the wavelength, a frequency may vary between a mere thousand vibrations per second and the immeasurably fast vibrations of, for example, X-rays and gamma rays. We also find rhythmic and periodical systems in biology, such as our own heartbeat or menstruation cycle. Notes about these periodical signals and vibrations are placed within yellow borders.

Green Boxes

Then there is the 'new' kind of science, cosmology. Physicists and astronomers have been able to map out a large part of the universe's history. From observations and calculations they have been able to deduce that the start of the universe was an explosive one, a 'Big Bang'. Within a fraction of a second not only was all the matter that makes up our universe created, but also time and space itself. The creation of time and space still continues, meaning that our universe continues to expand. The beginning of our universe is still the subject of lots of speculation but the picture is becoming more and more clear. This is something we like to illustrate in our book as well; at a ten-billionth of a second the universe had already expanded to such a level that it enables us to use the laws of physics known at present to understand its progress. It is no mean feat to calculate back to the beginning of the universe from where we are now, but this is something we are getting better and better at nowadays. We describe the various phases of the universe within green borders.

Orange Boxes

We do not know much about the size of our universe yet. It is perfectly feasible that the universe is literally infinite. However, for the purposes of defining the universe's size, we confine ourselves to that part of the cosmos that we are able to observe with our largest telescopes. The galaxies furthest

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away beamed their light towards us when our universe was still quite young, about 13 billion years ago. If we consider this the boundary of our universe, then we have established a good perimeter to determine its size. After emitting the rays we are now observing, these galaxies continued to move away from us. This means that by using our own definition of size, our universe has a radius of almost 50 billion light-years (one light-year is the distance light travels within one year, or almost 10 trillion* kilometers)!

We will see, though, that the universe was quite compact and small for the first few days of its existence. It might appear strange that two galaxies could be more than 13.8 billion light-years away from one another in a universe that is only 13.8 billion years old, and within which nothing moves faster than the speed of light. This apparent paradox is explained by Einstein's Theory of Relativity. This theory states that while no matter in a given region of space can move faster than the speed of light, space-time itself does expand faster than the speed of light. This is how it is possible that there may be galaxies that are almost 100 billion light years apart. Because light and light years play an important role in this book, we refer to distances travelled by light in the various time spans discussed in the book in orange sections.

Thus, summarizing, we are using the following color schemes throughout the book to indicate the subject of the facts and figures discussed:

🟪 decay times and half-lives
🟦 orbital and rotation times
🟨 periodical signals and vibration periods
🟩 the history of the universe from the Big Bang onwards
🟧 distances travelled by light

As mentioned, this book consists of a few hundred short, often illustrated, sections, which stand on their own. Only occasionally do we refer to other sections in the book for further details or interesting links with phenomena at other timescales. As described above, the first part of the book starts with increasing timescales. And we will not stop at the age of the universe, because chances are that the universe has a longer future than it has a past. In any case, according to modern science, there are particles that have a half-life much longer than the age of the universe. A case in point is the proton, a quite basic subatomic particle: its life span might prove to be more than a quadrillion times the current age of the universe!

But our story does not end with the lifespan of a proton — there are even longer timescales imaginable. We then venture into the world of absurdly high numbers. Our current knowledge of science is so

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* We use American 'short-scale' numbers in this book. In other words, a trillion is a million million. A billion is a thousand million.

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severely limited in this respect, that it is difficult to speculate about enormously large numbers. As such, we will only briefly touch upon these dark eternities.

Reverting to the concept of proton disintegration, the actual lifespan of a proton is altogether uncertain. It may be that it does not disintegrate at all — even if scientists have difficulty believing this. Most theories concerning the disintegration of the proton predict that the particle will disintegrate at some point, even if — as indicated earlier — this might take a quadrillion times as long as the age of our universe, which is also an incredibly difficult concept to comprehend. As the far future of the universe is entirely dependent on whether and when protons disintegrate, it is far from certain, which is why we will be brief on this subject too.

Borders

Natural phenomena that manifest themselves at almost unimaginably small scales are responsible for the forces that lead to the disintegration of protons. Here we are at the borders of the imaginable, where scientists can still only just conceptualize what time and space look like. It is truly remarkable that the phenomena that provide protons with such a long life span are the same phenomena with the smallest timescales. The Big Bang commences in a practically indivisible moment in time. The phenomena at play here are perhaps best explained as 'superstrings', a concept where we do not consider the most elementary building blocks of nature to be 'point-like', but vibrating 'strings', endlessly elastic, with lots of other characteristics that are difficult to grasp. Scientists are not at all certain about string theory, which is very mathematical in nature, and not yet well understood. This part of the book is based on admittedly shaky territory, but we will not be there very long.

After superstrings we revert to longer timescales, through the various stages the universe must have passed, via the extremely short time intervals of the elementary particles – the vibrations of gamma waves, ultraviolet light, radio and sound waves, and many others — until we reach 1 second again, the end of our story. This book can be read in any direction, from cover to cover, starting at whichever end you like; from back to front if the smallest fractions of a second particularly tickle your fancy.

Measuring Time

Nowadays, clocks are extraordinarily stable, meaning time can be measured very accurately. Astronomers measure vibrations, rotations and orbits of stars and planets quite precisely, sometimes up to a millionth of a unit, and sometimes even more precise. Therefore you'll see some very exact measurements in certain parts of this book. In the most extreme cases, intervals have been measured — in seconds — with a precision of 15 decimal places, and this accuracy is continuously being improved. As such, time is the most precisely-measured quantity we have at our disposal. In second place is the measurement of length, measured in meters — with a precision of 12 decimal placess. In third place is the kilogram, with an accuracy of 10^{-8}.

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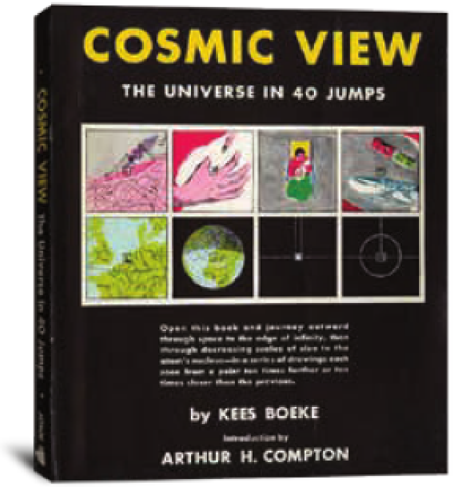
Tradition

Finally, we feel duty bound to note that the setup of our book is not entirely original. Kees Boeke, a teacher in Bilthoven (close to Utrecht) in the Netherlands, published a book with the title *Cosmic View: The Universe in 40 Jumps* in 1957, which was the precursor to the well-known short film *Powers of Ten*. After Kees Boeke's project, several works have been created inspired by the theme of powers and scales. Boeke's work was based on the distance scale, meaning distances and measurements of objects. It is enormously fascinating to compare the very largest objects in our universe to the smallest ones that we have been able to examine.

We even discovered that covering time in powers of ten has been done before as well. For example, there is a film entitled *Powers of Time*, a film based on timescales, but it is not nearly as elaborate as our book. Fortunately, there is enough room for various interpretations of and perspectives on this theme. With this book we are continuing the tradition started by Kees Boeke by looking at timescales, but based on 21st-century science.

Gerard 't Hooft and Stefan Vandoren



One of the last works of Kees Boeke, this book is a classic on learning about the scale of things.

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Large and Small Numbers

We are used to ordering numbers in terms of powers of ten. As such, a hundred is ten times ten, or $10^2 = 10 \times 10$; a thousand is ten times a hundred, or $10^3 = 10 \times 10 \times 10$, and a million is 10^6, so a thousand times a thousand or ten times one hundred thousand.

The terminology for the higher powers of ten is not standardized worldwide. There are two scales of naming larger numbers, the *short scale* and the *long scale*. The short scale is most commonly used in English- and Arabic-speaking countries, but also in Russia. Whereas the long scale is used in most other countries in Europe, parts of South America and parts of Africa. Other countries, like China and India, employ other counting systems. The terminology used in long and short scale systems starts to differ from 10^9 onwards. The number 10^9 is called a *billion (thousand million)* in the short scale, whereas in the long scale it is called a *milliard*. A billion in long scale then stands for 10^{12}, whereas in short scale this number is called a *trillion (thousand billion)*. In the table (top right), we summarize the most important numbers for which differences occur.

Number	Short Scale	Long Scale
10^9	Billion	Milliard
10^{12}	Trillion	Billion
10^{15}	Quadrillion	Billiard
10^{18}	Quintillion	Trillion
10^{21}	Sextillion	Triliard
10^{24}	Septillion	Quadrillion

The logic behind these scales is as follows. In the short scale, one counts with factors of a thousand, in the sense that a trillion is a thousand times a billion (1000×1000^3), a quadrillion is a thousand times a trillion (1000×1000^4), a quintillion is 1000×1000^5, and so forth. The long scale, on the other hand, works with factors of a million: a billion is a million times a million, or $1{,}000{,}000^2$, a trillion is a million times a billion, or $1{,}000{,}000^3$, and a quadrillion is $1{,}000{,}000^4$: a million times a trillion. The words milliard, billiard and triliard are not used in the short scale, and hence they are absent in modern English.

It is not difficult to find even larger numbers in nature. The number of bacterial cells on Earth is estimated to be 5×10^{30}, that is five nonillion in short scale, or five quintillion in long scale. Meanwhile, 8×10^{60} is the number of Planck-time intervals (5.39×10^{-44} seconds, see Chapter 22) in the lifetime of the universe, and there are about 10^{80} atoms in the observable universe.

Even larger numbers exist, which occur in problems of mathematics or computational theory. Most commonly known are the *googol*, which stands for 10^{100}, and the *googolplex*, which is 10^{googol}, or $10^{10^{100}}$.

Some large numbers are so commonplace that they have become embedded into our very language,

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by way of prefixes. We all know that *hecto* stands for a hundred, while a *kilo*-meter is 1,000 meters. The prefix for one million is *mega*, and for a billion (short scale) it is *giga*. We provide more unusual examples in the following table:

Prefix	Number	Name (short scale)
yotta	10^{24}	septillion
zetta	10^{21}	sextillion
exa	10^{18}	quintillion
peta	10^{15}	quadrillion
tera	10^{12}	trillion
giga	10^{9}	billion

For instance, one light-year — the distance that light travels in one year — is about 10 petameters, and the mass of the Earth is about 6,000 yottagrams, or 6 octillion grams. Similarly, there are also prefixes for small numbers:

Prefix	Number	Name (short scale)
deci	10^{-1}	tenth
centi	10^{-2}	hundredth
milli	10^{-3}	thousandth
micro	10^{-6}	millionth
nano	10^{-9}	billionth
pico	10^{-12}	trillionth
femto	10^{-15}	quadrillionth
atto	10^{-18}	quintillionth
zepto	10^{-21}	sextillionth
yocto	10^{-24}	septillionth

The fastest spinning pulsars rotate around their axis in a thousandth of a second, that is, a millisecond. The size of most atoms range between 30 and 300 picometers, and the mass of a proton at rest is about 1.6 yoctograms, or 1.6 septillionth of a gram.

The discrepancy in naming numbers within short and long scales sometimes leads to confusion, especially when translating numbers from one language to another. There is also the possibility of confusion with the terminology of the prefixes. For instance, in the words 'yotta' and 'yocto' one finds the Latin root 'octo' which stands for 'eight'. Yet, in septillion (the short scale name), we find the Latin root 'septem' which stands for 'seven'. This is confusing, since both 'yotta' and 'septillion' are used to indicate 10^{24}. (The long scale name for 10^{24} is quadrillion.) Similarly, in 'zetta' and 'zepto' we recognize 'seven', whereas sextillion clearly refers to the number 'six', though both are used to indicate 10^{21}.

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Chapter 1

$10^0 = 1$

1 second

The word 'second' is derived from the Latin word *secundus* or *gradus secundus*, which means 'second step' or 'next step'. The Romans divided the daylight time into 12 hours. As a further division, an hour was first split into 60 minutes, and as a second step, each minute divided into 60 seconds.

The Friesian clock usually ticks about once every second. It was well known for its steadfast craftsmanship and was elevated to an art form in its heyday. At the end of the 19th century, the invention of more accurate timekeepers made Friesian clocks less desirable, though in recent years these Dutch devices have regained a nostalgic popularity.

Most mechanical clocks tick approximately once every second. The Dutch physicist, Christiaan Huygens, improved their accuracy with the introduction of the pendulum. The time that a pendulum takes to swing back and forth depends mostly on its length and not on its driving mechanism. This is why it is relatively easy to set a pendulum clock so that its hands circle the dial at a precisely defined speed.

A weight at the end of a piece of string with a length of 99 centimeters takes two seconds to swing back and forth. So the pendulum of a clock needs to be about one meter long to provide a tick — half a swing — every second. The exact length a pendulum needs to be so as to tick once per second also depends, to a lesser extent, on its shape.

The ticking of a clock reflects our instinctive human need to mark the passing of time, the fleeting moments of our lives measured out in reliable seconds. In modern science, the second is used as a fundamental unit of time. Time can be measured more precisely than any other physically observable quantity. To enable the exact measurement and definition of a second, we use the most accurate and dependable clock available to us: the atomic clock.

Christiaan Huygens

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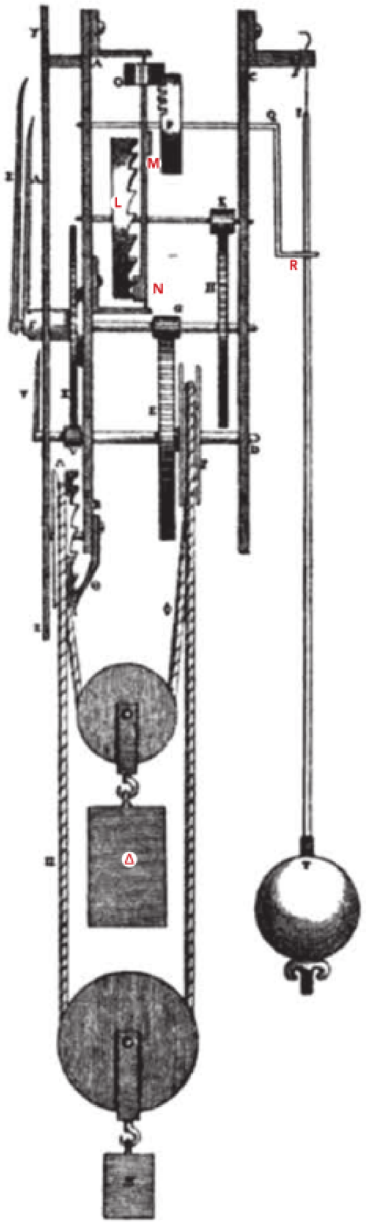

In 1658, Christiaan Huygens published this side view of his clock. The clock face is on the left side, 'MN' is the pallet verge powered by crown wheel 'L' and on the right, the pendulum moves in what resembles a fork (at 'R'). The weight Δ, which powers the clock, can be pulled up without disturbing the movement of the clockwork.

In ancient times, people believed that the rotation time of the earth around its axis was constant. So, just like the Romans, one could simply divide the average duration of a day by the number of hours, 24, and the number of seconds in an hour, 3,600, and one was left with 1 second. The rotation of the earth, however, is not quite constant. Movements in the atmosphere, the oceans and ice caps cause minimal but measurable variability. Hence the demand for a more precise definition of a second.

Nowadays, we use clocks based on the atom cesium-133 (^{133}Cs). Electrons in this atom can be made to vibrate and the frequency of this vibration turns out to be universally constant. A second is now defined as the time this atom needs to perform 9,192,631,770 vibrations. Modern atomic clocks are extremely stable and deviate no more than 1 second per 10 million years. More about this on page 148, where we talk about 10^{-10} seconds.

0.86 seconds
The average duration of a human heartbeat

The heart is a pump that provides our body with flowing, oxygenated blood. The heart of a human being at rest pumps about once a second. The average frequency is roughly 70 heartbeats per minute for men — approximately 0.86 seconds per heartbeat — and 75 per minute for women. Athletes have a somewhat slower heart rate of around 40 beats a minute, and those who do not engage in any regular exercise have a heartbeat of about 80. When distressed or intensely physically

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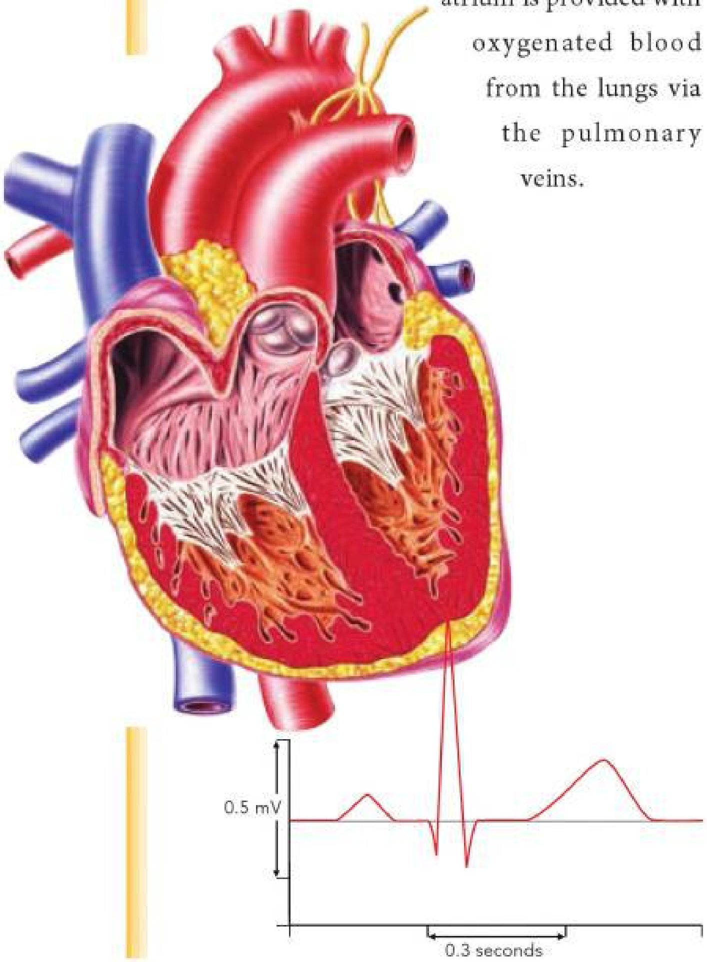
exerted, the frequency may rise to 200 beats per minute. When Neil Armstrong landed on the moon, his heartbeat was highly increased — this must have been caused by emotional tension, as he was barely able to move a muscle.

The pumping action of the human heart works as follows. In the initial phase, the heart is relaxed and both atria fill up with blood. The right atrium is provided with deoxygenated blood by the superior and inferior hollow veins, and the left atrium is provided with oxygenated blood from the lungs via the pulmonary veins.



Cross-section of a human heart. On the left is an electrocardiogram which shows the electrical activity with every heartbeat.

Then, the atria contract. The blood streams into the chambers passing the valves between the atria and the chambers. Next, the chambers contract and pump the blood away from the heart. This happens by opening the aorta valve and the pulmonary artery valve. Tiny muscles attached to the valves between the atria (the tricuspid valve on the right and the mitral valve on the left) prevent leaking and the reflux of blood from the chamber to the atria.

The oxygenated blood flows through the aorta (the main artery through the body) and then through smaller arteries to all the body's organs and tissues, and the deoxygenated blood through the pulmonary artery back to the lungs, where it is provided again with oxygen.

The cycle is now complete and another heartbeat brings the next cycle into motion. The complex action takes less than a second on average.

The natural pacemaker of the heart, the sinus node, controls the basal heart frequency. It consists of specialized muscle tissue in the wall of the right atrium. The sinus node periodically fires electrical impulses that force the heart muscles to contract. With physical exertion or stress, muscles and other organs require more oxygen, which is delivered by blood. When that happens, the sinus node makes the atria and chambers contract quicker, causing the heart to beat faster.

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0.995 seconds
The half-life of ^{79}Zn

Isotopes are atomic nuclei that contain the same number of protons as the element they are related to, but differing numbers of neutrons. Stable isotopes exist practically forever, unlike unstable isotopes, whose half-lives vary enormously. It so happens that the half-life of one element, called ^{79}Zn, is almost exactly 1 second.

The weight of an atom is comprised of the sum of the weight of its protons and neutrons. The mass number, the sum of the number of protons and neutrons, is usually indicated to the left of and above the abbreviation of the element in question, just as we have done in this book (for example: ^{79}Zn). The 'atomic number' only counts the protons, often indicated in scientific literature to the bottom left of the name of the element (for example: $_{30}$Zn).

Since neutrons have no charge, the electric charge of a nucleus is derived only from its protons and is thus defined by the atomic number. The number of electrons circling the nucleus is equal to the atomic number as well, since atoms are usually electrically neutral and electrons and protons have equal but opposite electric charge. This explains why an isotope usually has almost the same chemical characteristics as the element it is derived from. Therefore, chemically, zinc invariably behaves as zinc, irrespective of the number of neutrons in its nucleus.

Zinc is a metal with atomic nuclei that contain exactly 30 protons each. On average, 30 electrons circle each nucleus, as this number of negatively-charged electrons neutralizes the positive charge of its 30 protons. The stable isotopes (variants) of the element zinc contain 36, 37 or 38 neutrons. However, there are dozens of unstable isotopes with either a larger or smaller number of neutrons. Zinc-79 (^{79}Zn), for example, contains 49 neutrons.

The nucleus spins around its axis very quickly: its spin, or more precisely its angular momentum, is 9/2 in natural units, while the normal spin for a zinc nucleus is 0 or 5/2. The isotope ^{79}Zn can emerge from nuclear reactions, only to fall apart after about a second by emitting an electron. By losing an electron the element disintegrates into another element, gallium, which has 31 protons and 48 neutrons. In some instances, another neutron escapes.

On page 15, at 10^3 seconds, we look at neutrons and protons in more detail, including the matter of isotopes.

1 second

On planet Earth, this is the time it takes for a stone — or any other heavy compact object for which air resistance can be ignored — to fall to the ground from a height of 5 meters. On the moon we would have to drop the same stone from only 81 centimeters for it to reach the ground in 1 second.

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The Earth and the Moon, photographed from the Galileo spacecraft.

1 light-second

In an empty region of space, light travels 299,792,458 meters in 1 second — in other words, the distance of 1 light-second. The terms 'light-years' or 'light-seconds' are not measures of time but of distance. Nowadays, the speed of light is measured so accurately, that we define 1 meter as the distance that light travels in 1/299,792,458th of a second. Elsewhere in this book we will compare the distance that light travels during other time intervals.

1.28 seconds

This is the time it takes for a light or radio signal to travel the distance between the Earth and the Moon. On average — from center of gravity to center of gravity, and taking into account the elliptical shape of the lunar orbit — this is a distance of 384,403 kilometers. The speed of light is 299,792,458 meters per second, meaning that our light shines on the Moon within 1.28 seconds. Having a phone conversation with an astronaut on the Moon means you have to wait about 2.5 seconds for a response — the time it takes for a radio signal to travel back and forth.

No signal will ever travel faster than the speed of light, which means that even with extremely advanced techniques in the far future we will never be able to shorten this communication time, but perhaps there will be ways to lessen the annoyance factor of these waiting periods.

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