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L. V. Al'tshuler, and High Energy Density Research

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and

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ABSTRACT

Knowledge of high energy densities critical to cosmology and astrophysics was achieved and exchanged among a very few scientists at a time when science was even more constrained by political considerations that it is today. Resources for the early studies necessarily involved atomic weaponry. A history of L. V. Al'tshuler and some others in his science is given in cosmological context. In the beginning of cosmology and the Universe, negative Fortov-Planck[1] pressures $c^7h^{-1}G^{-2}$ of 4.6 10^{115} Pa are overcome by inertial-vortex anti-gravity (dark energy) pressures to achieve a turbulent big bang and the first turbulent combustion with power 10^{66} watts at the Kolmogorov-Planck scale 10^{-35} meters. The big bang event ceased when negative-pressure gluon-viscous-forces extracted 10^{100} kg of mass-energy from the vacuum to produce the observed fossil vorticity turbulence Universe and its inflation with power 10^{145} watts.

ABOUT THE AUTHORS

Professor Carl H. Gibson

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Gibson is the Founding Editor in Chief of the Journal of Cosmology and Professor of Engineering Physics and Oceanography in the Departments of Mechanical and Aerospace Engineering at the University of California, San Diego. He is a Fellow of the American Physical Society, an Academician of the International Eurasian Academy of Sciences, and one of their Gold Medal recipients.

Professor Gibson's interest in Lev Al'tshuler derives from Al'tshuler's role in creating a new field; that is, experimental cosmology or experimental astrophysics. This discipline consists of carrying out laboratory measurements under conditions occurring in the Cosmos. Following Al'tshuler and Zel'dovich, and most recently by V. E. Fortov, these experiments have given us data on which we may base many of our cosmological theories. The work of Fortov, a student of Zel'dovich, will be discussed later.[2] Ya. B. Zel'dovich, a co-worker of Al'tshuler (who was a mentor and colleague of Fortov), left the field in 1966, shifted to cosmology, and worked out a number of concepts with Academician Sunyaev.

Gibson[3] identified the dark matter of galaxies as Earth-mass primordial gas planets in million-solar-mass clumps (proto-globular-star-clusters). Schild,[4] the present Editor-in-Chief of the Journal of Cosmology, provided a completely independent confirmation of this prediction based on fifteen years of careful observations of quasar microlensing by a galaxy, where he concluded the missing mass of the lensing galaxy was not stars but planets. Together Gibson/Schild have developed hydrogravitational dynamics (HGD) cosmology, where all stars form from mergers of frozen H-He[4] planets within trillion-planet clumps. HGD cosmology combined with Wickramasinghe/Hoyle cometary panspermia provides a physical basis for a biological big bang in time interval 2-8 Myr after the cosmological big bang when the first stars produced the first chemicals and the first planet oceans.[5] Professor Wickramasinghe is the third scientific editor of the Journal of Cosmology. He and Hoyle founded the Cardiff University Center for Astrobiology (now at Buckingham University) thirty years ago, and have pioneered the field of Astrobiology. The Founding Managing Editor of the Journal of Cosmology Dr. Rhawn Joseph has demonstrated the critical importance of horizontal gene transfer to evolution.[6]

Dr. Nerses H. Krikorian

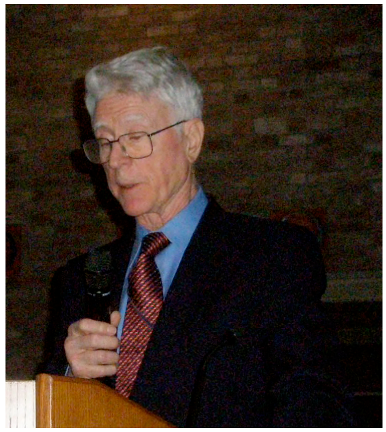
Dr. Nerses H. Krikorian was a part of the original Manhattan Project in 1943 at Union Carbide in Niagara Falls, where he produced high purity uranium. He transferred to Los Alamos in 1946 where as a chemist he became involved, over the years, in all aspects of chemistry that were part of the Laboratory's programs.

Specifically, these were radiochemistry, inorganic and physical chemistry, high temperature chemistry and material science.

Krikorian soon became a source of insights on what Russia, China and others were capable of doing in the nuclear field. He soon became an important part of bi- and multilateral meetings on such topics. For his work he was honored in 1991 with the Intelligence Community Medallion, presented by the CIA Director. He was one of the very first Americans to visit Sarova in 1991, and later, Chelyabinsk 90.

In 2003, he was awarded the Los Alamos Medal, the highest honor that can be bestowed on a Los Alamos employee.

Krikorian is fluent in Russian and Armenian, and is a member of the Armenian Academy of Sciences.



Dr. R. Norris Keeler

Dr. R. Norris Keeler worked in the field of high dynamic pressures for two decades. He was the first US physicist to be elected as a Fellow of the American Physical Society based on his work in the high dynamic pressure field. He served as two term President of the International High Pressure Society, AIRAPT. Keeler was only the second Westerner to actually meet with Lev Al'tshuler. His initial association with the Russian Scientific community led to his initiating several joint programs with Russian scientists. He was recently announced as the 2010 winner of the N. N. Semenov gold medal of the Russian Academy of Sciences for outstanding accomplishments in Research and Development. On February 19, 2009, he gave an address to the Houston Philosophical Society on the accomplishments of Lev Al'tshuler.

L. V. AL'TSHULER AND HIGH ENERGY DENSITY RESEARCH

In writing about Lev Al'tshuler it is important to appreciate that most of the hitherto unknown or previously classified aspects of Al'tshuler's life are available to the scientists and associates who helped the first author prepare this paper. Al'tshuler developed experimental techniques used then and later to obtain data for high pressure geophysics, planetary physics and astrophysics. This work was principally carried out by V. E. Fortov and his group in Russia, and a recent summary of this work will be available in this journal.[2] Fortov has recently published a text "Experiments under Extreme Conditions", which is available in Russian, but will shortly be printed in English.

In the pursuit of nuclear weapon capability both the US and Russia required high pressure dynamic equation of state (EOS) measurements to understand the response of nuclear materials to high dynamic pressure loading. The Manhattan Project scientists who were well acquainted with shock wave effects were Hans Bethe and Edward Teller. In 1940 Theodore von Karman of the California Institute of Technology encouraged them both to become involved in armor penetration physics. Bethe published on this topic.[7] This discipline, often called "shock wave physics" became part of the Manhattan Project under the direction of Roy Goranson, a high pressure geophysicist at the Carnegie Institution, as none of the project's principals were specialists in the discipline. Goranson, in fact, was a static high pressure geophysicist, but clearly understood the role dynamic pressure could play in compression of fissile material to criticality. He was not one of the close inner circle around Oppenheimer, however. The first US A-bomb, a uranium based gun arrangement, was designed by Francis Birch. Seth Neddermeyer insisted on an implosion based system using plutonium, which after Taylor instability problems were solved, because the basic design for all future fission devices.

During the Second World War and afterwards, the existence of the Soviet Nuclear Weapons Program provided a small nucleus of scientists free from party interference with their activities, and these scientists, recipients of numerous awards, both national and international, up to an including several Nobel Prizes, are well known in the Western scientific and political literature. This situation is well described by Holloway,[8] among other historians.[9]

Lev Al'tshuler (9/11/1913-23/12/2003) who was as scientifically accomplished as any of the others, has not been as broadly recognized. This is for a number of reasons. He was not widely traveled, did not speak English, and was rather shy and retiring outside his Russian scientific circles. He was a man of the highest scientific integrity and this led to conflicts with party bureaucrats, and he had no compunctions about aggressively defending his beliefs. In the course of his programmatic activities, he also became the father, as it were, of an entire area of physics; the use of high dynamic pressure to study the properties of materials under extreme conditions.

Lev Vladimirovich Al'tshuler was born in Moscow on 9 November 1913, the son of Anna Esfir' Kershner-Al'tshuler (1881-1968) and Vladimir Al'tshuler (1882-1965), a lawyer who was one of the active leaders of the Russian revolution. (Both are shown in Figure 1-1.) The senior Al'tshuler held a number of high posts under Stalin, but fortunately avoided being a victim of the many purges taking place during that period. Mrs. Al'tshuler was a homemaker, raising three children and being a center of a "spiritual gravitational anomaly" as described by her children, with intellectual pursuits for an entire extended family. Al'tshuler had a brother, Sergei (1909-1979), who was a science historian and a sister Olga (1912-1992), a chemist. In the early years, Vladimir Al'tshuler did a number of tasks in support of the revolution. At one point in time, he was given the assignment of delivering a certain sum of money to V. I. Lenin, at that time residing in Zurich. Upon arriving in Zurich, the elder Al'tshuler deposited the funds at a storage facility at the Zurich railway station, and set out to find Lenin. Upon finding him, Al'tshuler suggested that he might join him for a cup of tea. Lenin immediately demanded that Al'tshuler return to the station and recover the money and bring it to him. "Then, we can talk about a cup of tea".

Figure 1-1: L. V. Al'tshuler's Parents: V. A. Al'tshuler and Anna L. Kershner-Al'tshuler, Moscow, 1945

Lev Al'tshuler was home schooled from age 7-10, and from 10-17 attended state schools. It was here he first met Veniamin Tsukerman, who was to play such an important role in Al'tshuler's life. Tsukerman recalls, "When we were in school, I first saw Lev Al'tshuler engaged in a heated argument with another student. No sooner had I turned away when an inkwell shattered against the wall." I thought to myself, "I like the quickness of reaction. This one is always able to stand up for himself. Now, our friendship can begin."

Al'tshuler graduated with a diploma of "Foreman in Construction." He was ordered to a collective farm in the Volga River Region, with orders to construct pig sties. This effort was a failure because as Al'tshuler reminisced later, "I couldn't set the fence posts straight." Discouraged, in 1932, he returned to Moscow to look up his friend Tsukerman. Tsukerman invited him to work in the Roentgen laboratory of the "Evening Machine-Building Institute." (This laboratory was eventually moved to the Soviet Academy of Sciences in 1939.) Tsukerman had also been able to bring Vitaly Ginzburg into the laboratory in 1931 as a 15 year old boy with no prospects. So, Tsukerman brought both Al'tshuler and Ginzburg into his laboratory when neither had viable prospects for further education – not to speak of meaningful employment. Thus began a friendship between these three men, which lasted for half a century.

Al'tshuler's first science teacher at the laboratory was Evgeniy Bakhmetiev, the lab director who was seized and imprisoned in 1935, and perished as a victim of Stalin's purges. He had originally hired Veniamin Tsukerman as a young engineer to his laboratory in 1930. He exerted a strong influence on Al'tshuler in his earliest years. As mentioned previously, at this laboratory, Al'tshuler first met Vitaly Ginzburg, the future Nobel Laureate when both were hired together. Al'tshuler entered Moscow State in advanced placement as a junior in 1934 and he graduated in 1936 as a physical metallurgist in the x-ray analysis section of the Physics Department. He remained at what had become Tsukerman's laboratory after the loss of Bakhmetiev in 1935. The lab was moved to the Academy of Sciences' Institute of Engineering in 1939. The laboratory was then assigned the task of using flash x-ray sources to image bullets and other rapid moving objects. At this time Ginzburg moved over to the Lebedev Institute.

After the German attack on Russia on 22 June 1941, Al'tshuler was mobilized and was assigned to the Air Force branch of the Red Army as a senior mechanic-lieutenant in the bomber force. In 1942, at the request of the Academy of Sciences, 1,000 scientists were recalled from the front and evacuated to Kazan' and Al'tshuler was one of the 1,000, and was assigned to the Academy of Sciences Laboratory headed by his friend Tsukerman. (Al'tshuler, wife, and son are show in Kazan' in Figure 1-2.) In this facility he first met Yakov Zel'dovich and Yuli Khariton.

Figure 1-2: Senior Mechanic Lieutenant Lev Al'tshuler, his wife Maria Speranskaya and son Boris in 1942, after evacuation to Kazan'

Conditions were drastic at Kazan' initially. Veniamin Tsukerman provided some of his own lodging for Al'tshuler's sister Olga and her family, several of whom were in poor health. He also made sure that Al'tshuler had the very best co-workers. Initially, these were K. K. Krupnikov and S. B. Kormer.

The laboratory had responsibility for addressing various issues applying to the ongoing conflict. The first problem Al'tshuler was assigned was to investigate why German antitank projectiles were so effective against Russian tank armor. He and Tsukerman did flash x-ray radiography of artillery shells and found that the German shells used multiple jet effects to achieve maximum damage. For this accomplishment, the two researchers received their first State Award, and a personal commendation from Igor Kurchatov. Eventually, in 1946, Khariton invited them both to join the Soviet atomic project at Sarov, just getting organized.

Ginzburg, however, was not asked to join the Sarov project until 1948, being considered politically suspect. He had been forced to remain in isolation because his wife, Nina Ermakova was repressed in 1944 and charged with anti-Soviet activity. Ginzburg married her in 1946, when she was in exile in Gorky. She had been charged with planning to assassinate Stalin, but when the KGB found her window opened to an interior courtyard the charges were reduced. But she was still sentenced to internal exile after three years in prison – a sentence reduced to nine months. All charges and penalties were dropped after the death of Stalin in 1953. Nevertheless, Ginzburg was asked to join Andrei Sakharov as part of Igor Tamm's group at the Lebedev Institute, which supported Khariton's project at Sarov.

In the spring of 1947, Al'tshuler moved to Sarov, north of Moscow to join the Soviet Atomic Project. This city was associated with the retreat of an 18^{th} century Russian holy man, Saint Seraphim Sarovsky. He brought his family with him – his wife, Maria Speranskaya (1916-1977) and two sons, Boris (b. 1939) and Alexander (b. 1945). A third son, Michael, was born at Sarov in 1955.

In 1946, Igor Kurchatov had been placed in charge of the Russian Atomic Project, under the surveillance of Lavrenty Beria, head of the KGB. At the Sarov site, the leaders were Yuli Borisovich Khariton, Yakov Zel'dovich, later on, Andrei Sakharov, Igor Tamm (who remained at the Lebedev Institute in Moscow), and others. In the beginning, Zel'dovich organized the theoretical effort and Tsukerman organized the experimental effort. Of course the goal of the effort was to see how much energy from high explosives detonation was required to compress fissile material to the critical mass required to achieve nuclear fission. Soon US data and details were made available through espionage. This type of information was held very tightly; for example, it was not available to Al'tshuler or Sakharov, but was available at first to Kurcharov and Khariton, and later on, to Zel'dovich.

With the organization just beginning to be formed, it was decided that the Russian program should be based on duplicating the American results. Since the information on the US A-bomb was considered intelligence, the only scientists aware of this decision were Kurchatov and Khariton. This created certain problems. Al'tshuler argued that a design he could do would be far superior. However, since failure was not an option, it was necessary to go with the successfully tested (by the US) design. However, the Russian team was not allowed to accept these intelligence retrievals at face value (although they did not know the origin of the material) – they were required to check them very thoroughly. This procedure was puzzling to Al'tshuler and others, until they understood the reason for it many years later.

In addition to his overall responsibilities cited previously, Tsukerman took charge of an experimental division whose function was to carry out "hydro" shots (nomenclature used by Western weapons researchers), using pulsed x-ray techniques developed with Al'tshuler previously. His collaborators were Arkady A. Brish, Vera Sofina, Diador Tarasov and Marya Manakova. Other techniques used were explosive flash driven photography directed by Ilya Sh. Model', and electrical contact shock wave diagnostics by K. K. Krupnikov. This work continued later under N. G. Makeev and Y. M. Makarov.

Evgeniy K. Zavoiski ran a division using electromagnetic methods for measuring the velocity of explosion products and from this to derive the detonation pressure inside the charge. This technique was used extensively at the ICP at Chernogolovka in later years, where high explosive research was carried out, much of it supporting the activity at Sarov.

Al'tshuler had responsibility for equations of state. Here he worked with spherical implosion systems about 20 cm in diameter, immediately producing multimegabar pressures. All development of equation of state techniques was carried out under Al'tshuler's direction. His group included his personal colleagues from Kazan'; including Samuil B. Kormer, who with Zel'dovich mastered the measurement of temperature behind shock waves. His other Kazan' co-worker K. K. Krupnikov was joined by Boris Ledyenov, Anna A. Bakanova, M. N. Pavlovskiy, R. F. Trunin, and A. I. Funtikov.

Kiril I. Shchelkin directed the division of full-scale field test prototypes, assisted by his deputy Viktor I. Zhuchikhin. Shchelkin himself was the discoverer of "Spinning Detonation," striking evidence of detonation instability in gas phase detonations. (The same effect in solids was observed at Livermore by A. Kusubov of the USA in 1967.) The prototypes were exact copies, 1.5 to 2.0 meters in diameter, of the fission device designs, but U238 (ρ=19 g/cc) was substituted for U235/Pu 239. For alpha phase plutonium, a U238 alloy of the appropriate (reduced) density was fabricated at the Solid Alloy Plant in Moscow and used in the prototypes.

Following the direction of Yuli Khariton, the Soviet replica of Fat Man was constructed, fielded and tested successfully on August 29, 1949. After this successful test, Khariton promised

Al'tshuler that after his team carefully analyzed the data from this test, he would be able to design the second test device. This device using his design was fielded and tested on September 25, 1951. This device, "Joe 2," was half the size and weight of the initial test, called in the West "Joe 1," and had twice the yield of Joe 1; 38 kilotons to 22 kilotons.

Khariton was a different kind of leader than is usually encountered in such massive activities. He felt that not only should science serve defense, the converse should be true. He phrased this approach in programmatically styled verbiage " We must know ten times more than we need (to know) today". This policy in place at Sarov enabled Al'tshuler to begin his fundamental research in dynamic high pressure in addition to his programmatic responsibilities. The primary weapons program personnel were often prominent scientists, unlike the situation in the West after 1950. The same situation held for the second Soviet nuclear weapons laboratory started under E. A. Zababakhin, with E. A. Avrorin, Vadim Simonenko and B. K. Vodolaga having major responsibilities there. This second laboratory was not started until several years later, so that in the earliest years, Khariton was the director of the Sarov facility, with responsibilities quite similar to those of J. Robert Oppenheimer, a fact that Khariton himself pointed out years later on the occasion of his visit to Los Alamos. He was much honored by his countrymen, and received a full state funeral after his death. Academician Vladimir Fortov has generously supplied photographs of this occasion, shown in Figures 25-2 to 29-2 of Appendix 2.

It should also be noted that Al'tshuler's friend and sponsor Veniamin Tsukerman was completely blind. He told the time by means of a mechanical dial where he could "feel" the time. He learned speed typewriting with two hands. His wife, Zinaida Azarkh, prepared his lectures. He memorized them and was able to exhibit his x-ray shadowgraphs with the help of indentations placed on the film. This deception was so effective that at a seminar in 1944 attended by Ioffe, Tamm, Landau, Zeldovich, Semenov, Pavlov, and Shalnikov at the time his work was being evaluated for a state prize no one was aware that anything was amiss. After the presentation, Landau and Shalnikov came to complement him on his talk. Shalnikov commented that Tsukerman's eyesight must have improved since their days together in Kazan. Sadly, Tsukerman had to confide in his friends, admitting the reality of the situation. His life story has been the subject of a separate biography, as will be mentioned later. Years later, after the end of

WWII, he was involved in smuggling streptomycin from the Mayo Clinic, going outside official channels, in order to save his daughter Irina's life who had tubercular meningitis. This medication also saved the life of many Russian children. Irina became deaf as a result of the large amounts of medication she required to save her life. Tsukerman then became a leader in developing techniques to help deaf people. Years later, Tsukerman dictated his memoirs to Arzakh describing these events; they were published in Russia at the time of the two archives used as the background for this article, and give a description of some of these events from Zuckerman's perspective. They are now available in an English translation.[10]

In the period 1945-1966, Al'tshuler and his colleagues were considerably ahead of their American counterparts in achieving ultra high pressures in dynamic high pressure experiments. This disparity was not evident until the first publication of his work. In fact, his first publications[11] followed those of US investigators,[12] indicating that not only had the initial US publications allowed Al'tshuler to request permission to publish his own work, but also let him show the achievements of the Soviet scientific team. He published a comprehensive review of his work in 1965,[13] and this paper quickly became required reading for those entering this field in Russia- and in the West. A comparison of early results with US work is shown in Figure 1-3.

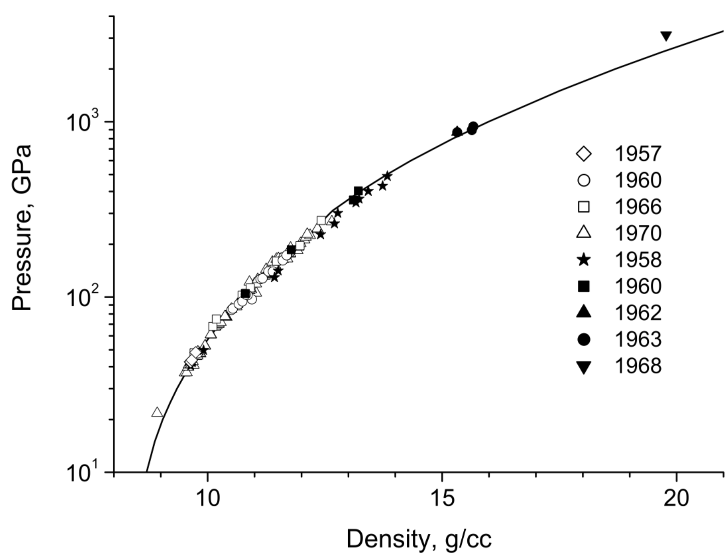


Figure 1-3: Comparison, US (open points) and Russian (solid points) Shock Hugoniot data for Iron, to 1968.

Confronted by this pressure disparity between US and Soviet work, in 1959, J. M. Walsh, a leading Los Alamos investigator, wrote directly to Al'tshuler with 16 questions. Al'tshuler answered 15- the question left unanswered was "How do you achieve such high pressures?" The question was, in fact, answered several years later, but eventually became understood by US investigators.

The Soviet scientists had to invent much of their efforts "from scratch". Fortunately, Tsukerman was an experimental genius with an incredible talent for improvisation. Differences were sometimes found between the theoretical calculations and experimental results. These differences were always ironed out after intense and often combative arguments.

At the same time, research on thermonuclear weapons was going on. Sakharov has written about "the Three Ideas" in his memoirs. The first idea was the "sloika" (alternate layers of fusion and fission fuels- also called "layer cake") and the second idea was Vitaly Ginzburg's 1948 suggestion of the use of Li^6D as the thermonuclear fuel. These ideas were combined in the Soviet test of the first deliverable hydrogen bomb on August 12, 1953. Al'tshuler was asked to provide EOS data for the device detonated in this event, but he demurred, arguing that the conditions for fusion were so extreme that they could not be realized in the laboratory. "You must rely on your best theoretical equations of state", he advised.

The Soviet team was well aware of radiation transport as a mechanism for compression of the thermonuclear charge from an idea first proposed by Fuchs and John von Neumann at Los Alamos in about 1945, which eventually became a figure in a classified 1946 Los Alamos report. Actually, this figure had been provided by Klaus Fuchs for that report, as Fuchs was the report secretary. At first, there was some uncertainty as to that authorship of that drawing as none of the report authors could recall having inserted it. Los Alamos personnel eventually found that that Fuchs was responsible for it. By the time the issue arose, Fuchs was not available for comment. He had told his Russian contacts when he delivered this information that the concept was one he and von Neumann had worked out at Los Alamos. The Fuchs-von Neumann configuration in the report was one for which radiation compression would have been the only credible method of achieving fusion. Radiation compression was what Sakharov called "the third idea". So, in the Soviet Union, radiation compression was an option that was always around in the early years. It was called by the Russians the "Fuchs-Neumann" approach.

The Russian thermonuclear effort for some time consisted of trying to improve the "sloika" scheme, an idea of Sakharov tested in a deliverable version on August 12, 1953. At the same time, there was a study of a "stick deuterium burn", which involved setting off a thermonuclear detonation wave which would propagate along a cylinder of thermonuclear fuel, called in the US the "Runaway Super" a version of a concept attributed to Edward Teller. Attempts were made to precompress this fuel by, among other things, using shock hydrodynamic means, a technique proposed by Ulam in the US, but found to be unworkable. Zel'dovich eventually realized that the energy provided by shock compression raised the fuel temperature and pressure to very high levels but did not provide the compression required for fusion. In the US, Alder, interestingly enough, described this point in some detail,[14] showing why high compression could not be attained using shock hydrodynamic means. Also there were concerns with the stability of propagating detonation fronts; if we were to initiate a thermonuclear detonation front in an uncompressed thermonuclear fuel, could it propagate indefinitely? Zeldovich was aware of the role detonation stability played in conventional explosives where a one-dimensional detonation cannot propagate indefinitely. Finally after discussions with D. A. Frank-Kamenetskiy, who understood atomic opacity issues, a key part of the radiation transport calculations, and with others, this "third idea" was addressed in early 1955 by a review panel. This panel consisted of Igor Tamm, Chairman; Vitaly Ginzburg, Yakov Zel'dovich, Mstislav Keldydsh, Mikhail Leontovich, Andrei Sakharov and Isaak Khalatnikov- three future Nobel Laureates and a president of the Soviet Academy of Sciences. The panel decided in favor of the idea, even though they realized that if the idea didn't work, there would be repercussions. As to Vitaly Ginzburg, he had agreed to serve on the panel, because he knew he would be reunited with his friends Al'tshuler and Tsukerman, as shown in Figure 1-4. It should be noted that although Frank-Kamenetskiy came up with several interesting approaches for implementing the third idea, they were not deemed to be practical. The original Fuchs-von Neumann geometry was decided upon. Nevertheless, it was Frank-Kamenetskiy's knowledge of molecular and atomic opacities that played a key role in the deliberations of the panel.

Figure 1-4: Vitaly Ginzburg, Lev Al'tshuler and Veniamin Tsukerman in front of the Tsukerman cottage, Sarov 1955, after the panel evaluation of the "Third Idea" cited by Sakharov.

After the favorable review of the idea by the panel Sakharov proceeded forward with the third idea using the Fuchs von-Neumann configuration, and immediately commenced work with Yakov Zel'dovich. A device using this idea was successfully tested on November 23, 1955. This brought the Soviets into rough parity with the US.

During this time, encouraged by Yuli Khariton, Al'tshuler was proceeding with series of his own dynamic high pressure experiments. The data and experimental procedures to design, field and test nuclear devices had been established. He now branched out to expand knowledge of materials at very high pressures and temperatures, and enhance the technological and scientific base of the Soviet program.

The equations governing shock wave are given in Courant and Friedrichs.[15] They are:

(1) $$v = v_0\left(1 - \frac{U_p}{U_s}\right)$$ conservation of mass

(2) $$p = p_0 + \rho_0 U_s U_p$$ conservation of momentum

(3) $$\Delta E = \frac{1}{2}(p + p_0)(v_0 - v)$$ conservation of energy

p = pressure, Megabar (1 Mbar = 10^{12} dynes/cm;= 10^{11} Pascal, 100GPa)

ρ = density, gm/cc

v = specific volume, cc/gm

E = specific internal energy (Mbar-cc/gm = 10^{12} ergs/gm)

U_p = particle velocity, cm/μsec

U_s = Shock velocity, cm/ μsec

The set of p, v and E are not a complete thermodynamic set. It is necessary to apply an equation of state (EOS) theory to obtain the complete EOS at the shock Hugoniot point. A way of getting around this is to observe the state of the shocked material upon release, since the release process is isentropic. That means the entropy at release is the same as the entropy of the shocked state. So, in the shocked state, this procedure gives p, v and S, a complete thermodynamic set. This procedure was exploited extensively in Russia from the early years on, and extended it into the plasma region. No equivalent body of published work exists in the West.

Al'tshuler, Bakanova and Dudoladov discovered irregularities in the shock wave data on rare earth and alkali earth metals, indicating electronic shell effects.[16] E. B. Royce in the US made similar observations. His work was rejected initially by Physical Review Letters with the reviewer, Harry Drickamer stating that "…the paper would be of interest only to high explosive buffs." On the other hand, the cited Russian work was published immediately by JETP Letters. Royce's work was available in the same time frame[17] but was not published in the open literature until 1973,[18] although references to it were published in the proceedings of a 1967 conference.[19]

Kormer, having mastered the techniques for making direct determination of temperature behind a shock front, was able to show, with Zeldovich, that the conductivity observed in shocked ionic crystals was due to excitation of electrons from donor states associated with dislocations created by the shock front.[20] Thus, conduction electrons were being excited across an energy gap much smaller than the intrinsic gap. This preceded work by Ahrens on MgO.[21] Although these references were published after the Kormer work cited previously, all three mechanisms proposed by Ahrens were wrong.

Al'tshuler and colleagues summarized the totality of the accomplishments of the Russian program in detail in a lengthy recent review.[22] The full list of references based on Al'tshuler's pioneering work must be two- or three hundred. For the most part, each publication represented a major experimental effort. A comparison of Russian and US work on iron by 1993 is shown in Figure 1-5.

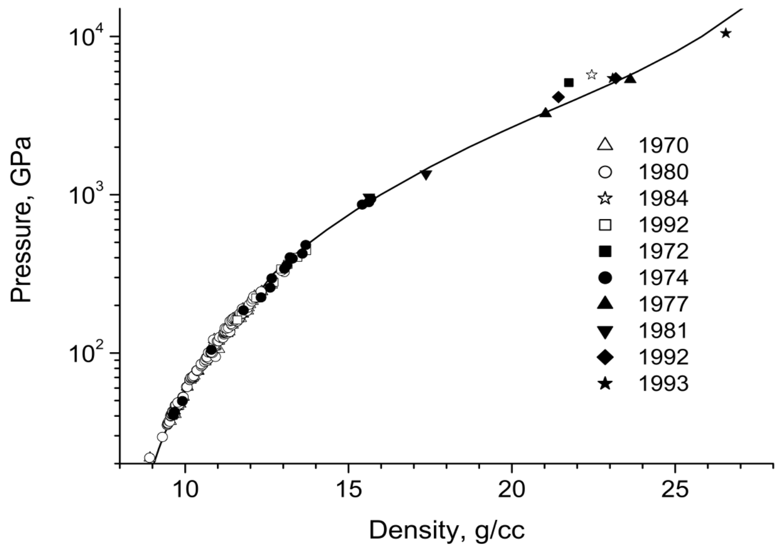


Figure 1-5: Comparison, hugoniot of iron, US Russian work to 1993. Open points, US work, solid points Russian. Note highest US point, work of C. E. Ragan, LANL

At first, his work applying shock wave techniques to a broad scope of physics problems took a long time to be recognized in the West. After Walsh's first letter and response, Los Alamos concentrated on routine EOS measurements. That scientific staff remained more or less static until about 1980. However, in 1960, Berni Alder[23] (shown in Figure 1-6) realized, even before the publication of Reference 8, that the techniques described by Al'tshuler had immense potential for application to physics issues, and immediately started to recruit personnel for the Livermore Laboratory to pursue this area.

Figure 1-6: Professor Berni J. Alder, University of California. Alder was awarded the National Medal of Science on October 7, 2009, by President Obama.

The situation at Livermore evolved as follows. In 1952, when Livermore was founded, Roy Goranson was brought from Los Alamos to take over EOS research. At that time, J. M. Walsh took over the Los Alamos work. Tragically, Goranson took his own life in 1953. In 1956, Alder brought Russell Christian to Livermore from Los Alamos to complete Ph.D studies with the expectations that he would remain to take over EOS activities, but after obtaining the degree, he left Livermore to join Mission Research Co. Alder agreed with the Lab Director to find someone to take this responsibility, and in 1961, Russell Duff came from Los Alamos to Livermore to take over the work. At about this time, Walsh left Los Alamos, and R. W. McQueen became the leader of the LASL effort. Historically, the US effort began to shift toward the use of two stage gas guns, pioneered by William Isbell and others,[24] and some rather sophisticated techniques introduced at Livermore, while Los Alamos concentrated until 1980 on more routine EOS while the Russian group extended their work to ever higher pressures and temperatures. Note was taken by Al'tshuler of some exceptional work by C. E. Ragan of Los Alamos who carried out experiments as a part of some nuclear explosive tests.[25] A comparison of the US-Russian work to 1993 is shown in Figure 1-5. These experiments brought US investigators closer to the highest pressures attained by the Russians. It should be noted, however, that although the Soviets continually reported higher pressures than Western investigators could reach, the accuracy of these results was never specified, and to field a large series of such experiments would have been very costly for US investigators. In any case, in 1988, W. Nellis had to admit his complete failure in an attempt to understand how the Russians attained such high pressures.[26]

A report on the developing Livermore work with a review and basic tutorial was given in a set of lectures at the Enrico Fermi School in 1969.[27] The tutorial aspect was emphasized because of the significant numbers of students attending.

Los Alamos experienced an increase in scientific effort from 1979-1998. During this same period of time, the Russian program became even more intensive and sophisticated. A good review of the Russian work up to the 2005 with comparison to US efforts was recently published.[28] As to the present time, most labs (except the Russian ones) are inactive in the EOS field.

Al'tshuler had his own set of difficulties at Sarov. In the later years of Stalin, attempts were made to bring physics into consistency with Marxist principles. Relativity was denounced as "Bourgeois romanticism"; quantum mechanics as "cosmopolitan fancies". Al'tshuler recalls the Nobel Laureate Igor Tamm losing his temper after having read some Party reports denouncing some of the aspects of modern physics.

Al'tshuler's run-in with the Party came during a visit of party officials to Sarov in 1950. When they asked Sakharov what he thought of Mendelian genetics, he responded that the theory seemed scientifically correct. There was a nervous flutter among his questioners, but no one dared to object to his statement. Al'tshuler was another matter. He went further in his statements, criticizing Lysenko, an agronomist in great favor with Stalin, but who was responsible for vast agricultural failures in the Soviet Union, Al'tshuler was immediately scheduled to be banished from the project- perhaps to the camps, until Sakharov interceded in his behalf with events eventually escalating to a late night call from Lavrenty Beria. After some prodding from Kurchatov, Beria took all these incidents directly to Stalin, who was in a rare magnanimous mood. He advised Beria to "Let the physicists go on about their business. We can always execute them later."

After these incidents, Al'tshuler spoke out on various human rights issues, including the Hungarian revolt in 1957, the Arab-Israel conflict of 1957 and the Czech Spring in 1968. Of course, after Stalin's death in 1953, conditions eased considerably and mass amnesties were declared. In any case, Lev Al'tshuler departed Sarov in 1969, by coincidence, on the same train as Andrei Sakharov. (This departure is shown in Figure 1-7.) At this time, Al'tshuler was proposed for the Soviet Academy for the final time. Although he had strong support, Communist officials intervened and prevented his election. At this point, Al'tshuler joined V. E. Fortov and collaborated with him during the rest of his active scientific life.

Figure 1-7: Lev Al'tshuler on his last day in Sarov, October 16, 1969 Note the historic monastery towers of Saint Seraphim Sarovsky in background. Andrei Sakharov departed Sarov the same day.

It should be noted that even today, in Russia, Lev Al'tshuler is considered to have been one of the very great ones. After a short time, after leaving Sarov, Al'tshuler joined the Academy of Sciences Institute of High Energy Densities and remained active there until his very last years. He remained close to Sakharov and Elena Bonner, spending much time with them over the years, and met them on their return from exile-see Figure 1-8.

Figure 1-8: L. V. Al'tshuler, Elena (Lusia) Bonner, and Andrei Sakharov, on their return from internal exile

An amusing story is told about Sakharov and Al'tshuler's initial meetings after his return to Moscow from internal exile. Sakharov told Al'tshuler that they could discuss highly classified nuclear matters, since they had been both cleared for such information at the highest levels. However, Sakharov pointed out that they really could not have such discussions after all, since "The people tapping our telephones and listening through the wall are not cleared."

Boris Al'tshuler received the Ph.D. in physics at Sarov, with his mentor Sakharov "opposing" his thesis. This is a Russian custom where one individual is chosen to be in charge of critical questions during the Ph.D. exam. When Al'tshuler left Sarov, Boris had to take a job cleaning the streets. Upon his return from internal exile, Sakharov brought Boris Al'tshuler to the Lebedev Institute as a member of its theoretical section, where he remains today.

Later on, in 1985, Al'tshuler greeted a frequent visitor to his house, who came to obtain handouts of food. Seeing a portrait of Sakharov over Al'tshuler's bed, he pointed to it and said "There is Sakharov, who sold out to the Bolsheviks." At that moment, Al'tshuler's beloved dog, named "Sharik" leaped out from under the bed and bit the man on the leg. Al'tshuler loved to tell this version of the story but his son Boris surmised that that the dog was awakened by the ensuing argument, and sensing his master's anger, bit the object of his master's invective.

The first encounter Al'tshuler had with Westerners was in 1974 in Moscow, when Berni Alder requested a meeting. Al'tshuler arrived, but after about 10 minutes, armed guards arrived and whisked him away. In the hopes of having more successful meetings with Al'tshuler, Alder asked Academician L. F. Vereshchagin to invite US delegates to an upcoming meeting in Moscow scheduled for June, 1975. This happened, and here, a number of Western scientists were able to meet and discuss physics topics with Al'tshuler, Kormer, Gandelman and others. In the Appendix, Figures 17-2 and 18-2 are shown of that meeting. Photos are also available of all the participants.[29] Shown in Figures 19-2 and 20-2 are Al'tshuler, Kormer, Gandelman, and V. E. Fortov.

The citation Al'tshuler valued the most was the one delivered at the Enrico Fermi School in Varenna, Italy in 1969, by Edward Teller citing Al'tshuler as "... one who has done the most in opening this new field." (High dynamic pressures; see Ref. 20, p 1) In Russia there is no controversy about Edward Teller in the physics community-he is considered to be one of the great physicists of history.

Finally, Lev Al'tshuler received the American Physical Society Shock Wave Award in 1991. This presentation is shown in Figure 1-9. This was appropriate since Al'tshuler was the world leader in the field for his entire active life.

Figure 1-9: John W. Shaner of Los Alamos presents the 1992 Shock Wave Award of the American Physical Society to Lev V. Al'tshuler

As to Al'tshuler's basic motivation he recalls a conversation with a colleague when on a bright and sunny day, surrounded by people, both were feeling a strong sense of vulnerability after Hiroshima. His friend told him "These people-I cannot but help seeing them evaporating in the fire of an atomic blast-leaving those horrid human shadows in their place". At that time, "overtaking and surpassing" America in this area became Russia's basic priority.

But Al'tshuler also had concerns much later. When he first saw the lines of prisoners marching past twice daily, he recalled Mikhail Lermontov's line "the country of lords and slaves" to which his heroine Tatiana Vasil'evna rebuked the hero "You don't love Russia". What does it mean to love Russia? Al'tshuler recalled Pontius Pilate's unanswered question "What is truth?" Al'tshuler felt that there were only ambiguous answers to such questions. As to his isolation, Al'tshuler quoted Dante, it was a situation in which one could only "Lasciate ogni speranza".

The question of why the US, and the West in general has lagged behind Russia in certain areas; shock waves, pulsed power, turbulence and oceanography is complicated and has been dealt with elsewhere.[30] Al'tshuler had his own opinions about this, which he was circumspect about stating. He respected much of what was done by US investigators. Among close associates and friend he was more outspoken. He expressed these views at Paderborn in 1989 through a Thomas Fermi theoretician, Dr. Galina Shpatakovskaya, a fluent English speaker. He was waving two papers on the melting point of iron- one by Ahrens, the other by Brown and McQueen from Los Alamos. He made the point-emphatically- that the work of Ahrens on the melting of iron was flawed.[31] He was very impressed by the work of Brown and McQueen of Los Alamos[32] which enabled him to correlate his iron results with others in the field, clearing up some controversy in the matter. The authors were aware of the controversy from a previous Gordon Conference.[33]

He was also interested in a previous (1979) Livermore paper by Hawke[34] in which hydrogen became metallic at 2 Mbar and 400 deg. K, because it was based on the work of Sakharov and Pavlovskii, who pioneered these techniques (See plate 30-2). This Livermore experiment was analyzed in detail by Max Fowler[35] of Los Alamos the long-time US leader in high magnetic field physics, who independently verified the procedures and results obtained. The Pioneer

Saturn flyby also verified Hawke's work in that it showed, with the discovery of a Saturnian magnetic field, the existence of metallic conducting hydrogen in Saturn's planetary core, providing the basis for a geomagnetic dynamo. Previous thinking was that Saturn would have no magnetic field, based on the general belief that hydrogen remained an insulator up to at least 10 Mbar. Some further details about this work are discussed in Appendix I.

Another problem was a perception by static high pressure researchers in the US that shock wave work was something for "high explosive buffs", as stated by Harry Drickamer, long the dean of US High Pressure scientists. Drickamer was burly, forceful and intimidating- a notable presence. In lengthy discussions, he argued that first-rate work in high pressure was carried out at universities, and shock wave specialists were generally doing unexceptional work as government contractors. However, at Paderborn, one of us (RNK) introduced him to Lev Al'tshuler. He listened to his talk and those of other Russian investigators and his attitude began to change. Drickamer hated to lose arguments, and so he jokingly conceded the point as far as the Russians were concerned, but said he would withhold judgment on the US investigators. As time passed, however, Drickamer was seen actively and enthusiastically participating in discussions where shock wave work of US investigator was being presented at US high pressure meetings.

In this connection, there was a lack of critical review in the Western literature. Reviewers were often willing to take Livermore claims at face value. One of the worst was the journal "High Pressure Research'. The first editor of this throwaway journal was Marvin Ross. As we now know, Ross prevented Zeldovich from being a candidate for the 1987 Bridgman Award; then, after Zeldovich had died a year later, Ross deleted most of an obituary for Zeldovich that had been submitted by Andre Kusubov, reducing it to a few short sentences.[36] The complete obit for Zel'dovich initially submitted (but subsequently abridged by Ross) to High Pressure Research, is published in its original version in this journal.

As mentioned previously, Russians have commented critically (but discretely) on US work; this was discussed in Reference 30 in the general sense. For the high pressure field, two examples are discussed here. The work of Mao and Hemley, both noted static high pressure scientists, will be discussed later. In the separate case of "Shock Induced Cooling", a theoretical explanation was published by Ross and Radoushky in *High Pressure Research* in 1988. This paper cited the active participation of W. Nellis. Submitted by the editor, there is no evidence that the paper was ever reviewed, because the principal paper in the area, “Shock waves in fluids with an arbitrary Equation of State”, Hans Bethe, Office of Scientific Research and Development Division B, Report No. 545, 1942, was not cited. (This is Reference 7.) Confronted by this omission, Bethe refused to read the paper. The investigators could have plugged their EOS into Bethe’s theory and seen if cooling could be observed. In fact, under certain anomalous conditions, temperature along an isentrope can decrease with increasing pressure. This can be true for a shock hugoniot, as long as the Hugoniot is very close to the isentrope. But at the extreme conditions discussed, this is not the case. The basic error here was that when someone claims an effect that is clearly counterintuitive, it is incumbent for the investigators to do all they can to establish the credibility of their data. Some of their data are suspect, as the Russians were not able to duplicate it. At one point, Nellis asked Shaner to verify his data; Shaner declined. “If we agree, I’ve done nothing new-if we don’t we will still disagree.” Another bizarre twist was the citation by Ross of liquid helium at 4 deg. K. where shock induced cooling was noted. Probstein provided assistance to the authors with the basic references applying to this alleged phenomenon. He suggested that in liquid water from 0 Deg. C. to 5 Deg. C., the effect might exist.

There is a tremendous amount of archival material becoming available on Al’tshuler and his colleagues, in the Russian language and not readily available. Many of the earlier publications from the US side were not authored by scientists and were undertaken with a set of preconceived notions. One of the worst was of these was by Hirsch and Matthews.[37] For years later, these two continued to frantically defend their initial claims, as one after the other was shown to be wrong.[38] Another one of the worst of these was William Broad.[39] Every point he made in the cited reference was simply wrong. Another writer in that same category was Richard Rhodes.

Probably the worst example of this was a book by Rhodes “Dark Sun”. Unfortunately it followed the publication of Reference 8. Rhodes and Holloway visited Russia at the same time, but although Holloway knew who to talk to and what questions to ask. Rhodes seemed to be adrift. This book was full of derogatory comments about major US personalities and references which when checked did not reveal the assertions made. Rhodes was the author of the Pulitzer

Prize Winning book "The Making of the Atomic Bomb", which has been characterized as a "Historical Novel"; historically correct but with imaginary conversations. As an aside, in a reference ten years ago, Rhodes attacked Stanley Prusiner, Nobel laureate for prions, (Mad Cow disease).[40] He made several objection, all of which were refuted by 2004. This was inexplicable to most other writers. One of them, realizing Rhodes' complete incompetence in the field, suggested he had a girl friend that didn't like Prusiner.

In a communication to the author,[41] Yuli Khariton addressed several of these articles, pointing out that they were simply wrong. He said that "…many of the American newspapers and reporters are tendentious when presenting the history of the Soviet nuclear weapons development. Probably, having not enough information, the publications of some American specialists are guilty of this too".

ACKNOWLEDGEMENTS

The insights on decisions made at Sarov in the early years were provided by Boris Al'tshuler, who, as a young physicist who was living with his parents in a closed city, was aware of the issues developing over time both with the Soviet program in general, and with his father personally, who was involved in these matters at the highest level.

The authors would also like to acknowledge with sincere gratitude, his assistance in providing us with volumes of documentation on his father's life. In particular, we wish to thank him for allowing us to quote from Lev Al'tshuler's 1994 memoir "The Lost World of Yuli Khariton" and his own 1994 tribute to Nobel Laureate Vitaly Ginzburg , presented to him on his 90th birthday "Three Friends: Lev V. Al'tshuler, Vitaly Ginzburg and Veniamin A. Tsukerman". By this time, both Al'tshuler and Tsukerman were deceased, and the memoir was presented by Boris Al'tshuler. These documents are still not readily available in the West. Also, he made available valuable archival files on the early life of Lev Al'tshuler.

We are indebted to Academician Vladimir Fortov for making available the photographs of the funeral and memorial services for Yuli Khariton.

The authors would like to express his thanks to John Shaner for some useful suggestions which will be implemented in a shorter version to be published elsewhere.

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APPENDIX I

As mentioned previously, Russians have commented critically (but discretely) on US work. This was discussed in Reference 30 in the general sense. For the high pressure field, two examples are discussed here. The work of Mao and Hemley, both noted scientists, will be discussed later in this Appendix. As mentioned previously, in the separate case of "Shock Induced Cooling", a theoretical explanation was published by Ross and Radousky in *High Pressure Research.*[42] This paper cited the active participation of W. Nellis. Submitted by the editor, there is no evidence that the paper was ever reviewed, because the principal paper in the area, "Shock waves in fluids with an arbitrary Equation of State," Hans Bethe, Office of Scientific Research and Development Division B, Report No. 545, 1942, was not cited. (Ref. 7) Confronted by this omission, Bethe refused to read the paper. The investigators could have plugged their EOS into Bethe's theory and seen if cooling could be observed. In fact, under certain anomalous conditions, temperature along an isentrope can decrease with increasing pressure. This can be true for a shock hugoniot, as long as it is very close to the isentrope. But at the extreme conditions discussed, this is certainly not the case. In Russia, Zeldovich viewed the proposal of shock induced cooling as being nonsensical.[43] A Russian attempt to duplicate some Livermore data on shock induced cooling was not completely successful.[44] No conclusion as to the validity of the theory was made.

While Los Alamos investigators played an important role in Hawke's work, comments of Mao and Hemley should be considered in some detail, as these investigators are first rate scientists, but are off base when criticizing technologies out of their field. The work of Hawke was carried out with the collaboration of leading groups at Sandia and Los Alamos, and was planned very carefully. The Mao and Hemley paper in Science[45] was featured as a "review of the long-standing quest for metallic hydrogen" and was the cover story. Actually, it was a review of their own work, which they indicated would lead to the creation of metallic hydrogen and a criticism of previous work. The work of Kawai was criticized, but in the 1966 Gordon Conference on High Pressure Kawai admitted that his use of carbonaceous gasket material created a direct short, giving a spurious indication of hydrogen conductivity. Next, the results of Yakovlev were cited, but the Russians rejected this work in a very public way (S. Ushakov, Literaturnaya Gazeta, June 25, 1986, No. 26 p.11. It was well known that his use of carbonado, with a significant metallic content led to shorting, not to speak of shear and compression differential between manganese-cobalt binding material and diamond. But these two examples were straw men, and were well known within that community. Of course Mao and Hemley were well qualified to criticize this work. It was when they began to address the work of Hawke (Reference 34) that they go astray, and their comments will be quoted in detail. (The following material was also presented at the 2004 Moscow Zeldovich Symposium, as Plenary paper PL-05.) The authors complain that ”although very high pressures can be attained in these experiments,… the pressure is maintained for only an instant.” Of course, Livermore investigators showed years ago by flash x-ray diffraction techniques that hydrostatic conditions are immediately obtained after passage of a strong shock front in solid crystals. What is most puzzling about this comment is that John Shaner of Los Alamos applied the use of the ruby scale for static high pressure work- but this information for the static scale was obtained from shock wave work- Mao was a co-author of that paper. So the scale he uses in his own work was calibrated by experiments in which “the pressure is maintained for only an instant”. Then the authors state that “the hydrogen was compressed by the rapid collapse of a powerful magnetic field The magnetic field was not collapsing; it was increasing to a very high level. The process is called “cumulating”. Another dubious statement they made is “neither the pressure nor the temperature of the experiment could be determined reliably, however, and the only measurement carried out on the hydrogen sample was an estimate (sic) of the conductivity.” In fact, the pressure is given directly by $P=B^2/8\pi$, and since the compression is isentropic, the entropy is known. The conductivity is measured directly, not estimated. So the conductivity increases suddenly when hydrogen is in the solid state at 2 Mbar and 400 deg. K- a clear indication of a metallic transition. As to questions of whether jetting and other phenomena could have given a spurious indication of metallization, Hawke did similar experiment on neon, cited in Reference 34. Neon remained an insulator up to 5 Mbar. As an aside, contrary to the hopes of Mao and Hemley, Salpeter has shown that metallic hydrogen cannot be stabilized upon release to normal ambient conditions.[46]

Both Mao and Hemley are accomplished researchers- having both won many honors. Now they are confronted by dubious claims by Nellis of having obtained metallic hydrogen.[47] It was pointed out to Nellis by V. E. Fortov that in fact, what Nellis observed was a high pressure plasma phase transition, not metallization.[48] In fact, this type of phase transition was first described by Teller in 1977, and later observed by Zel'dovich.[49] Mitchell, who carried out the experiments, commented that "We didn't do enough experiments to know what we had."[50] Nellis did not cite the Hawke work because he did not understand the physics described in reference 34. Hydrogen was metallized at Livermore twenty years before Nellis' unsuccessful attempts. Hawke's work was cited by Fortov in his Einstein Gold Medal Lecture, and in Reference 28.

Many people have left the shock wave field. No one in the US except Washington State University and Sandia Corporation are currently doing such experiments- the field has lost much of its appeal, although the NIF offers some interesting possibilities. The Russians, however, are still quite active, but in somewhat different areas, and with different experimental techniques.

As to the magnetic flux compression experiment in question, Max Fowler of Los Alamos, a world leader in the field, was always an active participant in Hawke's work, and favorably reviews it in Reference 35. An attempt to duplicate this work as Los Alamos was a failure, due principally due to the untimely death of A. I. Pavlovskiy, and the fact that subsequently, the wrong personnel were chosen to carry it on.

Another verification was provided by NASA, as mentioned previously. Upon observing the abrupt increase of conductivity at the onset of metallization, Hawke contacted NASA's Pioneer spacecraft team to tell them to expect a planetary magnetic field of a comparable magnitude to Jupiter's. The Pioneer personnel, on the other hand told Hawke that if they detected a strong magnetic field in their Saturn flyby, that would verify his experiments. The background is that for many years, until Hawke's work, hydrogen was thought to metallize at about 10 Mbar. Jupiter was known to have an interior pressure of up to 30 Mbar, and so its Jovian van Allen belt was felt to be due to liquid metallic hydrogen, and an MHD driven dynamo, such as exists on earth. With Saturn, the pressure was thought to be between 3.5 and 5.0 Mbar, with no conducting core to support dynamo action and further, no evidence of a Saturnian magnetic field (Van Allen belt radiation) had been observed up to the time of the flyby. Of course, a strong magnetic field was observed by Pioneer, setting the hydrogen metallization pressure somewhere between 2- and 3 Mbar, and confirming Hawke's results.

This is just an example of the situation analyzed in Reference 30, which extends into many areas of science. Problems with the shock wave results cited previously were not easily verified and so could not be adequately checked and instead, slipped into the U.S. literature- except in Russia, where much of these US results were discredited. In some cases, static high pressure scientists criticized or reviewed dynamic work critically because of lack of knowledge or prejudice. (Drickamer, Mao, as cited previously). It must again be pointed out that in the US, static work has been much better recognized than dynamic work, probably because of superior personnel, and arguably more significant accomplishments.

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