Seven Brief Lessons on Physics Study Guide

Seven Brief Lessons on Physics by Carlo Rovelli

Contents

Summary

The following version of this book was used to create this guide: Rovelli, Carlo. Seven Brief Lessons on Physics. Penguin Books, 2016. First edition.

Carlo Rovelli introduces the basics of several theories that were developed by physicists in the twentieth century. He explains how Einstein conceived of special and then general relativity. Einstein published three groundbreaking papers simultaneously at the age of 26. Rovelli explains that relativity imparts that space and the gravitational field are one and the same thing. He also describes the theory's beauty in its simplicity, and shares that he began to understand it through the inspiration of the Mediterranean ocean.

Rovelli explains quantum mechanics' origins in Planck's trial to divide energy into 'packets.' Einstein's wave-particle duality showed that light truly is quantized, and Bohr's atomic research showed that electron energies are too. Quantum mechanics describes positions and motion through probability, particles appear and disappear, and things can only be located completely during a collision. The theory behind quantum physics is still not understood entirely, but the equations that were developed have been used to build a variety of technologies.

The third lesson gives a quick overview of the development of human understanding of the structure of the universe. From solely the ground and sky, the view expanded to a spherical Earth. Then came the heliocentric theory, and eventually people were able to observe many solar systems. Now we know that our galaxy is one of many in a constantly expanding universe whose boundaries we cannot observe.

Particle physics studies the elementary particles – photons, electrons, quarks, and gluons – as well as neutrinos and Higgs bosons. These particles are also just quanta and move according to quantum mechanics. The Higgs bosons were first observed as recently as 2013. The current theory of how these particles function, the Standard Model, has many flaws and is still very much under development. Many scientists do not consider particle physics credible but its theories are evolving as we speak.

The fifth lesson is named "Grains of Space" and tackles the contradictions between relativity and quantum physics. In relativity, things are continuous and space can curve, but in quantum physics, space is flat and things are quantized. Rovelli describes loop quantum gravity, which attempts to combine the two views. The loops are links that form space, the connections between quanta of gravity. This is Rovelli's field of research.

Rovelli looks into the possibility that the flow of time is an illusion. He asserts that heat exchange is the way to determine if time has passed and explains the analysis of heat via probability. He then goes into how probability is tied to a person's subjective, limited view of the world. His theory is that considering these elements together will reveal the true nature of time.

The last chapter explores humans’ role and self-concept in light of the presented discoveries. Rovelli ensures that individuals can be singular entities according to their desire, even if they are made of constantly disappearing and re-appearing particles or space that curves. He also emphasizes that complex thoughts, deep feelings, and neurochemical processes are all a part of nature. Similarly, humans are an equal and integrated part of nature, as much as any other of its elements.

Preface to Third Lesson

Summary

Preface:

Rovelli explains that the book gives an overview of twentieth century physics for those who do not know much about it. Its chapters explore relativity, quantum mechanics, the cosmos, elementary particles, quantum gravity, and black holes. And, finally, he ties these findings back into modern life.

First Lesson:

Einstein spent a year in Italy, after abandoning his high school, largely aimless, reading, and going to some university lectures for fun. After that, he began studying physics and soon wrote three major theories: one was about atoms, one on quantum mechanics, and the other about (special) relativity. Because of a flaw in his piece on relativity, he was inspired to write his theory of general relativity, which has been called the “most beautiful of theories.”

Rovelli tells of a summer he spent in Calabria, Italy by the ocean. He was reading a book on physics and gained inspiration and understanding about relativity from the sight of the sea. Rovelli calls the theory of general relativity unequalled due to its stunning simplicity. He goes on to explain it, telling of Newton’s description of the force of gravity and ‘space.’ Faraday and Maxwell added on to this with their definition of the electromagnetic field. Einstein came to understand that there is also a gravitational field, and that the gravitational field is the same thing as ‘space.’ The force of gravity is actually the curvature of space and Einstein was able to express this in an equation only half a line long. This equation allowed Einstein to predict phenomena such as light curving due to mass and time passing more quickly at a higher altitude. It has facilitated the discovery of black holes, the expansion of the universe, the motion of stars akin to the movement of the ocean’s surface, and much more. Rovelli gives the admired equation (Rab – ½ Rgab = Tab) even though he does not expect most readers to understand it, seeing as one needs to study Riemann’s mathematics first.

Second Lesson:

Rovelli calls quantum mechanics the second pillar of twentieth century physics, along with relativity. He explains that it is a less clear and succinct theory than relativity, but that it has been validated experimentally and used to develop technology such as computers. In order to complete a calculation of electric field, Planck divided energy into ‘packets’ or quanta. The result corresponded perfectly with measurements although the concept seemed unrealistic. A few years later, Einstein showed that light truly is quantized in his wave-particle theory. Rovelli notes Einstein’s modesty and hesitancy in the phrasing of his theory, maintaining that “genius hesitates” (13). Bohr continued the development of quantum mechanics, determining that electron energy in atoms is quantized too. And in Copenhagen, the theory continued to be developed until a set of equations that replaced Newtonian mechanics had been devised. Heisenberg wrote the first version of the equations, based on the idea that electrons only exist when observed, becoming real in a place by a certain probability. In quantum mechanics, the definite position of an object can only be determined when it is colliding with another one. Otherwise its position is only known as the probability that it will appear in a particular area.

Einstein rejected many of these ideas at first, and he and Bohr spent years in dialogue. Einstein identified possible flaws, and Bohr asserted the theory's feasibility over and over. It led Bohr to refine and re-organize the theory, and the two delved further and further into its complexity. Today, quantum mechanical equations are being used in many fields even though they are not yet entirely understood. Einstein admitted their practical validity but maintained that there must be a simpler underlying explanation. It is possible that the equations work mathematically but the associated physical assumptions are incorrect. Rovelli also sees the possibilities that the current form describes a new facet of reality, that the theory is incomplete, or that we need to explore further for the insight into how the universe works.

Third Lesson:

Rovelli gives this lesson on the structure of the universe largely in visuals, as he maintains that science is based largely on seeing and 'seeing' things differently. He describes the progression of humans' perception of the cosmos. For millennia, it was seen as sky above us, earth below us. In the sixth century BCE, a sky around all sides of a floating rock was conceptualized. Aristotle then showed that the Earth must be spherical. Afterwards, Copernicus found that the sun is actually the center of the system. As technology developed, allowing people to see more and more, other solar systems could be observed, together forming our galaxy. After some time, other galaxies could be seen as well. We now know that the universe is moving like the waves in the ocean, and that it originated from a small, hot, dense cloud of matter. This cloud exploded to its huge current dimension and is still expanding today.

Analysis

Rovelli's writing, especially in the beginning, is inviting and soft; it is also mildly humorous and manages to impart warmth in a physics book. When telling of Einstein's youth, for instance, he says, "You don't get anywhere by not 'wasting' time – something, unfortunately, which the parents of teenagers tend frequently to forget" (1). The tone in this section is kind and light-heartedly joking. It also introduces the philosophical aspect of the book, as Rovelli shares his advice for life. The author's other technique for pulling his reader into the physical depths is the personal connection that he shares between himself and these scientific theories. He conveys the personal, emotional significance of these ideas to him, sharing that he was excited when he began to understand relativity. And he describes the ambience of the entire situation - his book missing chunks from mice, the sun shining down on him by the ocean, the sea glittering to impart elusive concepts.

Rovelli conveys his admiration of the theories he presents as well as their writers. He describes the beauty and elegance that he sees in the ideas. In some places, it is stated very openly, general relativity is named a “masterpiece,” compared to the Sistine Chapel, and its “breathtaking simplicity” is described (3; 4). At other times, there is perhaps just an adjective, such as when Rovelli describes quantum mechanics “replacing the entire mechanics of Newton” (14). The diction does not stand out, but it nevertheless conveys some of the magnitude that Rovelli sees in the development.

Rovelli develops the mind-twisting nature of the ideas he shares, and he creates almost fantastical descriptions of them. When explaining the unity of space and the gravitational field he describes space as “an entity that undulates, flexes, curves, twists…we are immersed in a gigantic flexible snail-shell” (6). This imagery may truly provide the reader with a deeper understanding of the concrete nature of gravity, even though the snail-shell is, of course, purely symbolic. Or perhaps it serves simply to engage and interest the reader. In discussing quantum theory, Rovelli writes that it seems reality was “not designed…with a line that was heavily scored, but just dotted…with a faint outline” (15). Again, he is describing it symbolically. Quantum theory describes things jumping in their existence from one place to another, location being indeterminable, energy being discontinuous but undivided. Rovelli’s image’s physical meaning is therefore that the boundaries and defining features of the world are faint or unclear in the aftermath of quantum mechanics.

The author also incorporates his interest in the history and philosophy of physics. Rovelli taught these subjects at the University of Pittsburgh for some years. Scattered between the theoretical pieces of information, he creates a rough timeline of their development. He introduces the major contributors to most of them, sometimes the place in which the formation happened, and elements of the creative process too. He shares, for instance, that a young group of scientists gathered in Copenhagen after Bohr published his insights to continue work on them. Einstein pointed to many flaws in the theories, leading to a long process of idea exchange between him and Bohr, and Rovelli describes that the scientists felt let down by the visionary they had looked up to. Thus, Rovelli gives the reader insight into how these ideas were created, the way in which people cooperated internationally, and the process of accepting some ideas while challenging others to come to an accepted concept in the end.

Vocabulary

loaf, elucidate, tedium, phantasmagorical, quotidian, cathode ray, point source, juvenilia, scored, resultant, nebula, furrow, diagrammatically

Fourth Lesson to In Closing

Summary

Fourth Lesson:

Light consists of photons. Atoms are made of electrons, protons, and neutrons. Protons and neutrons are made of quarks held together by gluons. These four smallest ones are the elementary particles. Other than those, there are neutrinos and Higgs bosons. These particles are quanta of fields rather than individual entities. They and their movement follow the principles of quantum mechanics, thus they appear and disappear. And they sometimes exist without being observable. Quantum mechanics and particle physics have determined the world to be continuous and ephemeral. From the 50s until the 70s, the Standard Model was developed and tested. It was an international cooperation between scientists such as Feynman and Gell-Mann. However, the model is not fully accepted today since it has some holes and flaws. Some elements seem to be makeshift, others have not been justified.

A related issue is that something now named ‘dark matter’ has been observed. Around every galaxy, something is exerting gravity and deflecting light. It cannot be seen and it is not made of any of the particles determined thus far.

Some attempts have been made to develop a better model such as SU5, for which scientists tried to see if protons disintegrate, or the supersymmetric theories. But the Standard Model remains the best one for now. Rovelli closes the chapter with the image of these particles forming all sunlight, mountains, young people at parties, and the night sky.

Fifth Lesson:

Rovelli maintains that the previous theories give humans a better understanding of the world than ever before. However, there is a contradiction in the theories of general relativity and quantum mechanics. They have both been used to explain observed phenomena and develop technology but cannot both be true in their current form. General relativity describes curved continuous space whereas, in quantum mechanics, space is flat and energy is quantized. Research in the field of quantum gravity is trying to develop a unifying theory. Rovelli describes the beauty of this field, he sees it as “incandescent in the forge of nascent ideas” and describes a scene of roads taken and roads abandoned (39).

Loop quantum gravity is an attempt at a unifying theory that rewrites the two hypotheses to make them compatible. It determines space to be made of many tiny links that are called loops. It theorizes that the interconnections of quanta of gravity are what forms space. Secondly, loop quantum gravity results in the vanishing of the independent singular flow of time, as quantum events become the source of time. There is no experimental verification of the theory, though scientists (Rovelli included) are trying. One attempt is focused on black holes. If loop quantum theory is correct, the matter of the star that has collapsed has condensed extremely, but only to a finite point. According to quantum mechanics, there must be an opposite force that, once the star is maximally dense (known as a Planck star) causes it to expand again. In other words, the black hole would explode. And, in this case, high-energy cosmic rays would be observable, which would be evidence for the loop quantum gravity theory. Such signals are now being searched for.

Similarly, though on a far greater scale, the theory suggests that the Big Bang was in fact a 'Big Bounce.' That the universe has not only expanded from an extremely dense state, but was once of a similar scale as today, contracted, and is now expanding again. The moment when the universe is condensed to its most extreme point is quantum gravity's specialty, as its equations can still describe it. Rovelli expresses that these theories highlight the inadequacy of our intuitive understanding of the world. Though perhaps he is thinking of early scientific attempts to explain the world rather than deep intuition.

Sixth Lesson:

In this chapter, Rovelli discusses heat – in relation to probability, time, and black holes. Maxwell and Boltzmann explored the nature of heat in the nineteenth century. They found that the rapid movement of atoms is what constitutes heat. Rovelli now describes time as a product of heat transfer. He argues that, in any situation with little heat transfer, the future behaves like the past, such as the planets moving in their orbits or a frictionless pendulum. Maxwell and Boltzmann also determined that heat moving from warm to cold objects is a matter of probability. It is theoretically possible that a cold teaspoon in a hot cup of tea gets colder, it is just very improbable. Rovelli explains that, generally, probability in physics allows one to predict an object's behavior while knowing only a few of its properties. He can only observe a balloon's shape and volume but not the movement of its internal molecules, so he can only predict its movement when he releases it through probability.

Rovelli transitions to the question of the relevance to physics of what one knows or does not know. He investigates how the knowledge of an individual is related to physical behavior. A prediction of an object's behavior is based on its characteristics that an individual knows about. Probability, he argues, is the development of those characteristics rather than the object's actual matter. He ends the section by saying that he hopes he has not lost the reader's attention.

Thermodynamics and statistical mechanics grew to include electromagnetic and quantum physics. The behavior of an electromagnetic field as it heats up is predictable, but that of a gravitational field is not. Since the gravitational field is spacetime, spacetime must vibrate. But no equations, and at times no concepts, have been conceived to describe this. To attempt to understand this, Rovelli wonders what time is. He describes how time appears to flow, whereas quantities like space or butter do not flow - pass by independently, exist only partially. The concept of time is that only the present exists, whereas the past and future do not. In relation to space, it is recognized that things both here and there do exist. Rovelli shares that the question of whether this passing of time is subjective or an illusion has been investigated in modern physics. Einstein's relativity showed that 'the present' is indeed subjective, and since then many physicists and philosophers have agreed that it is only an illusion. Rovelli wonders how come we sense the passing of time if it is an illusion. He brings up that many philosophers do not think physics is entirely capable of describing the world. Though Rovelli seems open to this thought, he still wonders where the subjective experience of time comes from, and continues to search for the answer in physics. He searches in the relationship between time and heat. Apparently, the flow of time emerges in the combination of statistics and thermodynamics. He believes that a hypothetical ultra-sensitive, highly conscious being would not experience the flow of time but see past, present, and future simultaneously. Stephen Hawking completed a calculation that shows that black holes are hot, a quantum effect that may lead to an answer regarding the nature of time.

In Closing:

Rovelli explores the implications of the twentieth century's physics developments to people's lives. He wants to explore humans' roles in the depiction of life that these theories present. For instance, if people are also made of quanta and constantly disappearing and reappearing particles that may shock the self-concept of some individuals. He poses some questions that he could imagine coming from his reader, such as “What then are our values, our dreams, our emotions, our individual knowledge…in this boundless and glowing world?” (63). Rovelli says he cannot possibly answer all these questions in one chapter, but he will essentially do his best.

He introduces humans as the collators of the previously presented knowledge, as elements of a network of knowledge. And he also defines them as an equal part of the world, which they are observing from its midst. Humans are a tiny piece of existence, and Rovelli compares them to an only child growing up to find that the world does not revolve around them. Rovelli believes there is a universal reality and each person has certain 'filters' that make them see it individually. He notes that, unlike Kant, he sees Euclidean space and Newtonian mechanics as a construction of those filters rather than the universal reality. He compares science to following a deer's tracks and contrasts it with telling stories around a campfire.

Rovelli also asserts that carrying and exchanging information about the world around us does not make humans unique. A ray of light, for example, carries information about the composition of the object it came from. But he continues to wonder what creates the subjective experience – humans' thoughts and emotions. Some theoretical developments, like Giulio Tononi's 'integrated information theory' are attempting a mathematical determination based on neuroscientific findings. Rovelli thinks humans' feeling of internal liberty comes from the fact that they are constantly amazed at themselves, because their functioning is far more complex than they can comprehend. In his view, the knowledge that our thoughts are determined by neurochemistry, our instincts animal, or our structure a result of evolution does not change how real our values and emotions are. Both the subjective feelings and the deterministic neurochemistry are equally parts of nature. And whatever element one wants to identify as what makes humans unique, is also a part of nature.

Looking into human nature, Rovelli identifies curiosity as an inherent feature of people. And he sees them as a short-lived species, since their evolutionary relatives are already extinct and they are damaging their surroundings. Birth and death are universal elements of existence. Quantized space, the ceased existence of time, and things disappearing are a product of human curiosity and, voluntarily or involuntarily, a part of the greater world. He quotes a description by Lucretius of all parts of nature’s common origin and co-composition. And Rovelli concludes that love, honesty, and the desire to learn are all a part of (human) nature.

Analysis

In these chapters, there is less humor in the tone, as Rovelli delves into the physics and focuses more on explaining details of that content. He has essentially cut the information down as much as possible while maintaining a coherent, linear view of what is known. And he gives more details on the parts that seem most interesting. To that, he adds some pieces that make reading the book enjoyable. While writing in a matter-of-fact style, Rovelli continues to use many metaphors to explain the physical concepts. He describes, for example, that “particles do not have a pebble-like reality” but are rather like “minuscule moving wavelets” (30). Thus, his visual and kinesthetic imagery serves to aid the reader’s understanding of the very abstract concepts that he describes. The subatomic particles are often represented, in textbooks or magazines, as small spheres. This is not entirely accurate but a compromise of simplicity and accuracy in order to provide some visualization. Rovelli likely brings a pebble to the reader’s mind since it is a readily available memory for many. And he uses that image to attempt to explain that particles look neither like pebbles nor spheres, and in fact do not have a steady individual appearance, as one may expect, at all. Soon after, on a similar topic, Rovelli writes, “Just as the calm sea looked at closely sways and trembles, however slightly, so the fields that form the world are subject to minute fluctuations” (31). At times, his imagery paints whole scenes that immerse the reader in a world which may feel like futuristic science fiction but is, apparently, just the world we live in.

Rovelli’s syntax and diction also add some excitement for the reader, providing for the likelihood that they will not all be as excited about theoretical physics as he is. He writes some short, snappy sentences to keep the text engaging. He follows a compound sentence that introduces historical conceptions of heat and their terminology with: “The idea turned out to be wrong” (49). And he writes of the updated theory, “Beautifully simple. But it doesn’t end there” (50).

Rovelli makes some fairly bold statements, catching the reader’s interest. He asks, “why, as time goes by, does heat pass from hot things to cold…?” And writes that “the reason…is surprisingly simple: it is sheer chance” (51). In the next paragraph, he explains how exactly the heat is transferred, which is not actually sheer chance but a matter of probability. Thus his statement was more of a pun and a hook than an explanation.

Rovelli reveals his relation to these theories throughout the book. He studied physics and shares the fascination that relativity inspired in him as a young student. He continued until receiving a PhD and began to work at different universities, researching and teaching. His current field of research is quantum mechanics, including loop quantum gravity theory, which he explains in detail though only implying his involvement through his use of pronouns. The other thing that becomes clear is Rovelli's love of these subjects. He finds many of the theories to be incredibly beautiful ideas and sees each as a new opportunity to re-interpret existence.

Vocabulary

quark, gluon, neutrino, sub-stratum, immutable, renormalization, supersymmetric, profligate, vanguard, forge, nascent, parochial, bastion, caloric, microstate, risotto, indexical, abstruse, enigma, fresco, idealism, arabesque, a priori, posteriori, mesoscopic, quarrelsome

Important People

Carlo Rovelli

Carlo Rovlli, the author, was born in 1956 in Verona, Italy. He researches quantum mechanics, including loop quantum gravity, which he explains in Chapter 5. He is also investigating whether time is validated by physical laws or if it is an illusion. He studied physics, obtaining a PhD, at the universities in Bologna, Padova, and Trento. He has also worked at the Aix-Marseille Université, Università di Roma La Sapienza, Syracuse University, and Yale. And he has taught history and philosophy of science at the University of Pittsburgh.

Additionally, Rovelli writes – for newspapers, scientific books, general audience books, and more than 200 scientific articles. His other popular books include Reality Is Not What It Seems: The Journey to Quantum Gravity, The first scientist Anaximander and his legacy, and What is time, what is space? He writes columns for the Italian newspapers Il Sole 24 Ore and La Repubblica that are personal but also include scientific and philosophical thought.

As a student, he took part in political movements and helped to found free political radio stations. He got into trouble for refusing his military service and expressing dissident opinions in the book Fatti Nostre on political events in Bologna in 1977.

Albert Einstein

Perhaps the most famous modern physicist, Einstein was born in 1879 in Germany. He lived in several countries in Central Europe and in the U.S. before he died in 1955. He is famous for his papers on relativity and quantum physics. The number of theories Einstein wrote at a young age, as well as their level of innovation, have strongly influenced today's intellectual ideals. Rovelli discusses his work throughout the book, but primarily in Chapters 1, 2, and 5.

Max Planck

Another German physicist, Planck was born in 1858 and died in 1947. He is most famous for the founding of quantum physics but also researched black-body radiation and relativity. During World War II he felt it was his duty to stay in Germany, and he suffered from his efforts to oppose the Nazi regime. Rovelli explains his discoveries in Chapter 2.

Niels Bohr

Bohr was born in Denmark in 1885 and lived there as well as in England until he was 77. One of the most commonly referenced atomic models is named after him, and he also made foundational contributions to quantum mechanics. Additionally, he was also a philosopher, encouraging scientific research, and he partook in the development of nuclear technology. Bohr’s work is most relevant to Chapter 2.

Michael Faraday

Faraday was a nineteenth century English physicist and chemist who focused on electricity. He contributed greatly to today’s understanding of electromagnetism. His research was largely experimental, and he never completed a formal education. Rovelli discusses Faraday’s developments in Chapter 4.

James Maxwell

Maxwell was a Scottish physicist and mathematician in the nineteenth century. A set of equations named after him provided the unification of electricity and magnetism. He studied science in Edinburgh and Cambridge and was fascinated by colors, investigating photographic technology. Maxwell is mentioned in Chapters 4, 5, and 6.

Ludwig Boltzmann

Boltzmann, living from 1844 to 1906, researched mechanical physics in Austria. He contributed to the atomic explanation of physical properties, the behavior of gases, thermodynamics, and energetics. Boltzmann also involved himself in philosophy to share his insights from his physical discoveries. His work is explored in Chapter 6.

Isaac Newton

Newton, often referenced as the father of modern physics, lived from 1642 to 1726. His descriptions of motion, gravity, optics, and several mathematical theories constitute much of physics’ basis. He also built telescopes and argued against superstitious and magical elements of Christianity. Rovelli talks about him primarily in Chapters 1 and 5.

Werner Heisenberg

Heisenberg was another of the founders of quantum mechanics. He lived from 1901 to 1976 and is famous for his ‘uncertainty principle.’ Directing Germany’s major physical research institute during World War II, his research became a part of the Nazi nuclear weaponry project. Some of Heisenberg’s theories are explained in Chapter 2.

Paul Dirac

Dirac was another twentieth century contributor to the foundations of quantum mechanics and quantum electrodynamics. He also contributed to atomic physics and the theory of antimatter. He grew up in England, with Swiss parents, and lived for some years in the U.S. Rovelli introduces Dirac's work in Chapter 4.

Stephen Hawking

Hawking is an English physicist and cosmologist, focusing his research on relativity and quantum physics. He has written several books that explain advanced physics to a general audience, A Brief History of Time is his most famous. Continuing his research during progressing symptoms of ALS and speaking about this experience, he has contributed significant social understanding of handicapped living. His work is mentioned by Rovelli in Chapter 6.

Objects/Places

Pavia, Italy

Pavia is a small and quiet town in Lombardy, northern Italy. Many agricultural products are made there and its university was founded in 1361. Rovelli mentions it in Chapter 1 as a place in which Einstein spent some of his year 'loafing.' His family had moved there to build up a new electricity company, and he sat in on lectures at the university.

Condofuri, Italy

Condofuri is a community in Reggio Calabria on the almost southernmost tip of Italy. It is on the coast to the Mediterranean and backed by the Aspromonte mountains. Rovelli enjoyed the ocean here on his breaks from university courses. He stayed in a "hippy-ish" old house and read his textbook on the beach, where the waves inspired his understanding of relativity (3).

Spacetime

In the twentieth century physicists developed a four-dimensional view of the universe, combining space and time, which explained many physical phenomena. Relativity showed time and space to be dependent on each other, e.g. a change in speed can cause a change in the rate at which time passes. In relativity, mass curves spacetime and gravity is that curvature. It is primarily the subject of the first lesson, though it is referred to throughout the book.

Hubble Space Telescope

The Hubble telescope is a NASA and ESA project that has produced very detailed, high-resolution images of outer space. It has been used for research into far-away space and the history of space. Anybody can apply to use it, and even some amateur groups carried out observations with it from its launch in 1990 until 1997. It is still in orbit today and might remain so until 2030 or 2040. Rovelli shows an image taken by it in Chapter 3.

CERN Large Hadron Collider, Geneva

The LHC is an underground particle accelerator on the border of Switzerland and France. It is 27 kilometers in diameter, was built between 1998 and 2008, and research began in 2010. It is being used to test theoretical physics by accelerating hadrons (protons, neutrons, and other particles) close to the speed of light, colliding them, and observing the resulting particles. It has given insight into quantum mechanics, and continuing research is focused on particle physics, the Big Bang, the structure of space-time, string theory, etc. Rovelli explains in Chapter 4 that the discovery of the Higgs boson here in 2013 confirmed the Standard Model.

Earth

We have estimated the planet we live on to be 4.5 billion years old. It is one of eight planets orbiting our sun, and the third closest of those. Our solar system is, on average, 27,000 light years from the center of our galaxy, the Milky Way. Rovelli investigates the solar system in Chapter 3.

Sun

What we refer to as the definitive sun is the star closest to the Earth. It is about 73% hydrogen and 25% helium. The sun is about 4.6 billion years old, thus roughly halfway through its lifetime. It is a main sequence star on the Hertzsprung-Russell diagram and a yellow dwarf. Rovelli investigates the solar system in Chapter 3.

Universe

The universe is the entirety of space and matter in existence. We have not determined the size of the universe, though its diameter seems to be greater than 93 billion light years. This is as far away as we have made observations, and in that region there appear to be over 100 billion galaxies. It seems to have no edge and no center, and it is constantly expanding. We estimate it to be 13.8 billion years old. Rovelli explains the structure of the universe in Chapter 3, but the concepts are also relevant in Chapters 1, 5, and 6.

Quark

Quarks are the elementary particles that protons, neutrons, and other hadrons are made of. In scattering experiments, where particles are fired at other subatomic particles, it was observed that protons contain even smaller objects and are not one of the smallest objects in existence, as was previously thought. Rovelli introduces them in Chapter 4.

The mind

Perception is central to the concepts Rovelli explains. Relativity shows that the same distance or span of time can be measured to be different depending on the measurer. Being able to see further into the universe or into atoms has given new understanding of physical laws. And choosing to investigate a phenomenon from a particular perspective, such as heat with probability, can also give an entirely different understanding of that phenomenon as well as others. Our mind is the carrier of our perception and the information that we gain, which shape each other. Rovelli explores such contemplations mostly in Chapter 7, but also in the other sections.

Themes

Increasing Understanding Of Our Surroundings

Rovelli believes that humans' understanding of their physical surroundings is improving over the ages. He speaks, for example, of "the numerous leaps forward in our understanding that have succeeded each other over the course of history" (4). This is the most common view of the natural sciences, and perhaps part of their basic principles. Rovelli believes in truth and pursues some abstract set of rules, mechanisms, or foundations that are inherent to the external physical world. Discussing his understanding of relativity, he explains that it was "as if a friend was whispering into my ear an extraordinary hidden truth, suddenly raising the veil of reality to disclose a simpler, deeper order. Ever since we discovered that the Earth is round and turns like a mad spinning-top we have understood that reality is not as it appears to us: every time we glimpse a new aspect of it…another veil has fallen" (4). He often refers to a constant, independent physical reality, for example when saying that Einstein "came to understand that the 'packets of energy' were real. Einstein showed that light is made of packets" (12). The level of abstraction and unfamiliarity of the modern theories that Rovelli presents highlights the absurdity of the extent to which scientists believe firmly in this external constant truth. Understanding this reality seems to be Rovelli's motivation and reason for scientific research, aside from his fascination with the beauty of the theory.

A defining feature of scientific writing, and perhaps scientific thought too, is that the content is spoken about with certainty. Rovelli writes, for instance, "The things we see are made of atoms. Every atom consists of a nucleus surrounded by electrons" (26). Or "precise measurements by astronomers of the nebulae…showed that the Galaxy itself is a speck of dust in a huge cloud of galaxies…" (29). The statements are definitive, leaving no room for doubt in their phrasing. Though one could argue that scientific statements are based on belief as much as any others, and if another field were spoken of with the same certainty it may take the place of describing existence and reality. In another section, Rovelli writes that "Aristotle devised convincing scientific arguments to confirm the spherical nature of both the Earth and of the heavens around it…" (23). His use of the word 'argument' brings to light a whole different aspect of the natural sciences, namely that persuasive logic is used to sell a particular point.

An alternate view of these developments is that people have created a philosophy surrounding scientific research, which is actually a set of individuals' creative ideas rather than a reflection of the surrounding world. That is, perhaps people's beliefs about the way in which the world is structured and functions lead them to behave as if it is so, reinforcing the beliefs over and over. This is a consideration in opposition to the idea that the world has a set structure and function which people are gradually unearthing, though perhaps they can be true simultaneously.

The Scale Of Subjectivity

Relativity disclosed that, contrary to the previous principles, even physics is subjective. Measurements in physics were, until that point, thought to be objective in that they are the same to any observer, as well as in the absence of an observer. Relativity showed that both length and time measurements of the same object or phenomenon can come out differently. It is a change to the field of physics and its approach, as well as to many people’s view of how the world works. Contemporary Western philosophy is influenced by the sciences to the point that many people view their existence defined by the same laws that define science. And so a change in the way contemporary physicists view the world has a significant impact on many people’s view of life.

Another example of Rovelli’s descriptions of subjectivity in physics is contained in the sixth lesson. Here, he discusses the use of probability in thermodynamics. He highlights that an object (his example is a spoon heating up in a cup of tea) interacts with the observer through a limited number of variables. That is, an observer will almost never know all the properties of an object, to the extent of the movement of all its atoms. And so any predictions that an observer can make about an object depend on which properties they can observe.

Physics is viewed by many as one of the most objective fields. So if even physics can be subjective, one may begin to question if there is anything entirely objective out there. Many philosophers would argue that the answer is no, and this opinion already existed before the twentieth century.

The other insight Rovelli gives to subjectivity in physics is in the development of theories. His explanations of how these modern (and some older) theories formed reveal that they are often the brainchild of one individual. They are discussed with other physicists and peer-reviewed, but there does seem to be a lot of weight in the initial proposal. Rovelli says, for example, that after sending three articles to a physics journal “Einstein became a renowned scientist overnight and received offers of employment from various universities” (2). So there seems not to have been the time in this instance for the universities’ physicists to review his work before offering him employment. His initial statement must have been convincing enough to inspire them. In the case of Heisenberg’s quantum contributions, Rovelli states that Einstein “didn’t miss any occasion to grumble that this did not make much sense” but nonetheless proposed him for the Nobel Prize (16). The idea, the slogan if you will, of physics is that it is based purely on observation and reasoning. But Rovelli reveals that the viewpoints of the individuals working on the subject do carry some weight. Especially considering the hierarchical structure of the physics field, which results in few individuals being considered to be ‘at the top’ of the field, and those individuals carry the most authority in the development of theories.

The Abstract Becoming Real

The theories Rovelli presents argue in several instances that the physical, tangible world is physically formed of things that were previously considered purely abstract.

Relativity revealed that space is actually the same thing as the gravitational field. Rovelli describes it as follows, “the gravitational field is not diffused through space; the gravitational field is that space itself…’space’…and the ‘gravitational field’ are one and the same thing” (6). And, to top it off, the force of gravity curves space. Gravity is the attractive force between masses, the thing that keeps us sticking to the ground, sometimes described as being like an invisible rubber band that holds planets orbiting each other together as they circle around. And relativity declared that exactly that is what constitutes space – length, area, and dimensions. Space is visible and tangible all around, but “what this ‘space’ was made of, this container of the world he invented, Newton could not say” (5).

Though loop quantum gravity has not been supported by any evidence, it presents a particularly interesting possibility in this line of thought. Rovelli shares that scientists are considering whether things consist of interconnections rather than elements. The idea is somewhat like that of a network. A social network, for instance, can be argued to consist of interconnections between people rather than people. Similarly, space in loop quantum gravity theory, consists of the links between quanta of gravity. And time of the links between quantum events. Again, the argument is that these tangible experiences consist of something abstract, interconnections.

The other discoveries that present a similarly stunning perspective are those of particle physics. Recent research has shown that matter is made of particles that are constantly appearing and disappearing. And their movement is described by quantum mechanics, which means they cannot be directly located. Rovelli describes quantum mechanics’ laws as “strange” and explains that by their description “everything that exists…is nothing but a jump from one interaction to another” (30). He also adds that they describe the world as “a continuous, restless swarming of things” (31).

Concepts Of Reality Are Interpretations

Rovelli writes that our collective interpretation and definition of the world are determined by how much we can observe and which observations we prioritize. Reality is the concept of all the things that exist and how they function. This concept is formed collectively through the, usually implicit, agreement of individuals. Rovelli highlights that the extent and focus of our abilities of observation have a large impact on that development.

In Chapter 3, Rovelli outlines the process of humans observing more and more of the planet and outer space. Such a broadening in perspective significantly impacts the interpretation of reality. One thinks differently about life, after realizing that one lives on “a great stone that floats suspended in space” or that there are billions of other galaxies out there (23). The differences between the conceptions over the ages show, not only, that ability of observation changes the view of reality, but also that it really is just an interpretation if it changes so readily.

The theories of relativity and quantum physics illustrate a shift in prioritization, of focus. Quantum mechanics' subject matter is just the same as that of Newtonian mechanics, how things move, but it was inspired by entirely different observations. It focuses on the instances of mechanics that are not in line with Newton's theories. Thus it also came to entirely different conclusions. Determining that all space ripples like the surface of the ocean or that particles are appearing and disappearing forms another unique conception of reality. When the discoveries were first revealed, they were a shock to many a person. Now, as we are in the process of integrating these points of view into the collective idea of reality, we give the observations of Michelson, Lorentz, Poincaré, and the other scientists whose work Einstein based his theory on increasing priority in our definition of reality. Rovelli's consideration, for example, of the possibility that the flow of time does not exist, brings forth the malleability of conceptions of reality. He writes of the consequences of quantum physics, "The world described by the theory is thus further distanced from the one with which we are familiar. There is no longer space which 'contains' the world, and there is no longer time 'in which' events occur" (42). Thus he shows the reader how this line of enquiry has brought about a different representation of how things work.

People are an equivalent part of nature

Especially in the last chapter, Rovelli emphasizes several times that people are entirely a part of nature. Linguistically and thereby conceptually, there is often a separation between nature and humans or 'man-made' things. However, Rovelli reminds the reader in several ways that these are one and the same thing. Human beings constitute one of the extremely diverse and numerous forms that nature takes on. Some of these points he ties directly to this theme and others are a part of their own arguments, but contribute to it upon reflection.

One of Rovelli's arguments is that, evolutionarily, humans have developed in the same way as all other species. And, at some point in history, we came from the exact same source. Rovelli gives the specific examples that humans share ancestors with butterflies and larches, perhaps this specific relationship has been genetically researched. So his first point can be interpreted to say that our common source implies that all animal and plant species are to some extent composed of and structured in similar ways.

Another of his points is that progress in the sciences has increasingly shown humans that they are not as important as they may have thought. Beyond being an equivalent species, there are many other planets, we are not the center of the solar system, there are many other solar systems and galaxies, and we are not the center or a special part of any of it. In this way, Rovelli lets the reader imagine how vast the remainder of nature is, with humans a grain of sand somewhere on the beach. This perspective on the scale of things makes it harder to imagine that, being surrounded by so many other similar elements, Earth or people somehow stand above or apart from it all.

What is logically a continuation from this idea, is when he addresses the remaining concept that life on Earth is unique – that this planet is special because there is not life anywhere else in the universe. His point is essentially that, having observed the learning outlined above, it is quite illogical to maintain that this one part of nature is so special in some way. He maintains that it is far more likely that whatever else is out there is too complex for us to understand. Nature can form so many combinations and “extraordinary complexities” that there must remain much to be discovered (74). Again, this shows that humans are but one of the many elements of nature. This one is a more abstract assertion, more like a logical argument in philosophy, than the scientific-evidence-based arguments before.

And the other line of thought which the author addresses is that of consciousness, as many people believe humans to stand above other parts of existence because they are self-aware. First, he approaches the question biologically. Neuroscience research has shown that our thoughts are connected to our neurochemistry. And the cells that constitute our brain are the same as those in any other animal. This argument is similar to the first one, that humans are composed of the same elementary constituents as all other organisms. But Rovelli also points out that, at this point, some people question whether people really do make free decisions. His interpretation is that our decisions are determined by the laws of nature as much as any other part of nature, but they are specifically determined by the laws of nature acting on the things in our heads. For contemporary Western science-based philosophy, this is quite a unique perspective on the question of free will. It is based on, as Rovelli states he prioritizes, the unification of previously divergent view points.

Styles

Structure

The book is structured primarily by topic, and to some extent chronologically. Relativity and quantum physics are the elementary components of what Rovelli presents, and they come first. He then describes further exploration based on these two theories, including astrophysics, particle physics, and quantum gravity. The last lesson explores far-out elements of thermodynamics. Both historically and conceptually, the later theories are based on the earlier ones. And the final chapter is a philosophical reflection upon this physics.

As the title promises, Rovelli gives brief lessons. He has created very condensed overviews, leaving some more detailed aspects that are perhaps particularly interesting or insightful. To this he also adds some historical and anecdotal information for variety. Rovelli alternates between explaining the theories and giving conceptual context, adding historical information, or exploring related philosophical enquiry. Though the book is written for a general audience, there are times when he details quite advanced physics or complex chains of reasoning. And at one point he concludes a flood of thoughts expressing his hope that he has not lost any of his readers.

Perspective

Rovelli's perspective on the material he presents is firstly that he has studied physics in depth. He has a PhD in physics and works as a researcher. Another major part of it is that he seems to love the subject, he admires its beauty and is fascinated by its concepts. His aim in writing this book seems to consist of him wanting to help the reader understand these concepts and thereby share the positive personal impact he gets out of them. He feels that society still needs to absorb the ideas delivered by physics a hundred years ago, much like thinking was revolutionized by the heliocentric theory. And this book seems to be an effort of his to spur this process.

The other significance of these theories to Rovelli is their philosophical implications. To any individual whose worldview is based largely on the natural sciences, of which there are many today, these theories present a vast opening of possibilities. If principles as basic as the constancy of length are being challenged, one may be inspired to wonder what other unnecessary restrictions we may assume to be true. And Rovelli shares his personal philosophical thoughts as well as academic enquiry on the topic throughout the book.

Tone

Rovelli manages to create a fascinating combination of physics textbook, fan literature, art review, and storytelling in his tone. His writing is at once personal, excited, stunned, knowledgeable, and patient as he carefully relates detailed explanations.

He speaks, for example, of the time at which he himself learned about relativity, “Every so often I would raise my eyes from the book and look at the glittering sea: it seemed to me that I was actually seeing the curvature of space and time imagined by Einstein” (4). Here, Rovelli not only shares details of his personal experience related to the topic, but also expresses his admiration of the theory through the analogy.

At times, it seems as though Rovelli is holding a conversation with himself: “We don’t have the equations to describe the thermal vibrations of a hot space-time. What is a vibrating time? Such issues lead us to the heart of the problem of time: what exactly is the flow of time?” (56) Here, his excitement becomes clear through the repetition of sentence structure. And the abrupt transitions between ideas express his enthusiasm and fascination too.

He explains abstract concepts through imagery, metaphors, comparisons, and many more tools. And he combines them all, giving one explanation after another, trying lots of different ways. As when he explains, “These particles do not have a pebble-like reality but are rather the ‘quanta’ of corresponding fields, just as photons are the ‘quanta’ of the electromagnetic field. They are elementary excitations of a moving substratum similar to the field of Faraday and Maxwell” (30). Rovelli continues with three further explanations in that paragraph.

Quotes

In his youth Albert Einstein spent a year loafing aimlessly. You don't get anywhere by not 'wasting' time – something, unfortunately, which the parents of teenagers tend frequently to forget.
-- Rovelli (chapter 1 paragraph 1)

Importance: This is how Rovelli begins the book, and it is a suitable introduction to what follows. Rovelli explains the modern developments in physics and simultaneously explores related philosophical enquiries. He begins by looking at Einstein's personal life before delving into the theory.

In quantum mechanics no object has a definite position, except when colliding headlong with something else. In order to describe it in mid-flight, between one interaction and another, we use an abstract mathematical formula which has no existence in real space, only in abstract mathematical space."
-- Rovelli (chapter 2 paragraph 5)

Importance: Rovelli describes some of the details of quantum theory. He manages to phrase the concepts such that they are accessible to many people but he has not skewed or misrepresented the information to do so.

In the 1930s, however, precise measurements by astronomers of the nebulae…showed that the Galaxy itself is a speck of dust in a huge cloud of galaxies, which extends as far as the eye can see using even our most powerful telescopes. The world has now become a uniform and boundless expanse."
-- Rovelli (chapter 3 paragraph 3)

Importance: Rovelli discusses the impact of technology and thereby our ability to observe on our understanding of the world. This physical approach to philosophy develops empirical observations and their logical interpretation into a generalization about existence.

Even if we observe a small empty region of space, in which there are no atoms, we still detect a minute swarming of these particles. There is no such thing as a real void, one that is completely empty.
-- Rovelli (chapter 4 paragraph 3)

Importance: The discoveries of particle physics imply surprises to classical physics. The observations are so stunning that they bring into question some of physics' basic principles.

Quantum mechanics and experiments with particles have taught us that the world is a continuous, restless swarming of things; a continuous coming to light and disappearance of ephemeral entities. A set of vibrations, as in the switched-on hippy world of the 1960s. A world of happenings, not of things."

-- Rovelli (chapter 4 paragraph 2)

Importance: Rovelli is exploring the philosophical implications of these scientific revolutions throughout the book. In this section, he is perhaps suggesting that this often dismissed social movement of the same era could in some ways reflect the same deeper understanding of nature.

Here, in the vanguard, beyond the borders of knowledge, science becomes even more beautiful - incandescent in the forge of nascent ideas, of intuitions, of attempts. Of roads taken and then abandoned, of enthusiasms. In the effort to imagine what has not yet been imagined."
-- Rovelli (chapter 5 paragraph 2)

Importance: Rovelli paints a picture that conveys his fascination, awe, and adoration of science. One image seems to spill from his mouth after another, and he explains what it is that draws him into physics.

The predictability and unpredictability of [a teaspoon in tea's or a released balloon's] behavior does not pertain to their precise condition; it pertains to the limited set of their properties with which we interact...Once again, the profoundly relational nature of the concepts we use to organize the world emerges."
-- Rovelli (chapter 6 paragraph 1)

Importance: Here the author explores another very abstract physical concept with strong philosophical implications. It is another example of subjectivity in physics.

Physicists and philosophers have come to the conclusion that the idea of a present that is common to the whole universe is an illusion, and that the universal 'flow' of time is a generalization that doesn't work."
-- Rovelli (chapter 6 paragraph 2)

Importance: Rovelli reveals another mind-blowing thought derived from modern physics. These theories defy the previous conception of reality and are the efforts to develop a new concept of reality or an entirely new paradigm.

To be free doesn't mean that our behavior is not determined by the laws of nature. It means that it is determined by the laws of nature acting in our brains. Our free decisions are freely determined by the results of the rich and fleeting interactions between the billion neurons in our brain...
-- Rovelli (chapter 7 paragraph 2)

Importance: In the last chapter, Rovelli focuses entirely on philosophy. He does philosophically what he described to be required of physicists today – he synthesizes different existing views to create a stronger new interpretation.

We are an integral part of nature; we are nature, in one of its innumerable and infinitely variable expressions.

-- Rovelli (chapter 7 paragraph 1)

Importance: Rovelli draws on beliefs and paradigms that exist in a multitude of cultures, social groups, and schools of thought and ties them together with the subjects he studies.

That which makes us specifically human does not signify our separation from nature; it is part of that self-same nature. It's a form which nature has taken here on our planet, in the infinite play of its combinations, through the reciprocal influencing and exchanging of correlations and information between its parts."
-- Rovelli (chapter 7 paragraph 2)

Importance: Rovelli presents a fully holistic view of humanity as part of his exploration of the philosophical implications of recent physical revelations.

Who knows how many and which other extraordinary complexities exist, in forms perhaps impossible for us to imagine, in the endless spaces of the cosmos…There is so much space up there that it is childish to think that in a peripheral corner of an ordinary galaxy there should be something uniquely special. Life on Earth gives only a small taste of what can happen in the universe.
-- Rovelli (chapter 7 paragraph 1)

Importance: This thought can be seen as an extension of Rovelli's descriptions of the discovery of further and further expanses of the universe (outwards from the Earth and on its surface). At each point, new possibilities were unearthed and Rovelli is recognizing here that the future will most likely expose more of what is possible in the universe.

Topics for Discussion

Masterpieces

Rovelli compares the theory of relativity to Mozart's Requiem and the Sistine Chapel, calling it a masterpiece. He believes that it might take a long time to appreciate such masterpieces entirely, but that the resulting enjoyment of them is worth it. Do you see beauty in the theory? Explain, either way.

Quantum theory

Quantum theory has been considered so strange to many people that they have not wanted to accept it to be true. And scientific theories have, in the past, been disproven after longer periods of time than what has now passed. However, as Rovelli says, its equations have been applied to develop many modern technologies. Look into its principles a little further and discuss their validity, using as much reasoning based on physics as you can.

The universe moving like waves

Rovelli describes the universe as moving like the waves in the ocean, with black holes being formed in the areas with greatest agitation. Identify the literal parallels to this metaphor, perhaps an online encyclopedia or other resource will be helpful.

The Large Hadron Collider

What is your opinion on the immense natural, social, and economic resources used to build and operate the Large Hadron Collider? Do you think it's an incredible step into humans' understanding of the world around them? An over-scaled endeavor compared to the number of results it has brought forth? Both? Discuss and look up any facts you are unsure about.

Reasoning and empirical observation

How valid is the generalization of reasoning based on empirical observation to the nature of life or existence? There are many ways to take in information and many ways to process it. Do you feel that the level of importance assigned to physics is in line with that multitude?

Bias in contemporary philosophy

To what extent does this approach inherently bias philosophical positions to recent technological developments and areas of research, as opposed to representing the entirety of life, time, or existence?

Loop quantum gravity

One of the implications of loop quantum gravity theory could be that, before the Big Bang, there was another universe similar to this current one, which contracted to the point where neither space nor time existed and is now expanding again. What thoughts does this possibility bring up for you in relation to the nature of existence?

Possible but very improbable

Rovelli shares that, according to the probabilistic explanation of thermodynamics, a cold spoon in a warm cup of tea could theoretically make the spoon colder and the tea warmer. It is possible but has a very low probability. How does this information impact your view of reality?

Whether science reflects reality

How do the insights into the process of how scientific ideas are formed affect your judgment of how definitive these scientific theories are? An example is the exchange and dispute between Bohr and Einstein. Do you see the theories as truths and descriptions of reality or as the subjective ideas of a small group of people, in this light?

Humans an equivalent part of nature

Does Rovelli’s argument that humans are an equivalent part of nature, one of its many and varied forms, go against any parts of your philosophy? Share which part it is, and discuss why they are at odds with each other.