Figure 1: Einstein in Bern ca. 1905, from the Lotte Jacobi Archives, University of New Hampshire.

Reflection on the Miracle Year

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1 Introduction

As many of you know, this is the centennial of Einstein's so-called *miracle year, 1905.* The U.N. designated it the World Physics Year (WPY), a year to promote science and science literacy. Scads of American Universities have followed along. There are countless symposia, magazine articles, and even several TV specials including one on NOVA. Many of you know of Einstein's most famous formula, $E = mc^2$, but probably are unsure what it means; even more of you, I dare say all of you, recognize Einstein's face on sight. He is the prototype mathematician/scientist–I would say in fact he has become the caricature of one. On the other hand, I'd guess that very few in this audience know what Einstein's miracle year is about, know what are the subjects of his papers of 1905, what are the impacts on physics of the time, and what are the legacy of those papers. My purpose here is to clarify this.

2 Einstein in myth

The typical story of the miracle year is that physics was a science in deep trouble in 1905. Allegedly, the most complete branches of physics, electromagnetism, mechanics, optics, and thermodynamics were at odds with one another and unable to deal with a bevy of new experimental results. Then a young physicist working the lowly and undeserved job of clerk in the Swiss Patent Office found a way forward–in fact he found two ways forward–one for the large scale universe and one for the small scale. Well, physics was repaired and revolutionized at this point, and Einstein was henceforth considered the world's smartest person and responsible for just about anything good in the modern world (refrigerators to microwaves). As proof of this I point to a typical website produced by respectibly educated people, the University of Colorado for example, which implicitly credits Einstein with making possible almost everything[1]. As another example, consider the endless uses of Einstein's image to promote–selling Science magazine and AAAS memberships, for example.

[1] The URL for this site is *www.colorado.edu/physics/2000/einsteins_legacy.html*

Figure 2: Science magazine uses this baby Einstein to promote AAAS and its merchandise. Would any other scientist even be recognized in such a context?

3 Einstein in fact

Einstein was in 1905 an unknown, even with a few publications a so-far unaccomplished, but self-absorbed young man who had finished a mediocre career as a student at a Swiss institute of technology in the nether-regions of physics. Being self-absorbed should have aided his career, of course, and it eventually did, but being a mediocre student in a mediocre institute holds the most self-interested person back for a time. He also had ethical lapses and dilemmas to contend with. He had already abandoned his illegitimate daughter, manipulated a vulnerable woman four years his senior, who he would marry and then eventually divorce and go on to marry his cousin, but only after being rejected by his cousin's daughter first, and carry on other affairs as well. He was a political naif, with the world-wide scientific stature to leave a troubled Germany in 1933, without providing aid for trapped colleagues and kin. He miscredited the work of his adversaries–perhaps unintentionally in the case of Heaviside, for example. It is a common irony that he would eventually become a world-renowned teacher, ethicist, and spokesperson for human rights. But that is another story.

As you may see, I am not a fan of Albert Einstein as a person. However, in preparing for this I read the five papers of 1905, and I came away with one firm conclusion. Einstein deserves every bit of his reputation as a scientific genius. His written work is concise, insightful, and clear of purpose. I have enormous, renewed respect for him. Yet, the 1905 myth remains. What parts it are not true?

First there is the idea that he struggled as a mal-treated genius forced to take a lowly job at the Patent Office.[2] Is anything more delicious than this sort of fantasy? People seem determined to promote this idea as a central part of the 1905 story. Considering his performance to date it was a good job. It gave him a comfortable income, and provided spare time for research. Einstein, himself, says he enjoyed it and that those were among his happiest years.[3] After taking an academic position at Zurich, he complains in a letter to Michele Besso[4] that "...lectures keep me very busy so that my *actual* free time is less than in Bern. But one learns a great deal in the process." What instructor cannot appreciate this? The Swiss Patent Office job was hardly a punishment.

Einstein's work did not revolutionize physics immediately. In fact, Einstein was at first depressed about the lack of interest in his papers, and was cheered after many months when Max Planck finally wrote for a clarification about the relativity paper. Scott Walter [5] presents a graph that explains response to the paper on the special theory very clearly. It begins rather slowly at the rate of ten papers (physics and mathematics) per year in 1906 and eventually reaches 120 per year by 1911. The revolution via special relativity was a gentle one. The so-called Brownian motion paper took half a decade to have much effect–a time period spent awaiting experimental results. Even worse, Einstein garnered very little credit for his work in statistical physics, the topic of the Brownian motion paper, until well after the 1930s. My impression is that most physicists could not believe the results of the paper on Special Relativity–they treated the subject like some problem with measurement that would go away with better technique. Rival theories persisted into the 1920s. Doubters remain even today. Even years later in his corre-

[2]Stachel refers to this a being rejected by the academic community.

[3]Although, if you read Einstein correspondences he began looking for an academic job in 1907–two years before taking a position at the University of Zurich.

[4]November 17, 1909

[5]Minkowski, Mathematicians, and the Mathematical Theory of Relativity, Scott Walter, Published in H. Goenner, J. Renn, J. Ritter, T. Sauer (eds.), *The Expanding Worlds of General Relativity* (Einstein Studies, volume 7), pp. 4586. Boston/Basel: Birkhuser, 1999.

spondences the letters that pass between him and physicists of renown were largely requests for, and thank you notes for, Einstein sending reprints of his papers. It is true that the University of Leiden hoped to snag Einstein as a faculty member in 1912; yet, this only means he was well thought of as a researcher and teacher, not that he had transformed physics.[6]

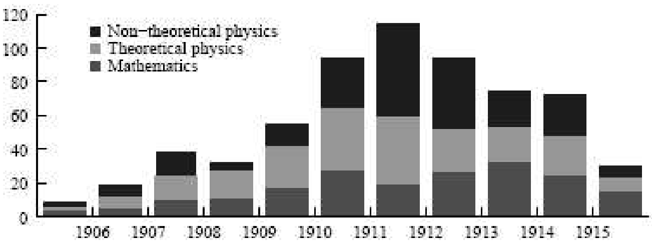

Figure 3: Growth of interest in the special theory as gauged by other papers on the subject. The revolution here is actually a steady growth that starts slowly. Figure after Walter, 1999.

Most physics students are told that the Nobel Committee awarding the prize in 1921 to Einstein for the so-called photoelectric effect paper was some sort of bad joke. Yet, over the time span 1905-1919, this paper, and Einstein's further work along the lines of quantum solid-state physics, would have more direct impact than any other among all the 1905 papers. In fact, as I read it several times over the past month, I concluded that among the 1905 papers, the one about the photoelectric effect was too good to have *not* garnered the prize. However, right up to the time he won the Nobel prize, Einstein still struggled with anonymity and receiving proper credit for his efforts. In fact, Einstein's reputation was made gigantic, not through his 1905 papers, but from verification of predictions of his 1917 *Theory of General Relativity*–the epitome of what Nazis would later label *Jewish science.*

4 Einstein's world

To understand how balled-up the story of Einstein has become, a person must review the state of physics in 1905. Physics in 1905 was built of four separate

[6]Letter from Lorentz 13 February 1912.

branches–Mechanics, thermodynamics, optics, and electromagnetism. Each of these was in pretty finished form, with a massive theoretical underpinning, and substantial experimental support. Yet, there were some problems in attempting to fit these pieces into a single, comprehensive whole. Odd observations such as Michelson-Morley's inability to detect the ether[7], the photoelectric effect, Blackbody radiation, and so forth are examples of what I mean by odd observations. I don't think of this time as a crisis. After all it is not like everything in the world stopped working just because physicist noticed their theories had a few problems. In fact, something Einstein himself wrote in 1910 sums up the situation with regard to the "crisis" of electromagnetism and the ether in particular.

> ...At first the physicists did not doubt that the electromagnetic phenomena must be reduced to the modes of motion of this [ether]. But as they gradually became convinced that none of the mechanical theories of ether provided a particularly impressive picture of electromagnetic phenomena, they got accustomed to considering the electric and magnetic fields as entities whose mechanical interpretation is superfluous.

If anyone is responsible for the idea of a "crisis" in physics it was a later generation of barely involved persons. This idea of crisis then gets passed from one generation of physicists to the next, with Einstein's role in crisis resolution growing at the same time. One professor told me that Einstein in a single year invented the Special Theory of Relativity, Quantum Mechanics, and Statistical Mechanics. It is hardly so, but most of us persist in this thinking because very few of us, like our professors, ever look at original documents.

Physicists and historians of science alike want nice, neat packages of explanation, and so they focus on, and credit, single individuals with accomplishments that actually had many inputs[8]. Einstein's papers are at the same time less, and I think much more, than we were ever told. Let me summarize their content.

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[7]The ether was a mechanical medium that could support the propagation of electromagnetic waves, and would tie electromagnetism to mechanics.

[8]Thus, Thomas Kuhn's hypothesis that science is a cycle of consolidation, crisis, and resolution has so much appeal for them.

5 Quick Einstein summaries

Einstein's 1905 papers have a common form. He begins each with a statement of a puzzling issue in physics. Typically he identifies a contradiction or controversy related to the puzzle. He then sets about methodically removing the contradiction and resolving the puzzle. What results is a significant step toward unifying two of the disparate branches of physics.

5.1 Brownian motion

Einstein proposes here to demonstrate the existence of atoms and molecules, and thereby reconcile thermodynamics with mechanics. To this end he proves that if molecules do exist, then particles large enough to be observed through a microscope should perform random motion from thermal energy. In order to demonstrate this he has to first repair opposing views of osmosis according to classical thermodynamics and a mechanical theory known today as the kinetic theory of gases[9] Through this reconciliation he infers that microscopic particles will diffuse throughout a container in a manner much like heat. By analogy, then, diffusion takes these microscopic particles on a journey away from original position that grows, on average, proportional to the square root of time (t). His formula for the root-mean-square (RMS) displacement (λ) is . . .

$$\lambda = \sqrt{t}\sqrt{\frac{RT}{N}\frac{1}{3\pi kP}} \tag{1}$$

Where the constants R, T, k, and P, are respectively, the universal gas constant, absolute temperature, fluid viscosity, and radius of the "Brownian" particles. From this we conclude that an observation of particle displacement that grows with the square root of time provides strong evidence for the existence of molecules. Moreover, because every quantity in this formula is known or could be measured except for N, Avogadro's Number, Einstein provides an independent means of enumerating molecules in a *mole* of matter.

[9]Called molecular-kinetic theory of heat in 1905.

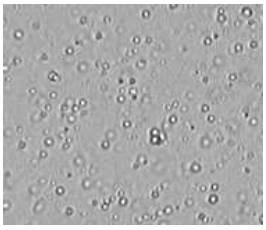

Figure 4: The small spheres in this photomicrograph are about one millionth of a meter in diameter and made of plastic. They display random Brownian motion. The photo, and an accompanying video is available online at www.microscopy-uk.org.uk/dww/home/hombrown.htm

5.2 Quantum Mechanics

Again, Einstein begins with a statement of a contradiction to resolve. In this case he observes that physicists treat light, in fact any field quantity, as a continuum that can fill an arbitrarily large region of space by becoming arbitrarily more dilute. Material matter on the other hand, physicists treat as composed of individual particles, and cannot possibly cover arbitrarily large regions of space without becoming grainy.

> According to Maxwell's theory, energy is considered to be a continuous spatial function for all purely electromagnetic phenomena, hence also for light, whereas according to the present view of physicists, the energy of a ponderable body should be represented as a sum over the atoms and electrons. The energy of a ponderable body cannot be broken up into arbitrarily many, arbitrarily small parts, but according to Maxwell's theory (or more generally according to any wave theory) the energy of a light ray emitted from a point source continuously spreads out over an ever increasing volume.

Einstein first demonstrates that the continuum view will lead to infinite amounts of energy in blackbody radiation within any small enclosure. Something is most sincerely wrong! From here Einstein proceeds to re-analyze Planck's resolution of this Blackbody radiation problem and shows that state variables for radiation obeys relationships identical to that of an ideal gas.[10]

[10] Specific entropy in this case.

Since kinetic theory explains all relationships for ideal gases in terms of individual molecules, Einstein suggests that individual light quanta ought to explain the same for radiation, and proceeds to show how light quanta explain the following better than other contemporary ideas:

- Stoke's rule for photoluminescence
- The photoelectric effect
- The ionization of gases by ultraviolet light.

The relationship he obtains for the photoelectric effect is extremely simple. In modern notation it is

$$h\nu = \varphi + KE \tag{2}$$

where $h\nu$ is the energy of a light quantum based on its frequency (ν) of vibration, and which is split in quantity then between the work (φ) required to remove an electron from a substance, and the kinetic energy (KE =energy of motion) the electron has once it escapes the substance. In the accompanying figure I show data collected by undergraduate students which displays this linear form. This Einstein paper was a significant step in connecting optics to mechanics–specifically in understanding how light interacts with material.

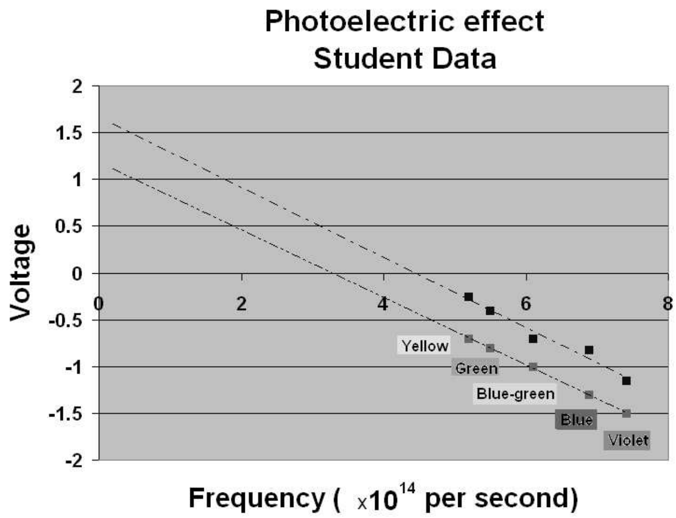

Figure 5: Student data for the photelectric effect. Voltage on the vertical axis is a proxy for kinetic energy in this instance.

5.3 Special Theory of Relativity

Once again, Einstein begins with a summary of some conflict between points of view. Here the issue will seem quite obscure to most of you. Physicists had used the principle of relativity for 250 years–but it was a principle valid in the Galilean/Newton concept of mechanics. Electromagetism apparently did not obey such a relativity concept. Yet Einstein did not address this issue, but instead a more esoteric one. Michael Faraday had shown in the 1830s that a moving magnet will induce an electric current in a wire. He showed in particular that whether the magnet or the wire was the object moved didn't matter–only relative motion between the two mattered. Yet, in 1905 the explanation of how electromagnetism interacts with material required a different explanation if the magnet moved than it did if the circuit moved instead. Two different explanations for the same outcome! In addition Einstein points out failure at all attempts to measure differences in speed of light with respect to motion of source.

As Jackson[11] points out, the fact that electromagnetism did not adhere to the Galilean/Newtonian concept of relativity seemed to be a problem in 1905. There were three possible solutions to this problem: 1)Maxwell's theory was wrong. Yet, there was too much physical evidence in favor of it for this to be possible. 2) Assume a mechanical hypothesis that would grant a special frame of reference for electromagnetism only–the ether with Lorenz contraction seemed a reasonable hypothesis to nearly all physicists in 1905. 3) Assume the postulate of relativity was in need of repair. This is the route Einstein takes in his paper.

The Special Theory of Relativity paper has two parts. The first involves the kinematics of material bodies; the second involves electrodynamics. The paper on Special Relativity begins with an attack on a tacit assumption about time. Einstein shows that there is no absolute flow of time in the sense that Newton envisaged, by showing that simultaneous events in one coordinate system are not necessarily simultaneous in another. He now postulates two guiding principles. The first is the principle of relativity, the other is that all inertial systems observe the same, constant velocity of light. From here he derives the coordinate transformation between a coordinate system at rest and one moving with constant velocity that must hold true.[12] This transformation turns out to be none other than the Lorentz transformation, which to this point in physics has applied only to electromagnetic phenomena. Einstein now derives the velocity addition formula and shows that the Lorentz transformation is a symmetry operation. He ends the kinematic part of the paper by showing that the principle of relativity and the constant speed of light are mutually compatible.

The electrodynamic part of the paper begins with a demonstration of how Maxwell's equations in space free of charge transform according to the Lorentz formula. This is not new, Lorentz and Poincare' had separately already shown this, but Einstein demonstrates in particular that the magnetic field derives from motion relative to an electric field, and that electromotive force arises from motion relative a magnetic field. He goes on to demonstrate three applications; aberration, doppler shift, and radiation pressure. Then he repeats all of this for Maxwell's equation in a space containing free charge. His final application is to the equations of motion of an electron.

Generally the paper presents an almost complete system. He does not

[11] D.D. Jackson, Classical Electrodynamics, Wiley

[12] There is an additional assumption that the relationship coordinates be linear.

write directly about the dynamics of mass in the absense of charge, but suggests that it is derived from the dynamics of an electron in the limit of no charge.

6 How did Einstein create?

There is a myth that Einstein was too brilliant to understand. However, if you examine his work he displays a fixed, and productive method of creating his work. This is one that I can describe in four steps. 1)Find controversial topics. 2) Attack the controversy with statistical or symmetry principles. 3) Argue from specific to general results by analogy; and 4) identify data to support the argument or ways to test it.

Let me speak about the Brownian motion and photoelectric effect papers first very briefly with this creative model in mind. Keep in mind that Einstein had worked and published along these lines already–his dissertation for example. Numerous researchers had attempted a physical explanation of Brownian motion involving thermal equilibrium–most notably the cytologist Karl von Nägeli in 1879 applied equipartition of energy[13] to the large particles treating them simply as massive molecules, and found that in collisions with ordinary molecules they would attain negligibly small velocities. Guoy and Ramsey in response tp such failures tried to substantiate the molecular explanation by assuming the more or less coordinated effort of large assemblies of molecules on the particles, but foundered by focussing again on velocity. All results seemed to point away from thermal motion being the source of Brownian motion. Einstein on the other hand succeeded for two reasons. First, while other attempts foundered on examination of velocity of Brownian particles, *Einstein focussed on displacement*. He understood the statistical physics well enough to recognize this as the measureable effect. Second, while other people made attempts along the correct path through collective action by large numbers of molecules, they had no theoretical or comptutational means to determine the outcome. Einstein instead looked at osmosis, and argued through analogy about what form the displacement of particles would take as a function of time.

In regard to the photoelectric effect, once again Einstein's thinking was along the lines of subjects he had contemplated for many years. Planck had already introduced an empirical formula to explain blackbody radiation

[13]The same approach that got blackbody radiation into trouble.

valid over the entire electromagnetic spectrum, and proposed quantization of oscillators in units of $h\nu$ as a way to justify it. Einstein had this information, and he had additional tools which he had developed through his work on Brownian motion and other statistical physics at his disposal. He used all of this to calculate the specific entropy of a volume of radiation and showed in the high frequency limit that it resembles the entropy of an ideal gas. By analogy therefore he argues that such radiation can take the form of discrete bundles of energy. This might have remained only a calculational device if not for Einstein noticing additional loose ends to connect by way of explaining Stoke's rules, the photoelectric effect, and ionization of gases by ultraviolet radiation.

Abraham Pais, Einstein's friend and biographer, said that Einstein was remarkable in his use of invariance principles and calculating statistical fluctuations. Invariance has nothing to do with either the photoelectric effect or Brownian motion, but but both involve statistics. I would add that Einstein was very good at tying loose ends together, but even better at knowing which loose ends to tie together. Knowing the loose ends indicates to me that Einstein was unusually well read–something historians apparently deny. Finally, as the photoelectric effect paper shows, Einstein thought carefully about how to test theories with observations. His title may use the word *hueristic* perhaps, but he is thinking *empiricism*.

6.1 Special Theory of Relativity

Oliver Heaviside observed that the foundation of a theory is like the foundation for a grand building; a good building does not show its foundation.[14] Einstein's Special Theory of Relativity takes this idea to an extreme. We have no direct knowledge of the process that produced this work. Einstein left no notes or drafts, although in a letter to Conrad Habicht he talks about it being in "draft" form. The paper on Special Theory of Relativity appears first in complete, and I mean complete and polished form, just as though it sprang from his mind that way.

How Einstein came to envisage the Special Theory of Relativity is just pure speculation. I'll summarize the leading ideas and add some speculation.

[14]Heaviside, Electromagnetic Theory, Vol. II, Chelsea.

6.1.1 Conspiracy theory

Einstein stole the idea from his wife. The problem with this theory is that we have no evidence to suggest this is true. The letters that pass between Einstein and his first wife are ambiguous.[15] She never claimed any specific credit. We have no notes of hers, none at least of which I am aware; and so, this claim falls in with claims that Dr. Watson actually wrote Sherlock Holmes and Sir Francis Bacon the works of Sheakespear.

6.1.2 Standard model

Einstein scholar, John Stachel, has refined this model for decades. It takes the following sequence of steps. 1) For some reason around 1902 or 1903 Einstein came to reject the standard model of the ether, and embarked in a new direction. 2) He abandons the Lorentz theory because it seems too dependent on the ether. 3) He explores possible theories in which light emission, *per se*, explains constancy of light relative to its source. 4) He returns to fret further about the Lorentz theory, and realizes that he can reconcile his ideas with Lorentz's by abandoning kinematical assumptions like simultaneity for all observers. 5) He develops a new theory of kinematics. Part of the evidence for Stachel's view comes from Einstein himself, but only by way of discussions and subsequent remniscences of his work on the topic. With a person as self-absorbed as Einstein I would never consider any of his memories good sources of information. To do so would be like letting Edison write the definitive biography of Edison.[16]

6.1.3 Vestigial earlier manuscript

In the 1982 Proceedings of the Philosophy of Science Association Earman, Glymour, and Rynasiewicz[17] proposed that historians need to look more

[15] Einstein refers to '...our work on relative motion' in one letter for example.

[16] Thus, Edison could concoct a story about having conceived of the carbon filament electric light while on a fishing trip to Battle Lake, Wyoming in August 1878–a story that is demonstrably false.

[17] I aplogize for having lost this reference at present – I found it through a Google search however.

closely at the final paper itself, which had garnered surprisingly little attention to this time. They note its "odd" structure and profess to seeing within it, a “proto-manuscript” composed of the introduction, section 6, and section 10. They hypothesize from this to suggest that Einstein solved puzzles of relativity here and there over several years, and pieced together the theory out of order with its finished form using “earlier arguments and building blocks,” as Einstein once said.

6.1.4 Technological inspiration

Peter L. Galison, author of a new book on Einstein and Poincare’, recalls seeing a series of synchronized clocks on a train station platform in northern Europe. This vision prompted him to ponder the history of the problem of synchronizing clocks for things like train schedules and communication, a topical issue in 1900-1905 Switzerland, and to consider that Einstein being, immersed in the descriptions of all this technology, at the patent office did little but think about clocks and synchronization. Well, it is an intriguing suggestion, but can he point to any specific patent or other mechanical inspiration that Einstein mentions? How does simply being immersed in a technology permit a person to invent new sciences?

6.1.5 Another speculation

It seems to me that a person can combine these ideas. Earman, et al’s, suggestion about haphazard creation of the Special Theory seems very close to the truth to me. It suggests how a physicist solves problems–or at least how I solve problems. The structure of whatever paper results from research is completely artificial and has nothing to do with the order of creation. In the case of the Special Theory of Relativity paper the order is a pedagogical one that a person can recognize in practically any physics textbook–first kinematics then dynamics; first fields without sources, then fields with sources, and so on. Instead of being preoccupied with structure, a reasonable theory of creation ought to explain several puzzles: 1) Why did Einstein abandon the ether concept? 2) What inspired the space/time analysis? 3) Why does he mix kinematics with electrodynamics? 4)Where did he begin?

Suppose, as Earman et al do, that Einstein began with the Introduction and Section 6. Most of Section 6 is not new, being known to Lorentz and

Poincare', at least, a year earlier. But Einstein has a further insight. The results of Section 6 imply that the magnetic and electromotive fields do not have a separate existence of their own, but depend only on relative motion. Certainly Einstein realized the ether could go at this point, and perhaps this section was done as early as 1902, in line with what Stachel suggests about Einstein's abandonment of the ether. Sections 7 and 8 on electrodynamics come together quickly at this point. They are straight-forward applications of Section 6. Section 9 required that Einstein derive the velocity transform of Section 4, but with Section 9 finished Section 10 follows straight forwardly. It seems to me that the velocity transformation is what first brings kinematics into the scheme, but then Einstein sees a way to reconcile mechanics with electrodynamics.

In 1902 Poincare' wrote a book entitled *Science and Hypothesis*. John Stachel states that Einstein was well aware of Poincare's arguments in this book against the ether. Certainly it is the sort of book that would catch the attention of a young man with ambitions of becoming a great scientist. I read the book perhaps 20 years ago, and I have not found a copy recently to refresh my memory, but seeing Poincare' mentioned twice in the source of a week of reading got me to thinking about the following.

In *Science and Hypothesis* Poincare' asks at one point, what is the meaning of Newton's second law, $F = ma$, or more to the point here, $F = m\frac{d^2x}{dt^2}$? His answer is that it signifies only that the equations of mechanics are of second order. This is a more profound revelation than it seems at first, and central to my speculation. What Poincare' means is that we may change origin and initial time without affecting the physics of a problem, so long as the transformation is *Galilean* of the form $x' = x - vt$. In effect being of second order denotes what symmetry operations are compatible with mechanics.

Suppose that Einstein read this, and, being predisposed to principles involving symmetry, he began to ponder what being invariant under a *different* symmetry operation, specifically the Lorentz transformation[18] would mean for Newtonian mechanics. There are several pieces of evidence for this speculation, and they come from the only contemporary source that can shed direct light on the matter–Einsteins 1905 paper itself. In his paper Einstein shows that the Lorentz transformation applied to any particle velocity (U) in a *system at rest*, Einstein's phrase for a Newtonian system, produces an

[18]which I have removed to the appendix to save the non-technical reader from brain melt-down.

apparent velocity (U') when viewed from a second coordinate system moving at velocity V with respect to the rest system according to $U' = \frac{U+V}{1+UV/c^2}$. This Lorentz transformation maps sublight-speed velocities in one system to different apparent sublight speeds, and thus "form[s] a group–as indeed they must." The phrase has a uniqueness within the context of his paper that suggests special importance to Einstein. I would say that he sees it as the equivalent of $F = ma$.

To produce Part A Einstein could have simply assumed the Lorentz transform and worked forward from half-way through Section 3 through the end of Section 5. To produce Sections 1 through the first half of Section 3, however, Einstein required a way to demonstrate *why* the Lorentz transform should apply to kinematics in the first place. The transform itself provides a hint in that it explicitly shows that time increments in systems in relative motion do not appear the same to any single observer. Thus, simultaneity had to go. Perhaps his work in the Patent Office did provoke this final insight as Galison suggests; perhaps Einstein's wife provoked it, or maybe something Michele Besso said provoked it; thus, explaining Einstein's statements to Besso that "Thanks to you I have solved the problem" and "Time has to go."

7 What about $E = mc^2$?

What about the famous $E = mc^2$ formula? This formula first appears explicitly in the fourth 1905 paper. Einstein's language implies that $E = mc^2$ was something not contained in Paper Three, but was a new idea. I find this puzzling. It is contained in Paper Three in Section 10 under the derivation of kinetic energy of an electron. Possibly Einstein viewed the derivation in Paper Three as a highly special case, and tried to argue in Paper Four that the same result will hold for a mass that is emitting radiation.[19] Whatever his purpose, Einstein returned to this theme many times over the next two decades, but never managed to prove that $E = mc^2$ with complete generality. We believe it is so now because of volumes of observational data.

[19]Specially to explain the energy source for radium.

8 If not for Einstein, would history change?

What I am asking here is, "how important was Einstein?" I think the answer depends on which of his works we consider.

8.1 Brownian motion

Robert Brown had studied this motion in 1828, but even by 1905 no one had an acceptible explanation for it. I have explained how Einstein succeeded where others had failed, but no one accepted his explanation immediately, because there was no data with which to test it. That data would not come for another four or five years, and it wouldn't be especially convincing even then. Yet, Einstein's paper is not so much about Brownian motion, as it is about advancing mechanical explanations of thermodynamics–a branch of physics now called Statistical Mechanics. It was third in a series of papers he published on the subject. Yet, despite his significant contributions and unique approach, he would not attain a fair recognition for his efforts until 40 years later. Luiz Navarro explains the story of why this happened[20]–for reasons that needn't concern us here. However, for a disturbingly parallel tale of how genius goes unrecognize, consider Louis Bachelier.

Bachelier, like Einstein, worked in obscurity from having been a mediocre student at a mediocre school. Even considering that his dissertation advisor was Henri Poincare' Bachelier remained obscure. Bachelier noted in his 1900 dissertation that the price history of securities was like the random walk of Brownian motion[21], and behaved like diffusion of heat. This explained, for example, why a person could either lose or gain the largest sums of money on an investment the longer one held the investment. At any rate it took some 56 years before anyone noticed what Bachelier had done. So even after Einstein provided an explanation, it might have been another half century before someone else constructed an explanation for Brownian motion that people noticed. Getting one's work noticed takes luck and self-promotion!

[20] Archive for the History of Exact Science, 53, 147-180, 1998.

[21] I don't know if Bachelier even used the term Brownian motion. He may have only refered to heat–I need to find the original document.

8.2 Quantum Mechanics

Here I can provide a pretty definitive answer to the supposition "if not for Einstein." I claim the mysteries of quantized radiation would not have remained mysteries beyond 1912, the year Bohr published his theory of the hydrogen atom. In the case of atomic/optical phenomena the problematic explanations and puzzling observations were numerous and growing more numerous with time. Planck had already suggested quantizing radiation in his treatment of blackbody radiation in 1901. There was the example of discrete UV and visible spectra. Bohr eventually had to quantize energy in order to explain discete spectra and stability of atoms. I am not suggesting that Einstein's efforts weren't significant, but that other people would have filled the void his absense would create.

8.3 Special Theory of Relativity

Here I speculate we may have had to wait a long time for explanation without Einstein. Consider this evidence. Maxwell's Equations had been in finished form for 40 years already, the Michelson-Morley experiment was 28 years past, and Fitzgerald and Lorentz's explanations of this experiment, unsatisfactory as they were, were nearly 12 years old. Poincare' himself was thinking along these same lines, but had not connected all the pieces. Although the problem that Special Theory of Relativity answered was ripe for solution at the time, people accepted Einstein's explanation slowly, even reluctantly. There are people to the present day who sincerely doubt the correctness of his explanation because it is too foreign for them to accept. It took Einstein, or an Einstein, to examine the issues of invariance, symmetry, and measurement, that everyone thought they understood, but no one did in fact. In regard to Einstein's Special Theory of Realtivity, then, I found a pertinent quote that Judge Townsend, in a patent dispute over the poly-phase AC system, said about Nikoli Tesla.[22]

> "the apparent simplicity of a [theory] often leads an inexperienced person to think that it would have occured to anyone familiar with the subject, but the decisive answer is that with dozens and perhaps hundreds of others laboring in the same field, it had never occured to anyone before."

[22]quoted in Sunny A. Auyang's book in the list of references.

9 Was this a miracle year?

Einstein had worked on molecular-kinetic theory for seven years by 1905, and was in the process of finishing his dissertation. The Brownian-motion paper is an extension of this work, so we can hardly call this part of a miracle. The photelectric-effect paper, innovative as it was, is partially an extension of molecular-kinetic theory. Planck had, five years earlier, suggested the quantization of harmonic oscillators in regard to blackbody radiation. So to call this work a *miracle* ignores long, hard work in preparation on the part of several people.

The Special Theory of Relativity, on the other hand, does seem miraculous. Einstein had poked at the problem of electromagnetic interaction with matter for many years[23], but not along the lines of inquiry that resulted in the Special Theory. It simply occured as a problem to him, and he finished it, in polished form, possibly in a mere 5 or 6 weeks.[24] In fact, though, Einstein may have had pieces of this paper in progress for many years as well. I suppose a fair assessment is that 1905 might not be miraculous year, but having so many separate, and significant, ideas come to fruition in a single year is miraculous.

10 Einstein's legacy

Where has each of these papers led over the past 100 years? Once again, let me dispense with the papers on Brownian motion and the photoelectric effect together. Regarding Brownian motion and the larger context of statistical physics, Einstein's work had effect, but he obtained little credit for it for perhaps 40 years. In regard to Brownian motion directly, one of the outcomes of Einstein's work was means to determine N, but better methods established that value precisely. In regard to statistical physics people confused Einstein's work with that of Boltzmann–a confusion aided by the very influential review of statistical physics by the Ehrenfests in 1912. Therefore through lack of attention and the dilution of his efforts with that of later workers, Einstein left a significant but not overwhelming legacy. The same

[23]John Stachel refers to the story of Einstein pondering in 1895 how an electromagetic wave would appear to someone co-travelling with it at the speed of light.

[24]Einstein wrote to Conrad Habicht in May of 1905 telling him about a paper that is in draft form having to do with electrodynamics of moving bodies.

is true of the photoelectric effect paper. Despite the Einstein enthusiasm, Einstein doesn't even come close to "inventing" quantum mechanics in this paper. It is true that physicists become more interested in this and subsequent Einstein work after Nernst's experimental data on the heat capacity of solids shows Einstein's correctness. However, Einstein's work belongs in with what we now refer to as the "old Quantum Theory." Quantum theory is a huge, collective effort. The legacy of Einstein is diluted with the efforts of many other people. It is true that the modern world is full of wonders that depend on quantum mechanics, light, radiation and so forth, but to credit this to Einstein's legacy, or to that of physics in general, only confuses science with technology.

10.1 Special Theory of Relativity

Einstein left a true legacy through his Special Theory of Relativity. While later workers have elaborated upon Special Theory, and have thought of new ways to explain it, Einstein's first shot at the subject does a decent job. If a beginning student of physics really wanted to learn the kinematic aspects of the theory, that student could turn to sections 1 through 5 of the original paper and learn it as well as any other way. Einstein's pedagogic efforts have never been diluted in any way except for the space-time geometry which Minkowski added. More significantly, though, there is practially no branch of physics that has not benefitted from insights that the Special Theory provides. Let me cite a few examples.

In quantum mechanics Paul Dirac modified the Schrodinger equation for Lorentz invariance and discovered among its consequences the correct electron spin.[25] In nuclear physics it has provided a means of explaining the enormous energies provided from Beta decay and nuclear reactions. In engineering it has provided a theoretical foundation for how to construct high energy machines like particle accelerators. In metrology it has provided us with proper corrections for placing ourselves accurately using GPS, and corrections for transporting accurate clocks. Finally, and most significantly, astrophysics has many explanations that rest upon Special Relativity in some way.

For example, Special Relativity provides explanations for the current tem-

[25]The uncorrected Schrodinger equation led to results that were only half the correct value.

perature of the cosmic background radiation, and why the night sky is dark. The accompanying illustration shows another more homely example. The graphic shows large clouds of energy-emitting gas which are very apparent. Midway between the clouds is a region of space from which there issues a jet in one direction that terminates in one of these clouds. Physicists speculate that a black hole resides where the jet originates, but if that is so, then why is the jet visible in one direction only?

Because the particles that make up the jet travel so fast, Special Relativity applies. The visible jet is coming toward us, and is made more intense just as section 7 of Einstein's 1905 paper shows. Meanwhile the other jet, being directed away from us, is red shifted and attenuated to the point of being invisible.

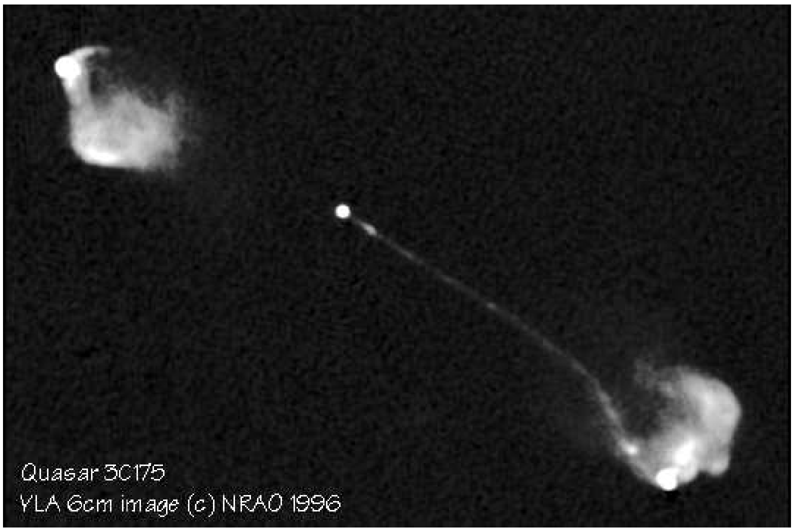

Figure 6: A radio object with jets of material moving at high speed and their appearance made asymmetric by demands of Special Relativity.

11 Conclusion

Let me say in conclusion that my recent study of Einstein and the papers of 1905 have given me a new perspective on the man, the state of physics at the time, and even a new perspective on the legacy Einstein left. In regard to a conclusion that pertains to amateur science, Einstein in 1905 was an *amateur scientist*. He faced all of the issues and problems we face in trying to do something significant–obscurity, lack of colleagues, lack of time and resources. Even more pertinent is that Einstein, often considered a theoretician, was actually very empirical in his outlook.

12 References

Here are a few books and papers I mentioned in this speculation that might be of interest to ambitious readers.

1. Einstein's Miraculous year. 1998. Edited by: John Stachel. Princeton U Press. This book has all the original papers. They are wonderful to read–believe me.

2. The (Mis)behavior of Markets. 2004. Benoit Mandelbrot. Basic Books. This book has a chapter about Bachelier and his troubles, and it is where I learned that Bachelier's advisor was Henri Poincare'. Serendipity in research!

3. Science and Hypothesis. Henri Poincare'. Dover books. I haven't read the book for 20 years, but I plan to get a copy again and read it once more. It'll make me feel smart at least. I don't recommend it to anyone.

4. Miraculous visions. The Economist Magazine, December 29, 2004. You can find this on-line.

5. The Year of Albert Einstein. 2005. Richard Panek. Smithsonian Magazine. Available on-line.

6. Sunny A. Auyang Engineering–an endless frontier. Harvard U press. 2004

7. A. Einstein, 1910. The Principle of Relativity and its Consequences in Modern Physics. Archives des sciences physiques et naturalles, 29, 5-28; 125-144.

8. Collected Papers of Albert Einstein, Anna Beck, Ed. Volumes 1-9, Princeton U. Press.

13 appendix

The Lorentz transformations are:

$$x' = \frac{x - vt}{\sqrt{1 - v^2/c^2}} \tag{3}$$

$$y' = y \tag{4}$$

$$z' = z \tag{5}$$

$$t' = \frac{t - vx/c^2}{\sqrt{1 - v^2/c^2}} \tag{6}$$

In these the primed coordinates are moving at velocity v in the positive $\hat{x}$ direction of the unprimed system. The transformation allows a person to determine the apparent space-time coordinates of any event in the unprimed system as observed in the primed system.

13.1 Minkowski's space-time

It is only a bit of algebra to show that $x^2+y^2+z^2-(tc)^2 = x'^2+y'^2+z'^2-(t'c)^2$. Because $x^2 + y^2 + z^2 = (tc)^2$ is the equation of a sphere that is expanding in radius proportional to time, t; it is apparent that an expanding surface of a light flash, for example, appears as an expanding sphere for observers in both the primed and unprimed systems, and expands at the same rate.

Minkowski was the first person to recognize that the differential relationship, $dx^2 + dy^2 + dz^2 - (c \cdot dt)^2 = (ds)^2$ represents a displacement element in a four-dimensional space, analogous to the invariant displacement element in a rotation of three-dimensional space. Einstein may have demolished the notions of absolute space and absolute time, but Minkowski replaced these with an absolute space-time.

13.2 Velocity addition

Now assume that within a reference system moving with velocity v relative to one at rest, there is an object possessing a velocity U. What will the velocity of this object be with respect to the system at rest. First locate two successive locations of the object, x'_1 and x'_2, and the corresponding times at which the object occupies these locations, t'_1 and t'_2. By definition the average velocity is $\frac{x'_2 - x'_1}{t'_2 - t'_1}$

Thus, applying the Lorenz transformations, one obtains $U' = \frac{x'_2 - x'_1}{t'_2 - t'_1} = \frac{x_2 - x_1 - v(t_2 - t_1)}{t_2 - t_1 - v(x_2 - x_1)/c^2}$ or $U' = \frac{U+v}{1+Uv/c^2}$. Note in particular that if U is less than c, the speed of light; then , U' is also less than c. Note further, that if U is an electromagnetic signal (light or radio etc), so that $U = c$; then $U' = c$ also. The speed of light is a limiting speed. The Lorentz transform and the set of all possible speeds less than or equal to that of light form a symmetry group.

13.3 Time dilation

Two events in the unprimed system occurring at a single point in space at times t_1 and t_2, according to an observer at rest, will occur at different x coordinates in the primed space, but more significantly, they will be separated by a time interval $t'_2 - t'_1 = \frac{t_2 - t_1}{\sqrt{1 - v^2/c^2}} > t_2 - t_1$ Thus, moving clocks will appear to run more slowly than clocks at rest. This appearance is symmetric between the two coordinate systems. In other words, it is the other person's clock that appears to be running slowly.

13.4 Space contraction

An object whose ends occur at the two points x_1 and x_2, has a length equal to $x_2 - x_1$ in the unprimed system. Measure the locations of the two ends *simultaneously* in the primed system to obtain the length $x'_2 - x'_1 = (x_1 - x_2)\sqrt{1 - v^2/c^2}$ which, therefore appears to be shorter. Like time dilation, this appearance is symmetric between the two coordinate systems. In other words, it is the other person's dimensions that appear contracted.

13.5 The end of simultaneity

Suppose in the unprimed system an event occurs at the same time at two locations x_1 and x_2, where $x_2 - x_1 \neq 0$. This is the railcar experiment and the event is the passage of the wavefront at the two separate observers on the ground. What I mean by simultaneous is that $t_1 = t_2$. Now what is $t'_2 - t'_1$? If this is zero, then simultaneous events in one coordinate system are also simultaneous in the other.

From the Lorentz transformation we can find that $t'_2 - t'_1 = \frac{v}{c^2}\frac{x_1 - x_2}{\sqrt{(1-(v/c)^2)}}$. Now apply space contraction to get rid of $x_1 - x_2$ and replace it with $x'_1 - x'_2$. Therefore

$$t'_2 - t'_1 = \frac{v}{c^2}(x'_1 - x'_2) \tag{7}$$

which is zero only if $v = 0$ or $c \to \infty$. Simultaneous events in one coordinate system cannot be simultaneous in another if the two are in relative motion. Sorry, Mr. Newton!