ANDREI SAKHAROV

QUARKS AND THE STRUCTURE OF MATTER

Harry J Lipkin

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Harry J Lipkin

Weizmann Institute of Science, Israel

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Published by

World Scientific Publishing Co. Pte. Ltd.

5 Toh Tuck Link, Singapore 596224

USA office: 27 Warren Street, Suite 401-402, Hackensack, NJ 07601

UK office: 57 Shelton Street, Covent Garden, London WC2H 9HE

British Library Cataloguing-in-Publication Data
A catalogue record for this book is available from the British Library.

ANDREI SAKHAROV
Quarks and the Structure of Matter

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ISBN 978-981-4407-41-0 (pbk)

Typeset by Stallion Press
Email: enquiries@stallionpress.com

Printed in Singapore.

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Preface

Andrei Sakharov — a distinguished Russian physicist

Sakharov was the "father of the Russian hydrogen bomb' and also made great contributions to our understanding and use of physics.

He pioneered the search for a way to tame the awesome fusion energy that exploded the hydrogen bomb. He developed methods that could enable fusion energy to be used for peaceful purposes. He also investigated the properties of matter. We knew then that there are two kinds of matter called matter and antimatter. Both kinds were created in laboratory experiments but the universe we knew contained only matter and no antimatter. This included all the stars and galaxies seen by astronomers. Their optical instruments could distinguish between light coming from matter and light from antimatter. They saw only light from matter. The mystery of the absence of antimatter occupied physicists for many years. Sakharov was the first to solve this mystery. Both matter and antimatter were created equally in the "big bang" theory of the origin of the universe. Sakharov showed how all the antimatter could decay leaving only matter. This matter–antimatter problem is still not solved but all searches start with the seminal work of Andrei Sakharov.

Saharov also investigated the structure of matter which was known to made of atoms containing protons, electrons and nuclei. In 1964 the Physicists Gell-Mann and Zweig proposed that the neutrons and protons were really made of smaller constituents called "quarks". The physics community rejected the quark picture as nonsense. But Sakharov and his colleague Zeldovich investigated this quark model and found very interesting results. At the same time this quark

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model was independently investigated by my group at the Weizmann Institute in Rehovot, Israel. But we did not know of their work until much later.

Sakharov was treated by his government as a great hero until he began to criticize the Russian Government. He wrote critical articles which were circulated abroad. The government then arrested Sakharov and sentenced him to isolation in the city of Gorky which was closed to foreigners. Despite all these restrictions he continued to do scientific work. He was not allowed to publish his work or send it to physicists abroad. In 1980 his wife and friends managed to smuggle some of his work abroad and tried to get it published in the United States. The Americans hesitated because they were afraid that the Russians would claim that Sakharov's work was being published only for political reasons. They wanted to be sure that it was a good scientific paper that would be accepted on purely scientific grounds.

My colleague Tom Ferbel was asked to review Sakharov's paper. Since it was on the quark model of matter and I was a recognized expert at the time, Tom asked me to review the paper. I was amazed to find that it was identical to work I was doing in Rehovot. This led to publicity with international implications. The Russians had claimed that Sakharov was a great man, but he was now old and senile and isolated for his own good. My analysis of his work showed that the Russian excuse was simply wrong. Sakharov was not senile. On the contrary he was engaged in great physics research. The *Washington Post* learned of my analysis and published an article about Sakharov and my work with a title "A voice out of the darkness". This led to a flood of articles in the media and led me to give a series of popular scientific lectures and magazine and newspaper articles for a wide variety of general audiences, including Rotary Clubs, high school students, laymen interested in science, and professors in the social sciences and humanities. These lectures were first motivated by the attempts to help Andrei Sakharov.

My further contacts with the scientific work of Sakharov turned into a remarkable adventure in which I received more manuscripts

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and postcards from him in his exile in Gorky, smuggled out of the Soviet Union. The story of this adventure and of Sakharov's work and achievements fit beautifully into the description of what scientific research is all about and how it is done. The quarks which were then rejected as nonsense are now recognized as the basic tiny building blocks which are bound together to make the matter we know. Lectures originally given for publicity of Sakharov's plight grew into lectures and articles which fascinated many general audiences, professors and professionals in other fields, and newspaper and magazine editors and readers. They all responded enthusiastically to this combination of the human interest story and achievements of Sakharov with an understandable description of modern physics and the present state of our knowledge of the nature of matter and energy. I explained how the quark building blocks of matter were discovered and understood. I also presented a picture of how how scientists work and develop new knowledge, and discussed the purpose of it all.

Professor Moshe Barasch of the Hebrew University and Mosad Bialik suggested that I put the material together in a book. This book grew out of these lectures.

From earth, air, fire and water to quarks

Throughout the centuries, scientists have puzzled over the questions, what is matter made of, and what are the forces of nature. The ancients believed that everything was composed of four elements, earth, air, fire and water. Now we know that water is a compound made of hydrogen and oxygen and that fire is a chemical reaction that produces energy which can be both useful to mankind and cause terrible destruction. Earth and air are mixtures of many different chemical elements and compounds.

During the twentieth century scientists have made very great progress in understanding the nature of matter and energy. They have found new sources of energy, which like fire are also capable of terrible destruction and of being harnessed to do useful work for mankind.

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They have broken up chemical compounds into chemical elements and then found that these elements could be broken up again and again into even smaller objects. They are still investigating whether the tiniest objects known may be made of even tinier building blocks.

In ancient times mankind learned to fear the destructive energy of nature's floods and also to harness the energy of water power for useful purposes. They learned to fear the destructive energy of the wind, and later on to harness it in windmills. Man has learned to use chemical energy in many forms for useful purposes and also to construct explosives for mass destruction. Electric forces and electrical energy were discovered more recently and have become an important part of our everyday life. Nuclear energy in various forms has now been used in recent years both for destruction and to benefit mankind, and there is extensive research today searching for better and safer ways to harness this new kind of fire.

Scientists looking for the basic building blocks of matter found molecules which were made of atoms which in turn were made of nuclei which in turn were made of particles called neutrons and protons. By 1966 new experimental evidence indicated that neutrons and protons were themselves made of even smaller objects. There was a crazy theory proposed in 1964 that the neutron and proton were made of tinier objects called quarks, but nobody had been able to break up a neutron or proton to find these quarks. The majority of physicists believed that the quark theory was plain nonsense.

A few physicists took the quark model seriously and found ways to test this model by experiments on the known particles, even though the quarks themselves were not found and the nature of the forces which held them together in the proton were completely unknown. At the Weizmann Institute in Rehovot, Israel, a group of theorists was active in this field and obtained interesting results which agreed surprisingly well with experiment and provided evidence supporting the quark model. Almost identical work was done independently in Moscow by Andrei Sakharov and his colleague Ya. B. Zeldovich. At that time Sakharov was completely free and his work was published

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in open scientific journals. But the physics "establishment" did not take quarks seriously at that time and Sakharov's work remained completely unnoticed until fourteen years later.

In 1978, when the quark model had become accepted, I returned to this work in Rehovot and discovered some new relations which agreed remarkably well with experiment. In 1980 I found in Sakharov's smuggled paper that he had independently obtained exactly the same results. This led me to rediscover Sakharov's old results and led to a fascinating correspondence with Sakharov via smuggled postcards.

Who needs quarks?

What is all this quark research good for? What will be its impact on society? Laymen asked the same question about atomic research a hundred years ago. Rutherford then told people that he could not predict the future of atomic research. But he was sure that the government would find a way to tax it.

Now we know that the new understanding of what goes on inside the atom has brought us new technology which has completely transformed our society and our everyday life. Nuclear power plants, transistors, modern computers and lasers did not exist forty years ago. They were developed only after the necessary basic knowledge was provided over a period of years by research into the properties of materials and the interpretation of experiments with the new quantum theory of the atom. Application of that theory to semiconductors enabled the invention of transistors, which in turn made possible the development of modern solid state electronics, which is the basis for modern computers.

This book attempts to describe the search for the basic building blocks of matter and the investigation of the nature of the forces that can either bind them together or blow them apart and can produce either useful or harmful energy. It also attempts to provide a picture of how scientists work and how new scientific knowledge is learned, communicated and passed from one group of investigators

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to another. The fascinating story of Andrei Sakharov and his contributions to this search provides a simple and easily understood framework for introducing the more technical aspects of the subject.

The first part of the book describes in general terms how scientists study nature and tells the Sakharov story. The second part goes into more detail in explaining the basic building blocks of matter and the development of our knowledge of forces and energy.

Voyages of Discovery

The twentieth century began with the consensus that matter is not continuous but is made up of atoms and molecules. It ended with the confirmation that matter is made of even tinier objects called quarks. But how are such realities established? And how can the process be explained in a plausible way to a non-scientist? I was surprised to find the answer in a book, *The Schools We Need and Why We Don't Have Them* (Doubleday, New York, 1996), by E. D. Hirsch Jr, a professor of English at the University of Virginia. Hirsch's answer also shows the comparison between physical scientific research and pedagogy.

Just as we know that matter is composed of basic building blocks called quarks we also know that literature is composed of basic building blocks called letters of the alphabet. This book describes the voyage of discovery of quarks, the forces that bind quarks into neutrons and protons, and further into the matter that we know. It also describes how to lead a child learning to read on a voyage of discovery of the alphabetic principle, the sounds that bind the alphabet into words and further into the literature that we know. These voyages encounter many obstacles. But the methods of scientific research studying nature have led the way to discovering these obstacles and overcoming them.

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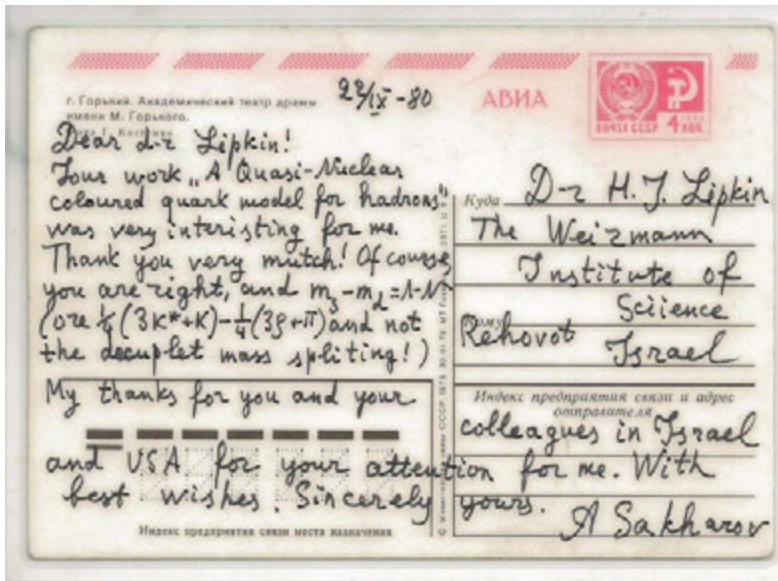
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23/IX-80

АВИА

Dear Dr Lipkin!
Your work „A Quasi-Nuclear coloured quark model for hadrons" was very interisting for me. Thank you very mutch! Of course you are right, and $m_3 - m_2 = \Lambda - N$ (or $\frac{1}{4}(3K^* + K) - \frac{1}{4}(3\rho + \pi)$ and not the decuplet mass spliting!)
My thanks for you and your colleagues in Israel and USA for your attention for me. With best wishes. Sincerely yours. A Sakharov

Индекс предприятия связи места назначения

Куда D-r H. J. Lipkin
The Weizmann Institute of Science
Rehovot Israel

Индекс предприятия связи и адрес отправителя

Figure 1.

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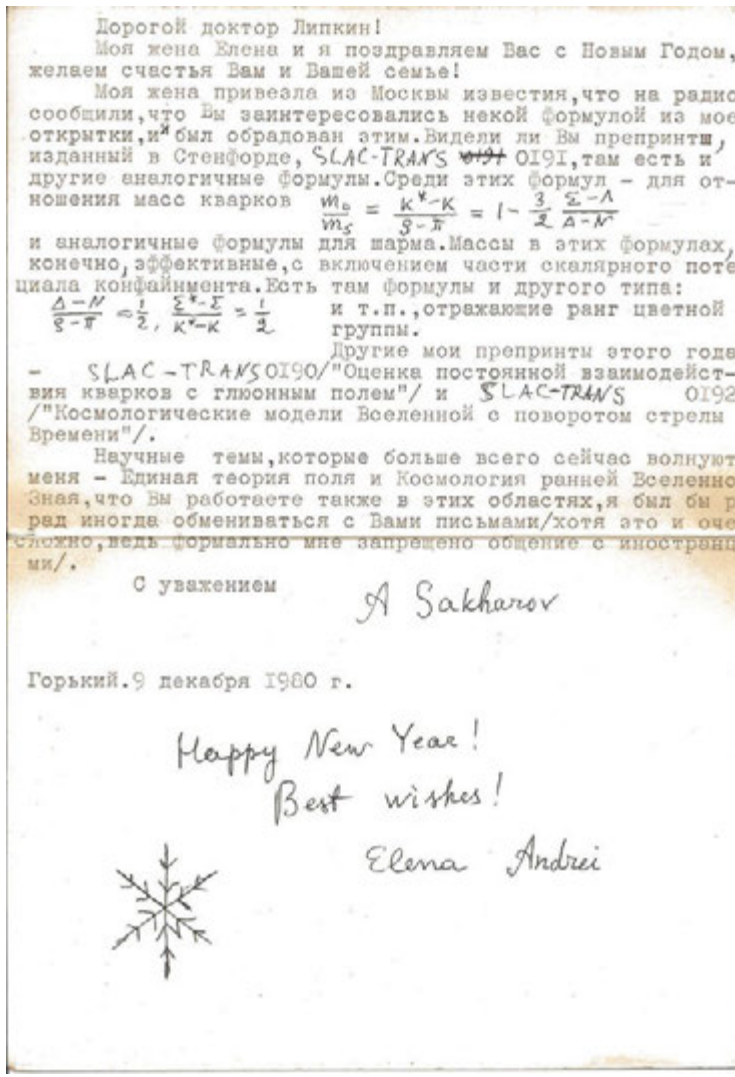

Дорогой доктор Липкин!

Моя жена Елена и я поздравляем Вас с Новым Годом, желаем счастья Вам и Вашей семье!

Моя жена привезла из Москвы известия, что на радио сообщили, что Вы заинтересовались некой формулой из моей открытки, и был обрадован этим. Видели ли Вы препринты, изданный в Стенфорде, SLAC-TRANS ~~0191~~ 0191, там есть и другие аналогичные формулы. Среди этих формул – для отношения масс кварков $\frac{m_u}{m_s} = \frac{K^* - K}{\rho - \pi} = 1 - \frac{3}{2}\frac{\Sigma - \Lambda}{\Delta - N^*}$ и аналогичные формулы для шарма. Массы в этих формулах, конечно, эффективные, с включением части скалярного потенциала конфайнмента. Есть там формулы и другого типа: $\frac{\Delta - N}{\rho - \pi} \approx \frac{1}{2}$, $\frac{\Sigma^* - \Sigma}{K^* - K} \approx \frac{1}{2}$ и т.п., отражающие ранг цветной группы.

Другие мои препринты этого года – SLAC-TRANS 0190/"Оценка постоянной взаимодействия кварков с глюонным полем"/ и SLAC-TRANS 0192 /"Космологические модели Вселенной с поворотом стрелы Времени"/.

Научные темы, которые больше всего сейчас волнуют меня – Единая теория поля и Космология ранней Вселенной. Зная, что Вы работаете также в этих областях, я был бы рад иногда обмениваться с Вами письмами/хотя это и очень сложно, ведь формально мне запрещено общение с иностранцами/.

С уважением

A Sakharov

Горький. 9 декабря 1980 г.

Happy New Year!
Best wishes!

Elena Andrei

Figure 2.

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Quarks and Smuggled Postcards from Andrei Sakharov

In November, 1980 Andrei Sakharov smuggled a postcard out of the Soviet Union from his exile in Gorky. The text of the card shown in Fig. 1 was a response to a reprint of a paper which I had mailed to him. Many people were very excited by this postcard.

It appeared in an editorial in the *Washington Post* and was copied in many newspapers, magazines and journals. Most recently it appeared in the book *The Physicists* by C.P. Snow. It showed that Sakharov was still alert and active in frontier physics despite his isolation, and exposed the rumors spread by the Russians that he was senile and needed to be isolated as completely false. The story behind this postcard is very fascinating.

In the spring of 1980 Professor Tom Ferbel from the University of Rochester Physics Department asked my opinion of a recent manuscript by Sakharov which had been smuggled out of the Soviet Union by a friend. Sakharov was having difficulty getting his work translated and published in the Soviet Union and his friend was investigating the possibility of getting it published in the U.S. He had translated it into English, but he was not an expert in the field of particle physics and did not know whether the work was sufficiently new and interesting to warrant a big fuss about publication. He was

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in Rochester and consulted Professor Ferbel whom he knew was working in particle physics.

I was at that time on sabbatical in the U.S. and was asked to read and referee the paper to be sure that its scientific value was adequate. The Americans wanted to avoid any charges that they had published the paper for purely political reasons. I was amazed to find that this paper was almost an exact duplicate of work that I had been doing during the past few years.

The history of my contacts with Andrei Sakharov and his association with the Weizmann Institute really begins in 1966, long before we actually met, when he and his Colleague Ya. B. Zeldovich published a paper which referred to four published Weizmann Institute papers: two by H. Harari and H. Lipkin, one by H. Lipkin and one by the Weizmann High Energy experimental group. We did not know of his work at that time, and there is an amusing note added in proof in the paper indicating that he did not know of our ongoing work. The note begins "In a discussion at the summer school in Balaton (Hungary), Bob Sokoloff (Berkeley, USA) developed the hypothesis on the additivity of total cross sections at high energies . . ." Sakharov did not know that Bob Socolow had come to Balaton after spending several months as a visitor at the Weizmann Institute. He reported at Balaton on the work of our group in Rehovot.

That Sakharov's group and our group were doing very much the same work did not come to our attention until 1980, when Tom Ferbel showed me the smuggled paper from the Soviet Union.

I immediately began referring to Sakharov's work in all my lectures and seminars and in invited lectures at conferences and summer schools. In discussions about my own work, I pointed out that the same results had been obtained by Sakharov in Gorky. The reaction of the audience was invariably one of amazement. Prof. Antonino Zichichi, the Director of the International School of Subnuclear Physics at Erice, Sicily was very excited by this. He said it was very important to let the world know that Sakharov

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was mentally alert and active and not senile. This work of Sakharov should be given maximum publicity. The Russians were circulating rumors that Sakharov was of course a great man, but now he was old and senile and was being isolated in Gorky for his own good. My evidence that this was not true would be crucial to counter this disinformation. The information that Sakharov was able to do any scientific work at all under his difficult conditions of isolation and harassment was very important and should be given the widest possible publicity.

Zichichi ashed me to write a popular article about this work, which he then translated into Italian and published in the Rome newspaper *Il Tempo* with a picture of Sakharov and a headline "An article by Andrei Sakharov from his exile in Gorky". This newspaper was read by many important political figures including the President of the Republic and the Pope. They would see the picture and the headline and understand that the rumor was false. The article appeared in a space regularly devoted to science, whose readers were able to appreciate the scientific aspects of Sakharov's work. But laymen and politicians who also read the paper and only saw the headlines got the message that Sakharov was alert and still making important scientific contributions.

Sakharov was confined to the city of Gorky with no access to scientific institutions nor libraries. The secret police followed him everywhere. They entered his apartment whenever he left and confiscated all papers that they could find. He carried all scientific papers that he needed for his work in his briefcase. Then, one day when he visited the dentist and left his briefcase in the waiting room, two men came in and took the briefcase. Yet he managed to work under these incredible conditions.

It then occurred to me to write Sakharov directly about our common scientific interests. I was assured by friends in contact with him that letters could not possibly do him any harm; he would probably never receive them. But any scientific material that did get through was important, because he felt so isolated in Gorky

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and appreciated all scientific contacts. Immediately after the Sicily summer school I sent Sakharov a letter and some reprints of my work. He never received the letter but did get the reprint, which duplicated much of his work. He answered with a postcard which he sent somehow to his stepdaughter Tatiana Yankelevich in Boston. She did not know that I was in America, because Sakharov never received my letter. Since the address on the reprint was Weizmann Institute, she naturally sent it to her husband Efrem's brother Boris, who was at that time a doctoral student at the Weizmann Institute. She also enclosed a copy of the smuggled manuscript, not realizing that I had it already. But Boris was doing military service at the time and passed it on to Edward Trifonov, an Institute scientist who knew me, but had no idea what it was all about. He sent the material to me in Chicago with a covering letter about manuscripts from Sakharov. I thought at first that they had gone to a lot of trouble just to send me these manuscripts that I already had. Just as I was about to toss it all out the postcard fell out of the package and I knew that I had received something very important.

At the advice of Sakharov activist Kurt Gottfried, I sent a copy of the postcard with a note to Jessica Matthews of the *Washington Post*. She was then about to write an editorial about the arrest by the KGB of the Soviet "refusenik" scientist Viktor Brailovsky.

At this time many Soviet Jewish citizens had applied for permission to leave the Soviet Union and settle in Israel. When their applications had been refused they sere severely penalized by the Soviet authorities. They were called "refuseniks", fired from their jobs and suffered all kinds of harassment. Refusenik scientists were not allowed to visit scientific institutions. A group of refusenik scientists created their own scientific seminars to enable them to communicate with colleagues and participate in scientific research. At the time that Jessica Matthews received my letter, she saw that it fit beautifully into her editorial.

A few days later my postcard from Sakharov appeared in the leading editorial in the *Post* with the headline "A Voice out of

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the Darkness". Together with the news of the arrest of Brailovsky, this postcard showed that the KGB could not silence Sakharov and the refuseniks. The postcard was then copied and appeared in many newspapers and magazines, including the *International Herald Tribune*, the *San Francisco Chronicle*, *New Scientist*, *Science News*, and C. P. Snow's book *The Physicists*. The story was broadcast by Voice of America in their Russian language broadcast and heard by friends of Sakharov in Moscow who told Elena Bonner who told Sakharov. He then sent me a second postcard, which again made the rounds of the media.

Publicity to Help Sakharov and Refuseniks

Keeping these issues alive and in the media was not easy. After a while the Soviet mistreatment of dissidents and refuseniks was no longer news, and the media were not interested.

Many people in many countries were then working hard to spread the latest news about individual refuseniks, about the harassment and imprisonment of Sakharov, Orlov and Sharansky (SOS) and about the breakup of the Moscow seminars. They also write letters to refuseniks to bolster their morale, to keep them informed of news from Israel and the rest of the world, and to show both the refuseniks and the police who censor their mail that the world had not forgotten their plight and was still actively interested in helping them.

After the arrest of Brailovsky and the breakup of the seminars, groups of concerned scientists in the U.S. organized special seminars similar to those in Moscow with the aim of showing solidarity with the refuseniks and giving publicity to their new troubles. These seminars were held in private homes in university communities throughout the U.S. with a format similar to the Moscow seminar. Outstanding scientists were asked to give talks about their work, and scientists who had attended Moscow seminars as foreign visitors also spoke. In addition there were reports on the present situation and discussions of possible action. Representatives of the press were

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informed and invited and later wrote articles in the local newspaper. I attended two such seminars, one at the University of Illinois in Urbana and one at the University of Chicago. In both I showed my postcards from Sakharov and told both the scientific and human story behind them.

After my first postcard appeared in the *Washington Post*, I sent the material to the Chicago newspapers, thinking that it might have some local interest. I never received any answer. However, when I sent it to Irv Kupcinet who writes for the *Chicago Sun-Times* and whom I had met at Chicago Weizmann Institute dinners, he was very interested and devoted considerable space to the story in his column. Immediately the competing paper, the *Chicago Tribune*, became interested and sent a photographer out to the laboratory where I was working to take my picture and get a story. But nothing came of this. Local small talk was more interesting for Chicagoans than the story of Sakharov. I also sent a copy of the card and the correspondence to the science editors of the *San Francisco Chronicle* and the *New York Times*. The *San Francisco Chronicle* published a full page in their weekly magazine, with the headline "Courage of an Exiled Scientist" and pictures of Sakharov and the postcard. The *New York Times* did nothing with the story.

In January, 1981 the American Physical Society held a special session on the scientific work of Andrei Sakharov at their annual New York meeting. Several talks summarized Sakharov's contributions to plasma physics and fusion, particle physics, the cosmology of the early universe and the theory of gravitation. A number of these contributions were far ahead of their time and were originally ignored or scoffed at by the physics community. But some of these ideas were accepted over a decade later, when most physicists were unaware of Sakharov's original contribution. Many physicists who had previously known of Sakharov only as the father of the Soviet H bomb and later for his human rights activities were amazed to learn that he had also made very significant contributions to basic research in physics in a wide variety of areas.

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After the New York Physical Society meeting, a report on the Sakharov session appeared in the Chicago newspapers, with a picture of Sakharov's step-daughter and a Chicago physicist who spoke there. But there was nothing in the *New York Times*. The story had come from an Associated Press report by their science writer who had been at the meeting. It had been picked up by a number of papers around the country, but not by the *New York Times*. The Associated Press did not report my talk at the press conference about the postcard, because the postcard story was two months old and no longer news. I called the Associated Press reporter after receiving the second postcard. He immediately wrote a story which appeared in many newspapers, with headlines like "Sakharov Finds Way to Beam His Idea" and "Notes from the underground: Soviet smuggles cards". Voice of America was very interested in the story that Sakharov had heard of my interest in his work from VOA. They offered to broadcast a response to his second postcard which I dictated and they translated into Russian. But major newspapers like the *New York Times* and the *Washington Post* did not carry the story. Sakharov's difficulties were old hat and not considered news any more.

I attempted to get as much publicity as possible for Sakharov in the media by the use of the two postcards. By this time a story had unfolded that could be told in many different ways to many different audiences from scientific seminars to rotary club meetings. Different versions of the story appeared in a number of publications.

I followed up the appearance of my first card in the British magazine *New Scientist* by writing to the Editors expressing strong approval about their use of my postcard. But I was surprised that they had not informed me. Their response was an apology and a request that I write an article about Sakharov's scientific work. By this time I had been impressed with the breadth and depth of his work and responded that he had done so much in so many different fields that no one person could adequately cover it all.

I agreed to write an article about my field and suggested that there be two other articles about his other contributions. The result

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was a special section of *New Scientist* on Sakharov's work, timed to correspond with a meeting in New York celebrating Sakharov's sixtieth birthday. It contained the three articles following the general outline of the New York Physical Society meeting, an editorial on Sakharov, entitled "An honorable dissident", with a picture of Sakharov on the cover of the magazine.

This section appeared in the April 30 issue, just in time for the international meeting in May 1981 honoring Sakharov's 60th birthday in New York. The program featured his contributions to Science, War and Peace and Human Rights. The reports by outstanding speakers in all these areas were very impressive. In all three areas Sakharov has been ahead of his time.

He had not been a lone naive voice in the wilderness fighting for hopeless causes. His contributions can be characterized as combining brilliant vision and analysis with a down-to-earth practical view of what will be realistically feasible ten years hence, and as recognizing the significance of new developments long before they were fully appreciated by others. He had already lived to see some of his early ideas which were ridiculed at the time accepted ten or fifteen years later.

The "Moscow Seminars in Exile" in Urbana and Chicago attracted the attention of the press. The Champaign-Urbana paper carried a big story, including material on Sakharov and the postcards. The two Chicago papers carried stories which mainly emphasized the presence of Sakharov's stepdaughter Tatyana Yankelevich who had come specially from Boston for the seminar. The plight of the refuseniks was also mentioned, and of course the fact that one of the speakers was a Nobel Prize-winner helped get attention from the press.

The story of my correspondence with Sakharov finally made the *New York Times* after the international symposium honoring his 60th birthday, as part of a report on the meeting. The meeting also provided an occasion for the story to appear in newspapers which had been sitting on it for some time, waiting for a suitable occasion.

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The story of the postcards meandered through the media in unexpected ways. Direct efforts to send the story to editors usually were unsuccessful, unless the particular writer had a special interest or a special incentive to write about it. But the public affairs office of the Argonne Laboratory, which had done nothing to publicize the story, noted the article on my talk at the Urbana Moscow Seminar in the local paper and assigned a summer student working at Argonne to look into it. She interviewed me and wrote a very good article entitled "Sakharov Writes to Argonne Scientist — East meets West through smuggled postcard", which was published in the internal Argonne magazine, *Argonne News*. This story was then picked up by another student, working for a master's degree in journalism at a local university, who called and asked for an interview. She thought the story would be suitable for the local Chicago papers. I was skeptical, since the direct contact with the editors and other reporters had led nowhere. But shortly afterwards she called, said that she was now working for the *Chicago Sun-Times*, and was ready to use the story. She sent a photographer to take shots of me with the postcard, and a full page article appeared shorly afterwards. Never underestimate the power of a student.

But by the fall of 1981, Sakharov was almost a forgotten man in Gorky. The Russians were succeeding in isolating him and keeping his views from reaching the Soviet people and the world. His letters received little attention when they were smuggled out of the Soviet Union. He sent a long letter on the suppression of human rights and on his own condition to a well-known physics professor in America. But no major newspaper nor magazine would publish it, because the standard suppression of human rights in the Soviet Union and the mistreatment of Sakharov was no longer news. The Soviet strategy was clear. Wait until the West gets tired of all this dissident and refusenik business. Then the KGB will be able to do as they please without notice or interference from abroad.

Sakharov found the way to get back into the media and the headlines. His wife's two children by her former marriage had

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emigrated to the United States. They had originally not wanted to emigrate, but they had been harrassed so much by the KGB because their mother had married Sakharov that they finally applied for emigration. But Sakharov's stepson's fiancee, Lisa, was still in the Soviet Union and was not allowed to leave and join her fiance. Sakharov and his wife went on a hunger strike to force the authorities to let her go.

When Sakharov began his hunger strike, many of his friends in America were very critical. Why make all this fuss about one girl who couldn't get out when so many refuseniks like Anatoly Sharansky are in much worse condition? Why is Sakharov going overboard for his own family? They did not appreciate Sakharov's brilliant tactics in bringing the whole problem of Soviet dissidents and refuseniks very dramatically to the attention of the world.

Strong letters of protest against the treatment of Anatoly Sharansky or even a hunger strike for Sharansky would have received very little publicity at that time. The world and the media were bored with the problem of Soviet dissidents. But the media went wild about the human interest story of this poor girl who only wanted to join her fiance, and whose only crime had been to want to marry a man whose only crime had been to let his mother marry Sakharov after he was already a grown man. The Soviets were trapped. They were besieged from all directions with the simple question "Why don't you let this poor girl go?" and they had no answer. They couldn't even find a standard Soviet lie, like calling Sharansky a CIA agent. Whenever their representatives abroad wanted to talk about important things to important people, they found themselves having to give evasive answers to the question "Why don't you let this poor girl go?"

Many people dismissed the possibility of exerting pressure on the Soviets by saying that it only depended upon getting Reagan to put pressure on top Soviet leaders like Brezhnev, Andropov or Chernenko. But pressure could have been exerted at all levels in the Soviet hierarchy. The Russians had other problems besides

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Sakharov and Soviet Jewry, and many were much more important and had higher priority. We exerted pressure whenever we could show the Russians that they were losing something more important by harassing Sakharov or Soviet Jews.

Sakharov's hunger strike was a beautiful example of such pressure. Brezhnev was going to West Germany to meet with Chancellor Schmidt. He wanted the maximum publicity for his visit, for his propaganda messages of peace and security and for his arguments against placing American missiles in Europe. The last thing he needed was to have his visit obscured by headlines in the media about Sakharov's hunger strike while Brezhnev's peace talk would barely make the back pages and to have all press conferences highlighting the question of why he did not allow Sakharov's stepson's wife to go to America. Sakharov won. They let Lisa join her husband. But Sakharov also won much more.

Sakharov's tactics showed a deep understanding of how the Soviet system works and of the psychology and the media in the West. His victory went far beyond the simple liberation of his daughter-in-law. He lost no time in using the limelight in the media to call the world's attention again to the despicable treatment of human rights in the Soviet Union and to give more publicity to the plight of dissidents and refuseniks in trouble.

During Sakharov's hunger strike his relatives here in Israel asked me to help organize a demonstration against Soviet Nobel Laureate Nikolai G. Basov, an outspoken leader in the denunciations of Sakharov, who was about to attend an International Conference on Lasers in the United States in December 1981. I did not find any Israelis going to that conference, but sent telegrams telling of Basov's visit to friends including Prof. Morris Pripstein of the University of California at Berkeley, chairman of SOS (Scientists for Sakharov, Orlov and Sharansky).

Prof. Pripstein did not know anyone attending the laser conference, but found out that Basov was attending another conference in San Francisco. A demonstration by prominent American scientists

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including one Nobel Laureate was described by large articles with pictures in the two major newspapers and by smaller articles in six other local papers. He sent copies to me with a letter: "Enclosed are the press clippings of our demonstration against Basov which we organized as a result of your telex to us. We didn't know he was coming since the organizers of the conference in San Francisco tried to keep it quiet. We learned from sources who were in contact with Basov afterwards that he was extremely upset about our demonstration."

In 1983 Andrei Sakharov was still sitting in Gorky, held without trial and without being accused of any crime. He continued to send his messages very clearly to the world, and we wondered how we could do anything to help. The least is to try to maintain all possible contact to help him in his isolation, and to let the rest of the world and the Russians know that we have not forgotten this great man. The Soviet authorities undoubtedly wished that everyone would forget about Sakharov, the refuseniks and the dissidents, so that they could get rid of all of them quietly. We did our best to prevent this scenario.

The Harassment of Andrei Sakharov Despite His Scientific Achievements

In October 1983 I passed through Boston, called the Sakharov family and spoke to his stepson Alexei. He was now happily reunited with his wife who had been allowed to join him as a result of the hunger strike. But he told me that Sakharov's situation had become worse because the KGB had finally succeeded in inciting the general public against him after his article expressing his views on how to end the nuclear arms race was published in the American magazine *Foreign Affairs*. Still fighting for his views, with no regard for its impact on his own situation, he had smuggled this article out of the Soviet Union. The KGB propaganda called him a warmonger and aroused the public. When one recalls how the antiwar people

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in the U.S. are aroused against Teller it is easy to see how the KGB controlling the media can give Sakharov, the father of the Soviet H-bomb, the image of a superhawk who wants to destroy the world in a nuclear war, even though he is fighting for nuclear disarmament and preventing nuclear war. The Sakharovs were now receiving threatening phone calls and were harassed by people they met on the street.

Meanwhile both Andrei and Elena Sakharov needed hospitalization and medical treatment. The Soviet authorities refused to allow them both to be hospitalized in Moscow as recommended by the doctors of the Soviet Academy of Sciences. Instead they were hounded by the KGB who followed him everywhere, confiscated all papers he left in his apartment, and again stole the papers he needed for his work, this time by attacking him bodily in his car. Elena had been told that she could be treated in the Academy hospital in Moscow, but she refused to go without Andrei. Andrei refused to go to the hospital in Gorky because he did not trust them after his treatment there during the hunger strike. They gave him various medications without telling him what they were.

Despite his illness, harassment and confinement in the city of Gorky, where he was barred from any access to scientific institutions or libraries, he continued to work and to be heard. He carried on trying to do physics and was writing another paper on the matter–antimatter problem in the early universe which was almost ready to be submitted to the prestigious Soviet *Journal of Experimental and Theoretical Physics* (JETP).

When I mentioned that there were rumors of a proton decay event in Japan, Alexei asked me if anyone had written to Sakharov about it. He said that Sakharov was starved for news about physics, and any news of this kind would be very good for his morale. Letters could be sent both to his address in Gorky and to the Lebedev Institute, where his wife picked up the mail. Some got through.

I immediately wrote to Professor Larry Sulak at the University of Michigan who was then active in a proton decay experiment and had

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been very excited about the proton decay rumor, suggesting that he write to Sakharov. When I returned home I wrote to others who had been active for Sakharov and active in the field of proton decay, urging them to keep Sakharov up to date by writing him letters and sending him copies not only of published papers but also interim reports on the progress of experiments, proposals for new experiments, letters to professional colleagues discussing the latest results and rumors, etc. I then suggested the same for all scientific refuseniks, who are so completely isolated from the everyday excitement of scientific research. I later received an answer from Prof. Sulak, thanking me for the suggestion and saying that he had never thought of sending anything to Sakharov before because he was sure that they would never get through.

Meanwhile the official campaign against Sakharov openly stated that he was mentally ill, and gave rise to fears that there would be attempts to place him in a mental institution. Soviet spokesmen up to the top level of Yuri Andropov told foreign statesmen and the press that Sakharov was unbalanced, even using the word "cuckoo" and needed isolation for his own good. The *Washington Post* again used the stories of my contacts with Sakharov in an article to refute these accusations. Robert Kaiser, who had spent three years in the Soviet Union and knew and respected Sakharov personally, was now an editor of the *Post*. He saw the article I had written for Sakharov's honorary doctorate at the Weizmann Institute. At his request I rewrote it as an answer to the Soviet propaganda statements. It appeared in a Sunday *Washington Post* with the headline "It's not Sakharov who's Cuckoo" and was reprinted in a number of other major newspapers, including the *International Herald Tribune* and the *Manchester Guardian Weekly*.

I do not know how much these demonstrations and newspaper publicity really helped. But one of my prized possessions is a photograph of Andrei Sakharov taken in Gorky, with the inscription "to Harry, true friend, from Sakharov's family."

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Continuing Harassment of Andrei Sakharov

Appeals for Humane Treatment of Sakharov

The lone voice of Andrei Sakharov's appeals for human rights and control of nuclear weapons had repeatedly attracted the attention of the world. As a brilliant scientist at the very top of the Soviet elite, he could have had everything he wanted before he gave it all up to fight for freedom and human rights. His courage, wisdom and strength were an inspiration to the Soviet dissident movement and to the Soviet Jews fighting for the right to leave the Soviet Union and come to Israel. Although he was not Jewish himself, he always supported the Soviet Jewish refuseniks in their struggle. Before his exile to Gorky, he attended the scientific seminars organized by the refuseniks.

Andrei Sakharov was an outstanding scientist. His contributions to science, as well as to war and peace and to human rights included early ideas which were ridiculed at the time and accepted ten or fifteen years later. A century from now, when all the political problems of today have turned into ancient history, students may still be studying his explanation of the absence of antimatter in the universe and his contributions to the development of fusion energy. He might even be considered as a Russian Galileo, whose important research contributions survived despite the harassment by the political powers of the time.

History has passed its judgement on the Catholic church for its harassment of Galileo and on the U.S. Government for its harassment of J. Robert Oppenheimer. In my letters published in major newspapers I reminded the Soviet leaders that they could face a similar judgement. Their grandchildren would some day study the work of this great Russian physicist and wonder with embarassment about the role of their grandfathers in his persecution. The Soviet authorities did not succeed in rewriting history to erase Sakharov's achievements. The western scientific textbooks and encyclopedias

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continue to describe his contributions to the research which enabled mankind to understand and control the forces of nature. Perhaps arguments like these did influence the Soviet authorities to stop the senseless harassment and persecution of one of their own great men.

Despite his isolation and harassment, Sakharov continued his scientific work as well as his struggle for more freedom in the Soviet Union and for ending the nuclear arms race. His efforts were limited to those areas where he could make useful contributions despite his minimal contact with the outside world. Fortunately he anticipated much of today's research with his pioneering work in the 1960's. The scraps of information that he received in Gorky were sufficient for him to see how his 1966 ideas could be developed further in the light of recent developments. The papers that he had written and still wrote in Gorky described such development of his work on the quark theory of matter and on the cosmology of the early universe.

The scientists all over the world engaged in investigating the structure of matter, looking for proton decay and developing new theories for the early universe were denied the benefit of contacts with Sakharov. One can only wonder what the impact on their work would be if Sakharov had been free to visit their laboratories, learn about their latest results and future programs and give them the benefit of his great knowledge and insight. It is a disgrace that a scientist of Sakharov's stature was not allowed to pursue his work for the benefit of all mankind with the freedom which we enjoy in the West.

Sakharov wrote letters and scientific papers which somehow managed to get out of the Soviet Union and were published abroad. The scientific value of these papers has also been recognized by his Soviet peers, who received them and allowed them to be published in their own prestigious Soviet *Journal of Experimental and Theoretical Physics*. Soviet scientists who read their own journals knew that Sakharov was still alert and active in frontier research, and not "unbalanced and isolated for his own good" as the government authorities claimed. His 1983 letter about the nuclear arms race

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published in the magazine *Foreign Affairs* also showed clear incisive thinking. In Gorky he was still pushing ideas whose time had not yet come. Freedom in the Soviet Union and an end to the nuclear arms race seemed like wild dreams. Now we can see that Andrei Sakharov was right.

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Andrei Sakharov and the Weizmann Institute

Sakharov's Contributions and Achievements

In May 1983 the Weizmann Institute of Science recognized the many achievements of Sakharov by awarding him an honorary doctorate *in absentia*. I was asked to receive the degree for him. Sakharov was known for his struggle for human rights in the Soviet Union and had already been awarded the Nobel Peace Prize. But he was being recognized here also as an outstanding scientist whose contributions rank among the leading pieces of research in theoretical physics of the past thirty years.

Sakharov's family was represented at the honorary degree ceremony at the Weizmann Institute by his stepdaughter's mother-in-law, Tamar Yankelevich, who lives in Israel. She brought me another postcard from Sakharov, a New Year greeting, together with a volume of selected reprints of Sakharov's scientific papers, autographed by her son on behalf of Sakharov. I also wrote an article emphasizing Sakharov's scientific stature which was distributed on the occasion of the award, and sent copies to major newspapers both in Israel and abroad. At that time the press was not interested.

Sakharov began working on the Soviet atomic bomb project in 1948 shortly after he began his graduate studies in physics. He is generally considered to be the father of the Soviet hydrogen bomb, and has been characterized as the Soviet equivalent of Robert

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Oppenheimer, Edward Teller and Hans Bethe, all rolled into one. At that time he felt that it was important for both superpowers to have the bomb, because then no one would dare to use it again like in Hiroshima and Nagasaki. But once they had it, he became increasingly concerned with the moral and environmental implications of nuclear testing and industrial pollution.

Sakharov's contributions to the political aspects of science were also ahead of their time. He saw clearly the necessity for a nuclear test ban at a very early stage. He also saw that banning only tests in the atmosphere was the only practical first step. In the late 1950's Sakharov began a campaign to halt the testing of nuclear weapons. Negotiations between the Americans and the Russians on nuclear testing were stalled. The Americans mistrusted the Russians and insisted on the right of inspection inside the Soviet Union. The Russians mistrusted the Americans and feared that the Americans would use inspection as a cover for espionage. A realistic visionary, seeing clearly the crucial points ahead of his time, Sakharov noted that the inspection issue only affected underground testing which would not cause radioactive fallout and pollution. He proposed a first step banning only the dangerous tests in the atmosphere, under the sea and in outer space. These could easily be detected without inspection. He was not taken seriously, came into conflict with the highest authorities including then Soviet Premier Nikita Khruschev, but persisted in his efforts and helped to promote the 1963 treaty banning just these tests. This test ban, successfully observed to this day, is still the main effective international agreement protecting mankind from the dangers of radioactive fallout.

Already while working on the H-bomb, Sakharov began investigating the peaceful uses of this awesome energy source, which is called nuclear fusion, and is most simply described as a new kind of fire which is literally too hot to handle. We can use the energy from burning oil and coal because we have materials like steel to build furnaces and stoves that can contain the fire. But the fire of nuclear fusion is at a very high temperature that no known material

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can survive. It is as if we had no metals and had only plastics to build stoves and furnaces for burning oil. This is why it is easier to use fusion for bombs than for peaceful energy. To make a bomb you don't need a furnace to hold the fire; you light it once and let it blow up.

In 1950 Andrei Sakharov and Igor Tamm wrote the fundamental scientific paper of the Soviet research effort on controlled fusion, in which they proposed containing the hot fusion fire in a "magnetic bottle". Powerful electromagnetic forces could prevent the hot fire from reaching the walls of the container and allow the fire to keep on burning without destroying the furnace. Sakharov developed a type of magnetic bottle called the "tokamak" which is today the main line of international research on fusion reactors. If Sakharov's "tokamak" can be developed into a new kind of furnace which answers the energy crisis, Sakharov will be remembered with the long list of physicists whose researches delivered new energy sources to mankind.

In 1966 Sakharov wrote two remarkable papers in particle physics very much ahead of his time. Throughout the centuries, scientists have puzzled over the question: what is matter made of? They found molecules which were made of atoms which in turn were made of nuclei which in turn were made of particles called neutrons and protons. By 1966 new experimental evidence indicated that the neutrons and protons were themselves made of even smaller objects. There was a crazy theory proposed in 1964 that the neutron and proton were made of tinier objects called quarks, but nobody had been able to break up a neutron or proton to find these quarks.

Sakharov and his colleague Ya. B. Zeldovich took the quark model seriously and found ways to test this model by experiments on the known particles, even though the quarks themselves were not found and the nature of the forces which held them together in the proton were completely unknown. Almost identical work was done independently at the Weizmann Institute by Pedro Federman, Hector Rubinstein and Igal Talmi. The results they obtained agreed surprisingly well with experiment and provided evidence supporting the quark model. But the physics "establishment" did not take quarks

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seriously at that time and Sakharov's work remained completely unnoticed until fourteen years later.

In 1978, when the quark model had become accepted, I returned to this work in Rehovot and discovered some new relations which agreed remarkably well with experiment. These were the results which had also been independently obtained by Sakharov and reported in the paper smuggled out of the Soviet Union in 1980.

Even more remarkable was Sakharov's explanation in 1966 of the absence of antimatter in the universe; a serious problem which had baffled the cosmologists. The protons and neutrons have their "antiparticles" called antiprotons and antineutrons. These can combine to make antinuclei, antiatoms and antimatter. Such antimatter can be produced in laboratory experiments and scientists wondered whether there were stars and planets made of antimatter somewhere in the universe. In the accepted "big bang" theory of the origin of the universe, there must have been equal amounts of matter and antimatter created, and there were speculations that there must be stars and planets made of antimatter somewhere in the universe. There were even jokes about Prof. Edward Anti-Teller who worked in an anti-laboratory on an anti-planet where all of the theories of physics were developed by anti-semites. But all the astronomical observations failed to find any trace of antimatter.

All other astrophysical observations favored this theory of the origin of the universe in which everything started with a "big bang" that created equal amounts of matter and antimatter. But there was no known mechanism for getting rid of all this antimatter. The astronomers' searches should have found some trace of the antimatter created in the big bang if it were still around. Thus there seemed to be a contradiction between the big bang theory and the astronomical observations.

Sakharov showed in 1966 how all the antimatter created in the big bang could have decayed away, leaving only matter. This resolved the contradiction with the big bang theory. But Sakharov's theory was not accepted because he made a number of assumptions and

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predictions that were ridiculed as being completely crazy at the time. He predicted that protons should decay into electrons and other particles and everyone knew that protons did not decay.

Today Sakharov's theory has become the accepted view on the matter–antimatter problem. His crazy assumptions are now a central part of the standard theory. Large expensive experiments all over the world are looking for proton decay predicted by Sakharov. Recently a Japanese group searching for proton decay reported some events in their experiments which look like signals from protons decaying, but their results are not yet conclusive and need further verification. This could be the most exciting discovery of the century. Most physicists are amazed that anyone could have foreseen all this in 1966.

In May, 1990 shortly before my wife Malka and I flew to New York from Israel, Boris and Larissa Altshuler, friends of Sakharov, visited us in Israel and gave us some manuscripts to give to Ed Kline in New York. We did not know Ed Kline, and they did not know his address or telephone number. But they said that Elena Bonner would know, and that she was visiting her son Alexei in Boston at that time. The telephone number that they gave us for Alexei turned out to be wrong (two digits were interchanged) and I had no idea how to find an Ed Kline (Klein? Cline?) in New York.

But the physics mafia works in strange ways. Prof. Sidney Drell, a good friend of the Sakharovs, was spending a sabbatical from Stanford at Rockefeller University in New York, which I was also visiting. I met Sid and asked if he knew someone named Ed Klein. "Of course", he said. "He is a wonderful person, a business man who is interested in human rights and has looked after the Sakharov children ever since their arrival. By the way, Elena Bonner is in New York today, and Ed Kline will know how to contact her."

Sid and I had a long talk about Sakharov. During Sakharov's last visit to the U.S. Sid had asked him whether it wasn't strange that this great breakthrough toward reform came from Gorbachev, a man who had been close to the KGB all the time and would be expected to support repression. "No," said Andrei, "it is not strange at all. The KGB

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are the only people in the Soviet Union who have all the information about how bad the situation really is. Only they know that drastic reform is necessary to prevent everything from falling apart."

This little remark gives some insight into Sakharov's brilliant abilities and talents. He was not only a great fighter for human rights and a man of high moral stature. He understood the functioning of the system repressing human rights and saw its weak points better than the people who were running the system. He also understood that the system would not be changed only by moral arguments; it was necessary to convince the leaders that the system would not work unless these changes were made.

It is interesting to apply this insight to the cause of Andrei's exile to Gorky: the Soviet invasion of Afghanistan. This was not only morally wrong, it was doomed to failure. If the leaders could have been convinced that it would fail, they would not have invaded Afghanistan. But as long as they believed that it would succeed, no moral argument or international pressure would stop them.

Andrei Dimitriyevich had the remarkable ability to understand how systems function — all systems, social, political, scientific, technological, as well as the interfaces between them. In a sense he was a kind of an interdisciplinary systems super-engineer. I now realize that during the process of working for his cause I learned many things from him. One example of his understanding of systems from which I learned a great deal was exhibited by his undertaking his hunger strike in Gorky.

I recently gave some of my old articles to friends of Sakharov visiting Israel. They were particularly impressed by one article published in the *Jerusalem Post* whose main thrust was to show how it was possible to work for the causes of refuseniks in the USSR and stressed what we could learn from Sakharov and in particular from his hunger strike. At that time many people dismissed the possibility of exerting pressure on the Soviets by saying that it only depended upon getting Reagan to put pressure on Andropov. I noted that the Russians have other problems besides Soviet Jewry, and many are

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much more important and have higher priority. Pressure is possible by showing the Russians that harassing Soviet Jews makes them lose something more important. I presented the hunger strike of Andrei Sakharov as a beautiful example of effective pressure.

That Sakharov's group and our group were doing very much the same work did not come to our attention until 1980, when Sakharov was in exile in Gorky and Tom Ferbel showed me the manuscript smuggled out of the Soviet Union.

Thus began a long campaign to publicize the scientific work of Sakharov. His human rights activities and his harassment by the KGB were well known and well publicized by others. But the importance and implications of his scientific work were not well known and offered us the opportunity to do something that wasn't already being done better by others. There were three directions to this public relations effort:

1. To show that he was still active in science and that rumors about his senility were false.
2. To tell an interesting story about his scientific work and his contacts with the Weizmann Institute. Such stories could find new places in the media and help keep Sakharov's problems in the public view. After a short time, the public and media were bored with hearing one story after another about human rights and Sakharov's ordeals in Gorky. It was hard to get news about Sakharov into the media. The scientific angle kept offering new opportunities for interesting articles.
3. The Galileo–Oppenheimer comparison. "Today the world remembers the names of Galileo and J. Robert Oppenheimer, while the names of those who persecuted them are forgotten". Sakharov's scientific contributions were sufficiently important to remain in a history that Brezhnev and Andropov would not be able to erase. They should wonder what their grandchildren will think when they study the work of this great scientist in school.

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An article written for the Weizmann Institute magazine *Rehovot* attracted the attention of the editor of the *London Times Higher Education Supplement*, who asked me to write an article along the same lines for them. In 1983 I used the Galileo theme in an article requested by the *Washington Post* which was then also printed by other newspapers including the *Manchester Guardian*. In 1984 I used this theme in an article published in the *Guardian* suggesting the creation of a prestigious Andrei Sakharov Prize for Energy Research where I pointed out that Sakharov's contributions in this area justified a prize bearing his name.

In 1983 the Weizmann Institute awarded Sakharov an honorary doctorate, and I was asked to receive the degree for him at the ceremony. Here again we used the occasion to publicize Skaharov's plight and to emphasize that he was a great scientist as well as a hero fighting for human rights. In 1985 I told my Sakharov story to an audience of biologists as part of the traditional interdisciplinary session of a conference in France where a physicist tries to tell about recent events in physics in a language understandable to biologists. The "Sakharov–Zeldovich" model figured prominently in talks given at a number of conferences and summer institutes.

After Chernobyl, I wrote several articles pointing out that if Gorbachev was really serious about working to prevent further nuclear accidents, he should get the best brains in the field of nuclear safety towork on this problem. The first step is to send one of the best scientists in this field, Andrei Sakharov, back from Gorky to Moscow where he can work again. In 1986, shortly before Sakharov's release from exile, I mentioned his work in a talk given at an international conference held in the USSR. I had checked with my hosts who told me that I was free to mention Sakharov's scientific work, as long as I didn't say anything political. Knowing the Soviet cultural trait of reading between lines, I began my talk by recognizing the great Soviet contributions to the field of my talk. I then expressed my regrets at the absence from the conference of some physicists who had made

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great contributions and whose participation in the conference would have been extremely useful.

Sakharov's return to Moscow ended this chapter in our public relations effort to promote his case. We actually met in Moscow in August, 1988, when we had dinner together at the apartment of Arkady Migdal, and were together at the Pugwash Conference in September, staying at the same hotel in Dagomys. I did not realize that this would be the last time that I would see Andrei, and we were looking forward to a visit by Andrei and Elena in 1990. Instead, I met Elena in Jerusalem in June 1990 at the dedication ceremony of the Andrei Sakharov Gardens in Jerusalem and at a ceremony at the Weizmann Institute where we had hoped to give Andrei his honorary degree in person. But Andrei was no longer with us.

The Jerusalem ceremony was a unique occasion honoring Sakharov. He will be given many honors by people and organizations all over the world who recognize his greatness and struggle for human rights. The Jerusalem ceremony was different. The people there were also giving a very personal message of thanks to Sakharov for his help and support in their own individual struggles for freedom and the right to leave the Soviet Union. They were now free and living new lives and wanted to thank Sakharov for his hard work in their behalf. The Sakharov Gardens are not only a memorial to a great man. They also represent the thanks of a multitude of people who were helped by him. I spoke at the dedication ceremony and was introduced as a "friend of the Sakharov family", who had asked that I be given the opportunity to say a few words. I was very touched by this introduction, and by being told by Elena and Tanya afterwards "Of course you and Malka are our friends, and Andrei always spoke of you in this way."

At the Weizmann Institute ceremony, one of Sakharov's unique contributions to the struggle of the Jewish refuseniks was described by the Minister of Science and Energy, Prof. Yuval Ne'eman, who told how Sakharov had once telephoned him personally to inform him

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that Evgeni Levich, the son of the refusenik Academician Benjamin Levich, had been called up for army service in the Arctic and that this was done only to harass the family and had no connection with Soviet security. Sakharov asked Ne'eman to publicize this case and his statement in the West as a way to bring pressure on the authorities.

Sakharov's friends told me just recently that his hunger strike is still being criticized by many people who do not understand the point that he was making and which I stressed in my article. They urged me to include my explanation of the real nature of the hunger strike in an article for the Sakharov Memorial Volume. This explanation is also important because there is also a campaign by forces opposing perestroika to paint Sakharov as a great scientist who was led astray by his "Jewish" wife into anti-Soviet activities mainly to help her family. The hunger strike is given as an example of such activities.

I conclude this chapter by returning to the story of Ed Kline and Elena Bonner in New York. I called Ed Kline at the number that Sid Drell had given me. That evening Malka and I had a wonderful visit at the Klines' apartment with Elena Bonner who was spending the night there. We discussed the hunger strike and its motivation and significance again. Elena Bonner told us that the evening after Lisa received her permission and Andrei ended his hunger strike, a group of friends including Sharansky's mother Ida Petrovna were celebrating with her in her apartment in Moscow. Someone criticized her for making such a fuss about this girl in her own family in front of the mother of someone who is in prison. Ida Petrovna retorted sharply Andrei is fighting for all of us!

Andrei is gone. But he still lives on in our minds and our hearts. And his heritage is still fighting for all of us!

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The Weizmann Institute and the Scientific History of Sakharov's Work

While publicizing Sakharov's recent work in Gorky, I also investigated the scientific history of this work. The text of the first postcard raises several interesting questions. My paper to which he referred was thirty pages long with many formulas. Why did he select this one particular formula for his comment? His remark "Of course you are right and . . ." suggest that my equation is controversial, and that he supports my argument. Why did he pick this particular controversial point? And above all, how did he happen to do exactly the same work in Gorky that I was doing in Rehovot? The answers to these questions are very illuminating and give interesting insight into the methodology and communication of scientific research.

Following up the Formula in the Postcard

Following up the implications of Sakharov's postcard had all the excitement of a good detective story. The manuscript smuggled out of the Soviet Union in 1980 referred to a previous paper by Sakharov and his colleague Zeldovich, published in the *Soviet Journal of Nuclear Physics* in 1966. This paper was available in any physics library in the West, but had been ignored and was not known. The paper contained

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work almost identical to work done at the Weizmann Institute at the same time by my colleagues Hector Rubinstein, Igal Talmi and Pedro Federman. This coincidence is not surprising. These groups in Moscow and Rehovot were both strong in nuclear physics and not part of the particle physics establishment at that time. It was very natural for theorists with this background to use the techniques of nuclear physics to describe the structure of the new particles.

The main part of the Sakharov–Zeldovich paper did not duplicate the work of the Rehovot group, but proposed a new model to explain some recently discovered new particles at the accelerator at Berkeley, California. These particles had an electric charge three times the charge of the electron and could not be accommodated in the accepted models. Unfortunately this discovery, although published in the scientific journals and presented at an international conference in particle physics, turned out to be premature. Continued experimental work showed that there were no such particles with a charge three times the charge of the electron.

This excitement about premature results occurs frequently in frontier research, where experiments are difficult, and preliminary indications of new and unexpected exciting phenomena are often unreliable. The experimenters cannot verify the existence of these new effects immediately; it requires the design of a new experiment, approval of the budget by a funding agency, and the granting of precious time on an accelerator by the program committee. But meanwhile the news leaks out to the theorists, who immediately start thinking about explanations for these results, just in case they should turn out to be right. If the new effects disappear in the next generation of experiments, they are quickly forgotten, and the theoretical papers explaining them sink into oblivion. This was the fate of the 1966 paper by Sakharov and Zeldovich.

This forgotten paper contained in a small corner the same results obtained by the Rehovot group. They were valid in the standard model and independent of the additional assumptions introduced to explain the nonexistent new particles. It also contained one result

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which the Rehovot group had not obtained, namely the formula which appears on Sakharov's first postcard in Fig. 1. I discovered this result much later, in 1978, and was very excited by it because it was a simple prediction from the model which agreed surprisingly well with the available experimental data. I was sure that someone else must have found it earlier, but checked both by looking in the literature and asking all the experts. Nobody had seen this result before, so I published it as original.

Sakharov was very generous in his postcard, writing "Of course you are right, and . . ." before this formula. Many of my colleagues would have added "You idiot. Why didn't you read my 1966 paper? I had this result twelve years ago." Of course as soon as I looked up this reference from Sakharov's smuggled manuscript, I realized that he had had my result long ago, and wrote him a letter apologizing for not referring to his work and for claiming the result as my own original discovery. He never received my letter.

This 1966 paper explains why Sakharov in Gorky should be doing the same work in 1980 that I had been doing in Rehovot. The old 1966 work had been carried as far as possible at that time and there were no new developments for several years. But in the mid 1970's a new theory was developed called Quantum Chromodynamics (QCD) which explained the forces underlying the structure of the particles. The 1966 work made use of the very incomplete knowledge of the forces available at the time. In 1978 it was possible to update the old work by using the new information from QCD. It was natural for me to do this in Rehovot, since I still remembered the old 1966 papers and most of the younger active particle theorists had never known of them. It was also the ideal type of research for Sakharov in isolation in Gorky. He remembered his old work, and is sufficiently brilliant to appreciate the implications of QCD from whatever meager information reaches him. He could combine QCD with his old work without access to scientific libraries or institutes.

Careful reading of the 1966 paper reveals a number of illuminating observations on the development of physics and on the

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parallel research carried on in Moscow and Rehovot. A footnote in the paper discusses a formula which Sakharov notes has particular significance. This formula, reproduced in Sakharov's second postcard in Fig. 2, contains a crucial factor of 3/2 which is absent in a similar formula previously derived from an earlier model. The new formula agreed with experiment, whereas the old formula was in strong disagreement. This was presented as additional evidence that the new approach succeeded where the previous approach had failed.

When I looked up Sakharov's reference to the old formula which disagreed with experiment, I was surprised to find a 1965 paper published in *Physical Review Letters* by Haim Harari and Harry Lipkin (!). I had forgotten this work completely, and had to look it up in the library to learn what it was all about. It concerned a point which keeps recurring at different levels in particle physics.

Why are There Always Too Many Particles?

There are always too many particles. Whenever the theorists come up with a beautiful simple explanation for the existing particles, the experimenters upset the system by discovering some new ones which destroy the simplicity and require a new explanation at a deeper level. Theorists are thus always searching for a unification scheme which puts all the particles together in a common framework. The most obvious explanation to a layman is that these tiny particles are made up of even tinier objects arranged in different ways. We have known for a long time now that matter is made up of molecules, molecules are made of atoms, atoms are made of electrons and nuclei, and nuclei are made of neutrons and protons. Why should this stop? Neutrons and protons can be made of smaller objects which can be made of even smaller constituents ad infinitum.

But maybe this does stop. Democritus believed that all matter consists of atoms which are indivisible. The atoms that we know today can be split and divided. They are not Democritus' atoms. But maybe Democritus was right at a deeper level and there are tinier indivisible

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particles from which all matter is made. This is compatible with another approach to the structure of matter. Instead of looking at the constituents of matter, we can consider the forces between them. Progress in our understanding of these forces has always involved finding new relations between forces which seemed to be very different. Thus the phenomena of electricity, magnetism, radio waves, light and X-rays were found to be all related and described by a single set of mathematical equations for a single field of force, the electromagnetic field. Einstein showed in his general theory of relativity that gravitation could also be described by slightly different field equations. In his later years he searched for a unified field theory which would describe all of the forces of nature in a single set of mathematical equations and would give a unified description of all particles.

Beams of light, x-rays and radio waves were found to consist of particles called photons which are all really the same, although they seem to be very different. Einstein showed in his special theory of relativity that a beam of light on Earth should look like an x-ray beam to an observer in a space ship moving very fast in one direction and that the same beam should look like a radio beam to an observer in a space ship moving in the opposite direction. The photons in light, x-rays and radio waves appear to be very different particles, but are really the same photons seen in different ways.

In recent years theorists have followed two approaches in trying to understand the large number of apparently unrelated particles known at any given time. One approach is to look for new smaller constituents from which everything could be built. The other is to search for Democritus' indivisible constituents and follow the approach of Einstein's attempts to find a unified field theory. The goal is a "grand unification" of all the known forces with all the known particles described as different aspects of the same few particles, like the photons in light, radio waves and x-rays.

In our 1965 paper Harari and I looked for such a "grand unified description" of the particles called mesons and baryons, in the context of an overall symmetry scheme. In this way we derived a relation

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between the masses of mesons and baryons which disagreed with experiment; our formula looked like the one shown in Fig. 2, but without the crucial factor of 3/2. By 1966 both Sakharov's group in Moscow and our group at the Weizmann Institute had begun to test the idea that all particles were made of even smaller objects called quarks. The 1966 papers from both groups were investigations of this quark model of hadrons, with mesons made of two quarks and baryons made of three. The particular formula noted by Sakharov pinpointed the difference between the grand unification and quark model approaches and showed that one worked where the other had failed. But the quark model was still very controversial and generally ridiculed by the particle physics establishment because quarks had not been observed experimentally and there was no independent evidence that they existed at all. Furthermore there were misleading experimental results like the supposed discovery of a new baryon which could not be made from three quarks. This led Sakharov and Zeldovich to devote the main part of their paper to a possible five quark model, which was discarded almost immediately afterwards.

Today the quark model has become accepted, but there are now too many kinds of quarks. Once again the two approaches are being investigated. The "composite model" approach says that quarks are made of even smaller objects called rishons or preons. The "grand unification" approach looks for a unified field theory that includes everything and in which basic indivisible particles naturally arise and explain all the observed particles. At present the field is completely open. Nobody knows which approach is right, or perhaps they are both wrong. It would be useful if a theoretical formula could be found to distinguish between the two approaches by testing against experimental data. So far no one has found such a formula, like the one of Sakharov and Zeldovich in 1966 which showed a crucial factor of 3/2 that distinguished between the two approaches.

All of this discussion refers to the correct part of the Sakharov–Zeldovich paper which considers the accepted three-quark model for baryons and not the five-quark model they invented to describe the

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