Chapter 2
Einstein's First Famous Thought Experiment

Having followed this rather arduous conceptual journey to the principle of relativity, which in the end is quite simple and clear, let's go back to the beginning Part I and recall Einstein's imaginary ride on a beam of light at the age of sixteen. Reprising the problem, which we will now speak of in the language of traveling in an inertial system moving at some given speed, we saw that when the system reached light-speed the space in our dwelling became dark and hence we knew our exact speed, absolutely. It should be clear now what the problem was – what Einstein called a paradox – for this knowledge violated the principle of the relativity of motion. The darkened room would be the experiment, so-to-speak, that detected absolute motion.

Before seeing how he resolved this paradox ten years later, we need to look at the historical context, for around this time he reached an important juncture in his life.

* * *

Albert Einstein was born in 1879 in the town of Ulm in southwestern Germany to unobservant Jewish parents, Hermann and Pauline. It was common among middle class German-Jews at this time to identify themselves as more German than Jewish. While Albert was still an infant, they moved to Munich.[1]

There are many myths about Albert's childhood and youth, most of which are not true. He was not autistic, he was not dyslexic, he was not a slow learner, he did not have ADHD, he was not left-handed, he was not a vegetarian, and he did not do poorly in school.[2] In his short autobiography (written in his late 60s) he speaks of himself as "a precocious young man,"[3] and his sister Marie (whom the family called Maja) speaks of his "remarkable power of concentration" where he would "lose himself…completely in a problem."[4] It is true that he did not like school, especially

[1] Munich is about 75 miles east of Ulm.

[2] This sentence is not written frivolously: I have seen Einstein seriously used as a poster-boy for these and other causes. For some such speculations, see Neffe [149], pp. 36–37. For a viewpoint closer to mine, see Isaacson [109], p.12, & p.566 n 15.

[3] Einstein [51] [1948], p. 3.

[4] Winteler-Einstein [214] [1924], p.xxii.

D.R. Topper, *How Einstein Created Relativity out of Physics and Astronomy*, Astrophysics and Space Science Library 394, DOI 10.1007/978-1-4614-4782-5_2,

the rigidity of the Germanic method of teaching; and he did not hide his feelings from his teachers, so much so that at least in one instance a teacher told his parents that his hostility and misbehavior in the classroom was a poor example for the other students. His attitude probably was less about pedagogy and more an expression of a contrarian behavior that would be nearly unwavering over the years.

Another expression of this nonconformity took place during his preteen years when he became extremely religious (from an orthodox stance) and distressed his parent considerably by admonishing them for their anti-religious outlook. But just about the time he would have been Bar Mitzvah, he discovered science (through reading popular science books, he says) and promptly abandoned organized religion, without Bar Mitzvah. He discussed this transition in his autobiography in two ways. First, as an intellectual and emotional transformation, when he came to see the religious worldview as subjective and solipsistic. He spoke of this as being involved with "the merely personal." Science, in contrast, offered liberation from this subjectivity. As he put it: "Beyond the self there was this vast world, which exists independently of us human beings and which stands before us like a great, eternal riddle, at least partially accessible to our inspection and thinking."[5] The objectivity of this independent, other-world freed him from the subjective world of the "personal" self. It also released him from the fetters of religion, which he came to see as mainly composed of lies, since he said he discovered that much written in The Bible was not true.

This, in turn, was coupled with a second transformation or un-conversion, which he spoke of in rather overblown political terms: "…youth is intentionally being deceived by the state through lies," is how he put it, and, he continued: "Mistrust of every kind of authority grew out of this experience."[6] Did he really feel this deeply on political and religious matters around the age of twelve or thirteen? Seemingly he did, because he made a most intriguing political decision a few years later. Here is the background to the story.

Albert's father was a businessman who was either incompetent or unlucky. His business was the electrical industry,[7] which was to the late-nineteenth century what the high-tech industry was to the end of the last century (read: "dot-com"): many tried, few survived. Hermann Einstein was in the latter category. When his business went under, his family was forced to move in with his brother: but Hermann's brother lived in northern Italy. Since Albert was in his last year of Gymnasium (high school), it was decided the family would leave him in Munich in a boarding house while his parents and sister moved to Italy. The arrangement was a mishap: Albert was not able to cope with his loss of his family and went into a deep depression, so much so that he left school without a degree. Before heading for the border, however, he obtained a letter from his mathematics teacher confirming that he had completed the curriculum.

[5] Einstein [51] [1949], pp. 4 and 5; Schilpp (ed.) [179], p. 5. The first phrase of this quotation ("Da gab es draussen diese grosse Welt,…") is usually translated as: "Out yonder there was this huge world,…" I believe my translation is closer to what Einstein was expressing.

[6] Einstein [51] [1949], p. 5.

[7] A photograph of the interior of the Einstein electric company and the machinery is in Renn (ed.), [172], Volume One, p. 133.

Contrary to another myth, Einstein did not have difficulties in mathematics. Indeed, his preteen replacement of religious zeal with scientific fervor involved mathematics too. He was given a book on Euclidean geometry, which he devoured, even trying to prove theorems on his own before reading the solutions in the book. In his autobiography he referred to this math textbook as the "holy geometry book"[8] – an extraordinary phrase for such a prosaic subject, but perhaps significantly it was an unconscious reference to his geometry book replacing the previous other "Holy Book" around the same time in his life. He went on to higher mathematical texts, teaching himself and mastering calculus by age sixteen. All of which explains the letter from his mathematics teacher that was in his pocket as he crossed into Italy.

Which brings us back to the political statement: shortly after this episode he renounced his German citizenship, and was therefore living in Italy as essentially a stateless person. This is quite a radical act for a person of his age. One wonders what he found so despicable about Germanic culture that would provoke this final severing of national ties.[9]

We can only wonder too about his parents' response with his arrival in Italy – and present-day parlance does apply – as a high school drop-out. His father had plans for Albert to be an engineer, which he thought would be the paramount profession of the next century. Luckily for Albert (and his father, too), the school Hermann wanted his son to attend, the Swiss Polytechnic Institute in Zürich, did not require a high school diploma but instead required a series of rigorous entrance exams. So Hermann sent the necessary forms and fees, and Albert took the exams. Sadly, he failed several of them: nevertheless, he did so well on the science and mathematics sections that he was given the opportunity to apply again the following year. The Institute director recommended that he spend the year at the Kanton Schule in the town of Aarau, not far from Zürich.[10]

The year Einstein spent at Aarau was of paramount importance in his life. The school had a progressive curriculum, based on using visual sources, hands-on learning in small classes, and strong teacher-student interaction. For the first time in his life he was at ease in school, and he did well, passing with high marks, enough to get into the Institute.

He was likewise happy in his personal life at Aarau. He lodged with a family of one of his teachers, and he became very fond of them. He even had an early romance with one of the daughters.[11] It is also reported that while his fellow students at the Kanton Schule spent their spare time drinking copious quantities of beer, Einstein was drinking from a different source: devouring Immanuel Kant's philosophical treatise, The Critique of Pure Reason.[12] Importantly, it was during

[8] "*das heilige Geometrie-Büchlein*" in German; in Einstein [51] [1949], pp. 8 & 9.

[9] A simple explanation, provided by his sister, is that he was avoiding the military draft. See Winteler-Einstein [214] [1924], p. xxi-xxii. Alternatively, Pyenson [169], p. 51, says: "His decision to renounce German citizenship…can be seen as a reprisal against an entire society that had taken away his family's livelihood."

[10] A Kanton is a Swiss entity similar to a state or providence.

[11] In addition, his sister, Maja, later married one of the sons; and a close friend, who we will meet later, Michele Besso, married another daughter.

[12] Quoted in Miller [143]; p. 181 in the 1981 edition. Actually this was his second read; he first perused Kant's book around the age of thirteen.

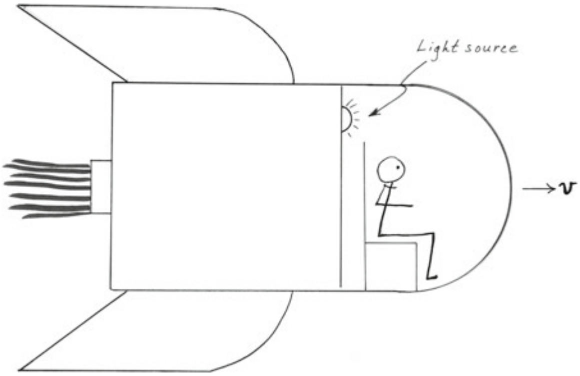

Fig. 2.1 Einstein's thought experiment of riding a beam of light: my reconstruction. When the spacecraft reaches light-speed the cockpit will become dark

this year that he fantasized about riding a beam of light. Most probably there was something about the ambiance at Aarau that stimulated his creative thinking. Reminiscing about Aarau sixty years later, and only weeks before this death, he wrote: "It made an unforgettable impression on me, thanks to its liberal spirit and the simple earnestness of the teachers who based themselves on no external authority."[13] This open and progressive atmosphere was the context of his now-famous thought experiment.[14]

* * *

Returning to the experiment and the puzzle. Einstein encountered at age sixteen a contradiction between the principle of the relativity of motion, and light disappearing in an inertial system moving at the speed of light. The solution he arrived at ten years later, which (to be seen) appeared in his landmark paper of 1905, is extraordinarily simple. Start with Galileo's idea of inertia, which elegantly explained the motion of bodies, and return to Fig. 2.1: if the motion (or speed) of light is independent of the motion of the system (or the source), then light will fill the room even at the speed of light.[15] This was Einstein's answer: light travels at the speed of light no matter what the speed of the emitting source. The paradox is resolved – but at a price; for it assumes that light behaves differently from other things. Consider throwing a ball with a given force; the ball will travel a specific distance based upon the initial force. If, however, you are running at some speed, the ball will travel further than if you throw it while at rest. In fact, the speed of the ball will be the sum of the speed you throw it from rest and the speed at which you are running. This addition (or subtraction, if you are running backwards) of speeds is a fundamental law of motion.

[13] Quoted in Holton [99], pp. 390–391.

[14] For some thought-provoking ideas about Einstein's background and personality see Pyenson [169], Chap. 3, "Einspänner: the Social Roots of Einstein's World View."

[15] A noted before, Fig. 2.1 is my reconstruction of Einstein's thought experiment. There are many attempts at historically retelling Einstein's idea but there is no definitive one because he never gave us one. It appears only in his autobiography, it is very short, almost cryptically written, and with a confusing if not contradictory sentence. I analyze this sentence in some detail in Topper [198], pp. 12–13. Recall too that the autobiography was penned in 1947, over fifty years after the event, which further clouds the historical record.

It should be pointed out that this applies to the case of motion in otherwise empty space, since a medium (air, water, and so forth) slows the speed of balls, other matter, and light too. Also, the phrase "otherwise empty space" is inserted because at the time most scientists held to the model of light as a wave in a diffuse medium known as the aether. (This topic will be explored soon.) As a result, experiments measuring the speed of light at the time were deemed to be measuring the wave-speed within the aether.

So Einstein, in order to resolve the paradox, bestowed upon light a special property that was not true of matter. It became in 1905 a postulate in his theory of relativity; stated simply it asserts that the speed of light is independent of the motion of its source. It follows from this that the speed of light one measures when the source is at rest is the same number no matter how or where it measured. If you are moving toward a light ray the measured speed is the same as when measured at rest; the same applies if you are moving away from a light ray. Always the same number. The specific number, incidentally, was measured with considerable accuracy throughout the nineteenth century, and was near the present value of 186,290 miles/second or 299,790 kilometers/second. Today's symbol little-c (which we will print in bold as **c**) was invented at this time for light-speed,[16] although it was not used consistently until well into the twentieth century.

To recap, Einstein's postulate, said in everyday terms, is this: if I turn on a flashlight while running, the beam of light is emitted at the same speed no matter how fast I go. This is a strange way for something to move – an action that, surely does not apply to my experience with throwing a ball.

The postulate that light acts differently from matter may be viewed from an absolutist viewpoint, too, since the speed of light is the same value in all systems. Behaving so, it took on the nature of being an invariant quantity. This also meant that it had the status of a universal principle, thus fulfilling Einstein's quest mentioned in his autobiography, and quoted in the epigraph beginning Part I. "How, then, could such a universal principle be found [for the behavior of light]? After ten years of reflection such a principle resulted from a paradox upon which I had already hit upon at the age of sixteen…." The principle? – the invariance of light-speed. Furthermore, as a result, there were two invariants in inertial systems – the equations of motion (as seen) and now the speed of light.

* * *

2.1 Summary

At the age of sixteen Einstein envisioned a mental puzzle that involved riding a beam of light. Ten years later he resolved the paradox with two assumptions. The first assumption was the principle of relativity, which asserted the impossibility of an observer in an inertial system knowing absolutely if the system is at rest or in motion. As a result, the equations of motion have the same form (invariant) in all inertial systems.

[16] Supposedly the symbol **c** was based on the Latin word <u>celeritas</u>, meaning very fast.

This principle had its origin in the work of Galileo and his attempt to prove a moving Earth, as asserted by Copernicus, despite evidence to the contrary. The concept of inertia was the key idea that led to the principle.

Einstein's second assumption, which he did not borrow from anyone, was the invariance of the speed of light ***(c)****. He showed that if the speed of light is independent of the motion of the source, then the paradox is resolved. In an inertial system, the speed of light is always* ***c*** *and everything behaves the same as if the system were at rest, obeying the principle of relativity.*

* * *

These two postulates will constitute the only assumptions in Einstein's first publication on relativity. From them he deduced several predictions about the world based upon those postulates. These deductions are the subject of the next Chapter.

http://www.springer.com/978-1-4614-4781-8

How Einstein Created Relativity out of Physics and Astronomy
Topper, D.
2013, XVI, 256 p., Hardcover
ISBN: 978-1-4614-4781-8