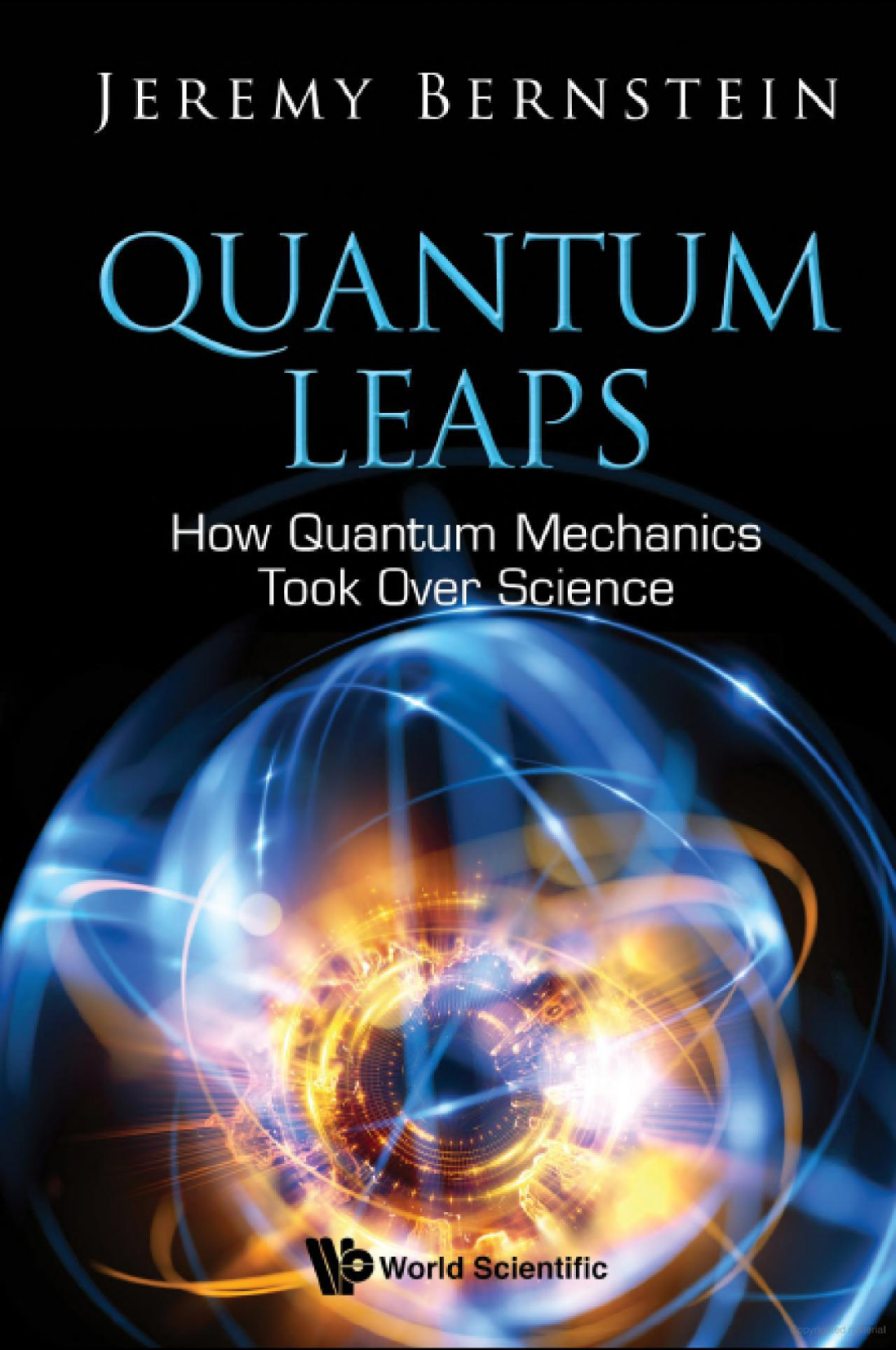
JEREMY BERNSTEIN

QUANTUM LEAPS

How Quantum Mechanics Took Over Science



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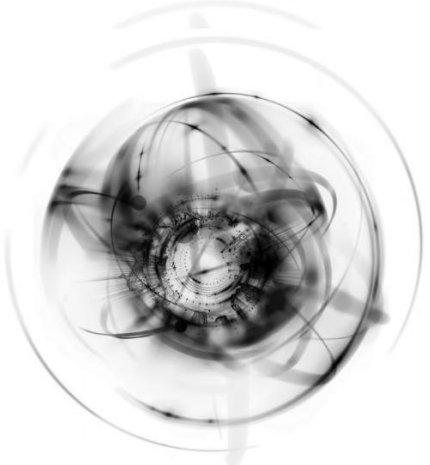

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A Frontispiece

Whatever properties may ultimately be assigned to the atom, there is one which cannot be omitted—its power to seize and captivate the human mind. In fact, if we judged by the output of the printing press in the last few years, we might not unfairly assume that no sooner does anyone fall within the sphere of influence of this radiating personality, then he is seized with an irresistible determination to go home and write a book about it. Nor is the proselytising zeal confined to the pure physicist, whose protégé the atom may be presumed to be. We have books on the atom, some of them well done by chemists, by mathematicians, by technicians, and by journalists, and addressed to all sorts and conditions of readers. Thus we have "Atoms for Amateurs", "Atoms for Adepts", "Atoms for Adolescents", "Atoms for Archdeacons", "All about Atoms for Anybody"—these are not exact titles, but they indicate the scope of the volumes well enough—in fact, there seems to be a determination that no class of reader shall be left without an exposition of the subject suited to his condition and attainments. As these volumes continue to pour forth—we must assume that there are purchasers and readers. If we add to these the enormous output of serious scientific contributions from the many laboratories engaged in investigating the structures and properties of the atom, it is clear that this infinitesimal particle exerts an attraction unique in the history of science over the minds and imaginations of many types of men [and women]." *The Atom Again*, Nature, 1926, 118:365.

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Acknowledgements

This is such an eclectic book and so many people have been kind enough to make suggestions and criticisms that I would like to distribute these acknowledgments by topics. On Auden I would like to thank Freeman Dyson, Nicholas Jenkins, Arthur Kirsch, Edward Mendelson, Oliver Sacks and Elizabeth Sifton. On the Dalai Lama I am grateful to Walter Isaacson and Abner Shimony. On all things Bohmian I am grateful to Ken Ford, Murray Gell-Mann, Basil Hiley and David Pines. On Léon Rosenfeld I am grateful to Loren Graham and Anja Skaar Jacobsen. On Newtonian matters I am grateful to Alan Shapiro and on Philipp Frank to Gerald Holton. On the vexed subject of the quantum theory of measurements I have had lively interactions with Elihu Abrahams, Steve Adler, Andy Cohen, Steve Gasiorowicz, Jim Hartle, Eugen Merzbacher and Bill Unruh. I have also had helpful comments from Peter Kaus, Arthur Miller, Bruce Rosenblum and Oliver Sacks. I would also like to acknowledge Michael Fisher of the Harvard University Press who kept the faith. I wish that I could acknowledge my debt to the late John Bell in person. His spirit hovers over this book.

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An Introduction

> "For those who participated, it was a time of creation; there was terror as well as exaltation in their new insight. It will probably not be recorded very completely in history. As history, its re-creation would call for an art as high as the story of Oedipus of the story of Cromwell, yet in a realm of action so remote from our common experience that it is unlikely to be known to any poet or any historian."
>
> J.R.Oppenheimer, 1953 BBC Reith Lecture

When Oppenheimer made these Delphic comments in 1953, I was just beginning a serious study of the quantum theory to which he refers. Not that I had any broad knowledge, but I would have agreed with him that at that time quantum theory and its history were "unlikely to be known to any poet or historian". Things have changed. The last time I looked there were nine million three hundred and thirty thousand entries on Google under the rubric "quantum theory" and these certainly included both poets and historians as well as film critics and Buddhist monks. It would take a serious cultural historian, which I am not, to trace what happened in those fifty odd years. Having lived through it, while I have some theories, I am not sure that I can pinpoint exactly when this transformation occurred. I am however, quite sure that it was not that more people were learning quantum theory, but that more people were learning *about* quantum theory and especially about its interpretation and foundations. I am also quite sure that at the time Oppenheimer gave his lecture only a tiny number of physicists had any interest in the foundations. I will give an illustrative anecdote.

I spent two years at the Institute for Advanced Study in Princeton beginning in the fall of 1957. Oppenheimer was the director. We had a weekly seminar which he attended. By the spring most of the obvious

speakers had spoken and it was getting more difficult to recruit new ones. A young and gifted colleague of mine was recruited on the basis of a preprint he had written on the quantum theory of measurement, to this day a highly controversial subject. Physicists disagree on how measurements, which are described by classical physics, fit into quantum theory. It was all but unheard of for a young physicist to work on something like this. It was not even considered physics. I admired his courage. I do not think that he asked to give a seminar. I think he was told to. Oppenheimer was notorious for cutting down seminar speakers whom he thought were wasting his time. At this seminar he outdid himself. The speaker had gotten out about five sentences when Oppenheimer said that Niels Bohr had answered all these questions in the 1930s and the speaker had nothing to add. It was the end of the seminar. I am glad to report that my colleague published his paper and that he went on to have a distinguished career.

I contrast this with another scene I witnessed in the 1980s—thirty odd years later. This took place at Columbia University. John Bell, whom I think is largely responsible for the renewed interest in this subject, had been invited to give a colloquium. This was meant to address an audience consisting of the entire physics department. It was held in the largest lecture room available to the department. It was packed-standing room only. People came from every university in New York city and its surroundings—even some from New Jersey. I can assure you that no one stopped Bell to tell him that Bohr had done it all.

The purpose of this book is to give an account of this cultural transformation. The subject matter is eclectic ranging from the Dalai Lama to W.H.Auden. I try to explain the relevant parts of the theory as I go along. There is essentially no mathematics. Words cannot really replace mathematics, but in a subject like this mathematics cannot really replace words. There is a good deal of autobiography here. I hope the reader will not find this intrusive but that is the kind of writer I am. I am sure that I have not covered the entire subject. There is too much for any one person to cover. But I hope that I have covered enough to make it clear that this subject is now known to both poets and historians as well as playwrights, novelists and film-makers, Buddhist monks and communist ideologues, as well as physicists.

Chapter 1

Bishops

"Rhyme-royal's difficult enough to play.
But if no classics as in Chaucer's day,
At least my modern pieces shall be cheery
Like English bishops on the Quantum Theory."

W.H.Auden, Letter to Lord Byron, 1936

"Ah, my Lord of Birmingham, come in, sit on the fire and anticipate the judgement of the Universal Church."[1]

Right Reverend Herbert Hensley

"I like the company of men of science: they are not excessively intellectual in their hours of leisure and they give good dinners."

Bishop of Birmingham E.W.Barnes[2]

In the fall of 1957, I began what turned out to be a two-year membership at the Institute for Advanced Study in Princeton. This was a banner time for physics. In 1956, the Chinese-born American physicists T.D.Lee and C.N.Yang noted in several papers that what is called "parity symmetry"—the symmetry between left and right handed descriptions—a cornerstone of physics up to that point—had never been tested in the sort of weak interactions that are responsible for the instability of many elementary particles and atomic nuclei. They proposed several experiments, and when these were performed they demonstrated that, in these interactions, the symmetry was indeed violated. This was a sensational discovery and all of

[1] **This quotation is taken from John Barnes, *Ahead of His Age; Bishop Barnes of Birmingham*, Collins, London, 1979. p.190. I shall have occasion to make several references to this book which I shall call "AA".**

[2] **AA, 344.**

us were gripped by its implications. In the fall of 1957, Lee and Yang, who were both at the Institute, were awarded the Nobel Prize for Physics. Soon after my arrival at the Institute I studied the membership roster. There were several physicists whose work I had studied and admired, but I came across a name that really surprised me—Reinhold Niebuhr.

Niebuhr, whom I had never met, was a hero of mine. During the ten years I was at Harvard (1947–1957), I had heard him preach and debate several times. He was a great orator. His language was simple but his ideas were profound and complex. He was also an imposing figure and gave the impression that you were directly in his gaze. When he spoke of the dangers of neurotic preoccupation with self, I was sure that he was talking specifically to me. As it happened, my father, who was a rabbi, had been on several liberal commissions with Niebuhr, so I thought that if the occasion presented itself I would introduce myself to him. In the event, the occasion presented itself quite quickly. We all took our lunches in the Institute cafeteria and I noticed Niebuhr and his wife eating alone. I passed by their table and said hello. They invited me to sit down. When Mrs. Niebuhr—Ursula—and I were alone for a minute she told me that her husband had suffered a series of strokes, which was one of the reasons he had sought the relative tranquility of the Institute. She said that he was feeling a little depressed and that if I would drop by their apartment from time to time it might help to cheer him up. I took advantage of this invitation. Niebuhr had sensed the excitement of the physicists and wanted me to explain what they were so excited about, which I did as best I could.

On one visit I noticed a book by W.H.Auden. I now forget which. Auden was another of my heroes and, as it happened, he was giving the Christian Gauss Seminars on literary criticism at the Princeton University, and I had attended some of his lectures. I mentioned this to the Niebuhrs and they were both surprised and delighted. I will never forget how Ursula Niebuhr pronounced Auden's first name—Wystan. It sounded like "whistle"—with a hiss on the 's.' I did not know at the time that the Niebuhrs and Auden were close friends. Although she and Auden had been at Oxford at the same time—the late 1920s—they had only met in 1940. Niebuhr had become a sort of spiritual advisor to Auden who indeed dedicated his collection, "Nones", to them. I felt that I had conveyed a useful piece of information to the Neibuhrs and forgot about it.

However, not long afterwards I was taking the "dinky"—the small train that connects Princeton to Princeton Junction—when on came Auden. You couldn't miss him. He had, at the time a face, which he said looked like

a wedding cake that had been left out in the rain. The train was pretty full but there was an empty seat next to me and Auden took it. The ride was short but I told him that the Niebuhrs were in Princeton, which he had not known. He seemed pleased to learn this and again I more or less forgot about it. But some days later in the morning I was called to the hall telephone in our building. None of us had private phones in our offices since Robert Oppenheimer, our director, had decided that these might distract us from our work. The hall phone distracted everyone from their work. It was a call from Oppenheimer's secretary. She said that I was expected for lunch and should come at lunch time to Oppenheimer's office. I replied that there was surely some mistake since there was no earthly reason why Oppenheimer would want to have lunch with me. She said there was no mistake and I was expected. Even as I write this over a half century later I can still see the scene in Oppenheimer's office. There was Oppenheimer, impeccably dressed as usual, and his wife "Kitty." There was Sir Llewellyn Woodward, a notable British historian who had come from Oxford to the Institute, and his wife. There were the Niebuhrs, and Auden, and myself, a very minor post-doctoral. Whatever this was about, I am sure it reflected the fine "Italian hand" of Ursula Neibuhr, who wanted Oppenheimer and Auden to meet. After a few introductions we all marched into the cafeteria.

A special table had been prepared for us in the center of the dining area. I am sure that we were served and did not stand in the cafeteria line. There was probably also wine. I remember the very fishy looks that my colleagues who were at our usual tables gave me. Freeman Dyson, who was then a professor at the Institute and a friend of mine, looked particularly amused. I had no opportunity to explain. I wish I could tell you that the conversation was memorable. Oppenheimer, who was sitting across from Auden, seemed rather ill at ease. At one point he told Auden that he had studied Sanskrit in Berkeley in the 1930s. This did not make any impression and Auden and Ursula Niebuhr then engaged in a lively conversation which pretty much ignored the rest of us. The Woodwards said nothing. Niebuhr caught my eye, and from the look on his face I would guess he was thinking that this too would pass. After lunch, I took Auden to meet Dyson. They played some word games on Dyson's blackboard, and then Auden left and I never saw him again.

I have thought about this extraordinary occasion many times over the years, usually with a sense of regret. If only I had it to do again, I would have asked Auden which "English bishops on the quantum theory" he was referring to in his Byron poem. What a conversation that might have turned

into. But, myself excepted, everyone who was at that table is now gone. "English bishops on the quantum theory," how many can there have been? Finally, I decided to try to find out. The first person I asked was Dyson. His answer was immediate, the Bishop of Birmingham, Ernest William Barnes. This suggestion was reinforced by the Auden scholars Edward Mendelson and Arthur Kirsch. But I have to confess that after Dyson said his name I did not have the foggiest idea who Bishop Barnes was and why he would have had anything to say about the quantum theory. I am now going to tell you what I have learned.

Barnes was born on the 1st of April, 1874—All Fools' Day—in the town of Altrincham in Cheshire. His father Starkie (John) Barnes was a schoolmaster and his mother Jane née Kerry was the daughter of the village shoemaker at Charlbury in Oxfordshire. But in 1876 the family moved to Birmingham. I would be fascinated to know at what age and in what way Barnes began to show special mathematical ability. Mathematicians begin very young. To take an example, Dyson once told me that when he was still young enough to be "put down for naps" he invented for himself the notion of the convergent infinite series. He noticed that if you added 1+1/2+1/4+1/8 . . ., the sum approached two. Where in this spectrum was Barnes? I do not know. In 1886, Barnes entered the King Edward VI Grammar school on a scholarship. Secondary education then was neither free nor compulsory. All of Barnes' higher education was done on scholarships. The family could not have afforded the tuition. At King Edward's, Barnes had the good fortune to come upon a truly great mathematics teacher, Rawdon Levett, who recognized Barnes' ability and was able to guide him into learning things like non-Euclidean geometry. Barnes was grateful to Levett for the rest of his life. It was Levett who encouraged Barnes to apply for a fellowship to Trinity College in Cambridge, which he won.

To graduate with honors from Cambridge, the student had to take the so-called Tripos examination. The mathematics Tripos consisted of hard problems that the student had to complete in a certain time limit. The student who did best was labeled the Senior Wrangler. Where the term "wrangler" came from in this context, no one seems to know. The student who did worst was known as the "Wooden Spoon" and was indeed given a spoon along with third class honors. As one might imagine, the list of Senior Wranglers from that period is quite impressive. It includes such people as the physicist Lord Rayleigh and the astronomer Arthur Eddington. But what one might not expect is that the list of Second Wranglers is even more impressive. It includes such people as James Clerk Maxwell, the greatest

physicist of the 19th century, and William Thomson—Lord Kelvin—who was not far behind. Thomson's case is instructive. In one of his courses he had come in with a theorem and its proof. The theorem was on the Tripos and Kelvin had forgotten the proof. He spent a good deal of his time reconstructing it. The man who became the Senior Wrangler had it memorized. One wonders how Einstein would have done on the Tripos.

In 1896, Barnes was Second Wrangler. The Senior Wrangler was a New Zealand-born physicist named Richard C. Maclaurin, hardly a household name although he did become the president of MIT. But two years later Barnes won the First Smith's Prize for his Ph.D. thesis, an even greater honor which led to a fellowship at Trinity. For something like a decade, Barnes did very significant work in pure mathematics. His work in the theory of functions is still being adumbrated. When I looked it up on the web, I was interested to note that one of the papers cited was written by Dyson. In 1909, at the age of thirty five, Barnes was elected to a Fellowship in the Royal Society. Soon after, he stopped doing creative mathematics. Dyson told me that G.H.Hardy, one of the most distinguished of the 20th century mathematicians, told him that once Barnes had been elected to the Royal Society he dropped mathematics like a "hot brick." It would certainly seem that way. Perhaps Barnes had realized that he would never be a mathematician in the class of people like Hardy and above all Ramanujan. Nobody was in the class of Ramanujan. He had been discovered by Hardy in 1913, who had invited him to Cambridge. He needed a formal tutor, and the more senior Barnes took on the responsibility. Barnes was remembered as a very good lecturer with a deep interest in mathematical education. Maybe it was not enough.

Barnes's family's religious tradition was Baptist and Wesleyan, but the King Edward School was strictly Church of England. Barnes had no difficulty adapting and his parents did not object. In 1902 Barnes became ordained as a deacon in the church, and from that time on preached sermons in various locales around Cambridge and elsewhere. From the beginning, his sermons had scientific content. Confronted with the facts of evolution, for example, he could not take the bible as a literal cosmogony. These sermons were referred to by others as Barnes's "gorilla" sermons. Another consistent theme of Barnes's sermons was pacifism. He was a confirmed pacifist from the time of his youth, and he never changed through two World Wars. At the time of the First World War this got him in trouble with his more conservative colleagues, though nothing like the trouble Bertrand Russell got into. Russell was then at Cambridge and his vivid denunciations of

the War landed him in jail. Barnes was prepared to give Russell a character reference even though they were not close friends and Barnes did not much approve of Russell's lifestyle. In 1915, Barnes received an offer he could not refuse. The Temple Church in London was looking for a new "Master." The church, which was constructed by the Knights Templar in the 12th century to serve their spiritual needs, had in the 20th century a very distinguished congregation. Barnes was only forty three—young to be a Master of the Temple. It meant leaving Cambridge and moving to London. There was also a personal matter. Barnes had fallen in love with Adelaide Ward, the only daughter of a distinguished family. She had great hesitations about marriage but relented when Barnes told her that he would refuse the job unless she came to London with him. It was a very happy marriage.

Barnes remained at the Temple until 1924. Then he received a letter from Prime Minister Ramsay MacDonald informing him that his name had been submitted to the King for an appointment as the Lord Bishop of Birmingham. The Church of England was the state religion and such appointments required royal approval, which Barnes got. It automatically carried a membership in the House of Lords. This enabled Barnes to participate in the debate in Parliament in 1927–28 about revising the Book of Common Prayer, which could only be done with the consent of Parliament. Barnes opposed the revisions and they were defeated by a narrow margin. When it came to church practice, Barnes was known to be very strict about not allowing any trace of Catholic ritual to enter into Anglican practice. And on the matter of transubstantiation he was dogmatic. In a sermon he said, " I am quite prepared to believe in transubstantiation when I can find a person who will come to the chapel of my house and tell me correctly whether a piece of bread which I present to him has undergone the change for which believers in transubstatiation contend . . ."[3] As one might imagine, this sort of thing rendered Anglo-Catholics, of which Auden's mother was one, livid. That Auden would make a reference to Barnes—however concealed—in his poem must tell us something about his relationship to his mother. In fact this was not Auden's first mention of Barnes in his poetry. The earlier one is much more explicit and curious.

In September of 1931, the British Association for the Advancement of Science had its centenary meeting. It was a stellar gathering featuring such things as a lecture on "holism", his term, by General Jan Christaan Smuts. There were the public scientists of the time, such as James Jeans. Jeans

[3] **AA, 194.**