ORIGIN OF ELEMENTS IN THE SOLAR SYSTEM

ORIGIN OF ELEMENTS IN THE SOLAR SYSTEM IMPLICATIONS OF POST-1957 OBSERVATIONS

Edited by

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by Glenn T. Seaborg and Oliver K. Manuel**

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Preface and Dedication

“Satyam eva jayate nanritan”
“Truth is victorious, never untruth”
Mundaka Upanishad, III.1.6

“From where did all this come?” has been one of the fundamental questions since the dawning of civilization. These proceedings record the diversity of opinions on this subject as the 20th century draws to an end.

When the landmark papers by Burbidge, Burbidge, Fowler and Hoyle (B₂FH) and Cameron on stellar nucleosynthesis appeared in 1957, the periodic table ended at element #101, the latest discovery of Ghiorso and co-workers. Experiments described here tell of the production of heavier elements in the intervening years, in labs at Dubna, GSI-Darmstadt and Berkeley. Element #114 was reported when this symposium was in the planning stages, and the Berkeley group reported the discovery of elements #118, #116 and #114 at the symposium. These proceedings also contain exciting new information from laboratory studies on the life-times and cross-sections of nuclides under extreme, stellar-like conditions, often far from the region of nuclear stability.

More stable nuclides are more abundantly formed in laboratory studies. “Fine-structure” elemental abundance peaks also occur in nature at multiples of the ⁴He nuclide, at iron (Fe), and at closed shells of nucleons. One issue debated here is whether this relationship between abundance and nuclear stability holds for the overall composition of the solar system. The answer depends if the solar interior ($\approx 99.8\%$ of the mass of the solar system) is mostly ¹H, the stable nuclide with the highest mass per nucleon, or ⁵⁶Fe, the nuclide with the lowest mass per nucleon. Several papers here suggest that

seismology, neutrinos and isotopic ratios from the sun may soon resolve differences of opinion on the sun's internal structure and composition.

Observations of the skies, particularly with the Hubble Space Telescope, have given us new details on the birth and death of stars and of planetary systems. The discovery of pulsar planets clearly illustrates one unexpected end product of a supernova explosion. The explosion of a nearby supernova, SN1987A, provides new details about the nuclear reactions that occur under these extreme conditions and the dynamics and composition of material ejected by supernovae. In these proceedings it is shown that the decay of doubly magic ^{56}Ni , rather than a heavy element like ^{254}Cf , dominated the light curve of SN1987A. Since ^{56}Ni is the parent of the most abundant iron isotope, ^{56}Fe , SN1987A has clearly demonstrated one way to make isotopic anomalies, short-lived nuclides, and a region rich in iron.

As the 20th century was ending, Professor Glenn Seaborg and I sought to bring together a blend of experimentalists and theorists from astronomy, chemistry, geology, physics and related disciplines to summarize the current understanding of the origin of elements that comprise the solar system.

Glenn Seaborg (Courtesy of Piermaria J. Oddone)

This volume is dedicated to the memory of the late Professor Glenn T. Seaborg, who agreed in April of 1998 to give the keynote address and to co-chair this symposium. Drs. Al Ghiorso and Ken Gregorich knew Glenn much better than I did. Their papers in this volume give great insight into the genius of this man and his influence on science, education, and government policies in the 20th century.

Although I hardly knew Glenn personally, his influence on my scientific career has been tremendous since April of 1976 when one of his former students, Vic Viola, attended the annual AGU meeting in Washington, D.C. There, two students of Professor Paul K. Kuroda were trying to convince the audience that isotopically “strange” xenon in meteorites came from nuclear reactions in the supernova (SN) that made our elements, not from later fission of a superheavy element (SHE) within meteorite grains. Knowing that his mentor would want to hear the debate on SHE vs SN, Vic invited me to speak at a San Francisco ACS symposium on the origin of the elements in the fall of 1976. That was where I first met Professor Seaborg.

The next year, Glenn asked me to comment on SHE vs SN at the Robert Welch Conference on Cosmochemistry. Over the next 20 years, “strange” isotopic ratios were found in several elements of meteorites and great advances were made in producing SHEs in the laboratory (*e.g.*, the first three papers in this volume). Glenn was eager to co-chair the 1999 ACS symposium where these observations would be discussed and a cross section of opinions at the end of the 20th century recorded in these proceedings.

Glenn personally invited many distinguished speakers but Death, the greatest teacher of all, intervened shortly before the program was completed and SHEs # 118, 116, ... were discovered in Glenn’s lab (Gregorich, this volume). Death itself teaches that, “*The all-knowing Self was never born, nor will it die. Beyond cause and effect, this Self is eternal and immutable. When the body dies, the Self does not die.*” (Katha Upanishad, I.2.18).

Following this tragedy, Professor Geoffrey Burbidge (this volume) graciously agreed to give the keynote address. Accompanied by his lovely wife, Margaret, these two towering figures firmly linked the discussion to the period when stellar nucleosynthesis was conceived, in the middle of the 20th century, to the time of the symposium, as the 20th century was drawing to an end.

In keeping with Glenn’s spirit, we adopted the following motto for the symposium: “*Satyam eva jayate nanritan*” (Mundaka Upanishad, III. 1.6). “*Truth is victorious, never untruth.*”

O. Manuel

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- **Doris Demerjian, Al Ghiorso, and Ken Gregorich** - close friends and associates of Glenn Seaborg - kept the forward momentum going during the difficult period of his illness and death and helped us bring the symposium to a successful completion.
- **Peter Armbruster** chaired the special session of the symposium in memory of Glenn Seaborg
- **Al Ghiorso** prepared the video about Glenn that was the highlight of the special session in his memory.
- **Ken Gregorich** told us about the culmination of Seaborg's career with the discovery of elements 118, 116 and 114 in his laboratory.
- **Geoffrey Burbidge** presented an eloquent and memorable keynote address on the synthesis of elements.
- **Margaret Burbidge and Truman Kohman** were present to share memories of pioneering work on the origin of the elements.
- **Carl Pilcher, Jack Larimer, Bin Li, and Greg Downing** gave important papers at the meeting but were unable to submit papers for publication in this proceedings.
- **Virginia Trimble and Akimasa Masuda** were unable to attend the meeting but contributed papers to this proceedings.

- **Kittie Robertson** and **Sherry Adams** handled daily planning and arranged for housing and the reception at the symposium.
- **Phyllis Johnson** typed and organized the proceedings. She was assisted by **Patty Chism** and **Ami Willett**.
- **Robert Johnson** helped with the symposium and the proceedings.
- **Paul K. Kuroda** and **The Foundation for Chemical Research, Inc.**, provided financial and moral support, as did **Bill Casey**, Chair of the Geochemistry Division of ACS and **Lester Morss**, Chair of the Nuclear Chemistry Division of ACS. **Madalyn A. Hardy** and others at ACS Headquarters helped with publicity.
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- Special friends, former and current students gave generously to the success of this undertaking: **R. Ganapathy**, **Marvin Rowe**, **Tom Ward**, **Ron Thompson**, **Koh Sakamoto**, **Calvin Alexander**, **Greg Downing**, **Golden Hwaung**, **George K.-Y. Chiou**, **Jiafu Fang**, **Vic Becker**, **Robert Ballard**, **Tadashi Shimamura**, **Uli Ott**, **Li Bin**, **Jauh T. Lee**, **Ken Windier**, **Yixiang Xie**, **Cara Lietz**, and **Robert Johnson**.
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Contents

Contributors	v
Preface and Dedication	xi
Acknowledgements	xv
Contents	xvii
PART I: GLENN SEABORG AND THE QUEST FOR SUPERHEAVY ELEMENTS	1
Ghiorso Remembers Seaborg ALBERT GHIORSO	3
Superheavy Elements at Berkeley: The Culmination of Seaborg's Career K.E. GREGORICH AND V. NINOV	21
The Discovery of Superheavy Elements 107-112 and of the Deformed Shell at $N = 162$ P. ARMBRUSTER	35

PART II: THE NUCLEAR REACTIONS THAT MADE OUR ELEMENTS	49
The Decay of ^{19}N D. W. ANTHONY, D. J. MORRISSEY, P. A. LOFY, P. F. MANTICA, J. I. PRISCIANDARO, M. STEINER, J. M. D'AURIA, AND U. GIESEN	51
Measuring the Astrophysics Rate of the $^{21}\text{Na}(p,\gamma)^{22}\text{Mg}$ Reaction JOHN M. D'AURIA FOR THE DRAGON COLLABORATION	63
Production and β -Decay Half-Lives of Very N-Rich Nuclei MONIQUE BERNAS	71
The Role of the $N = 28$ and $N = 40$ Closed Shells in the Production of the Neutron-Rich Ca-Ti-Cr-Fe-Ni Elements in the Universe O. SORLIN	81
Experimental Studies Related to s-Process Abundances K. WISSHAK, F. VOSS, C. ARLANDINI, AND F. KÄPPELER	93
Neutron Capture Cross Section Measurements for the Analysis of the s-Process ROBERT S. RUNDBERG, J. L. ULLMANN, J. B. WILHELMY, M. M. FOWLER, R. C. HAIGHT, G. G. MILLER, P. D. PALMER, F. KÄPPELER AND P. KOEHLER	103
About the Reliability of Extrapolation of Nuclear Structure Data for r-Process Calculations G. LHERSONNEAU, B. PFEIFFER, AND K.-L. KRATZ	111
The Astrophysical r-Process K.-L. KRATZ, P. MÖLLER, B. PFEIFFER, AND F.-K. THIELEMANN	119
Nuclear Aspects of Stellar and Explosive Nucleosynthesis THOMAS RAUSCHER, FRIEDRICH-KARL THIELEMANN, ROBERT D. HOFFMAN, AND STANFORD E. WOOSLEY	143
Proton Captures in the Atmosphere of Accreting Neutron Stars H. SCHATZ, L. BILDSTEN, A. CUMMING, AND M. WIESCHER	153

PART III: A COSMOLOGICAL VIEW OF NUCLEO-SYNTHESIS	165
The Origin of the Elements G. BURBIDGE	167
Chemical Evolution Tomorrow VIRGINIA TRIMBLE	175
LiBeB Nucleosynthesis and Clues to the Chemical Evolution of the Universe V. E. VIOLA	189
Measurement of the ^{44}Ti Half-life and its Significance for Supernovae I. AHMAD, J. P. GREENE, W. KUTSCHERA, AND M. PAUL	203
On the Half-Life of ^{44}Ti in Young Supernova Remnants ERIC B. NORMAN AND EDGARDO BROWNE	211
Abundances in SN 1987A and other Supernovae ROGER A. CHEVALIER	217
The Birth of Planetary Systems Directly from Supernovae WILBUR K. BROWN	225
Bipolar Outflows in Stellar Astrophysics ADAM FRANK	241
PART IV: NUCLIDES IN THE SUN	251
Mini-blackhole at the Solar Center and Isotopic Abundances in the Primitive Solar Nebula S. RAMADURAI	253
Abundances of the Elements in the Sun N. GREVESSE AND A. J. SAUVAL	261
Isotopic Ratios: The Key to Elemental Abundances and Nuclear Reactions in the Sun O. MANUEL	279

Critical Evaluation of CI Chondrites as the Solar System Standard of Elemental Abundances M. EBIHARA, K. SHINOTSUKA, H. OZAKI, AND Y. OURA	289
Sensitivity of Solar Oscillation Frequencies to Element Abundances JOYCE A. GUZIK AND CORINNE NEUFORGE	301
Inverse and Forward Helioseismology: Understanding the Interior Composition and Structure of the Present Sun CARL A. ROUSE	317
Heterogeneous Accretion of the Sun and the Inner Planets GOLDEN HWAUNG	345
Interstellar Matter, Sun, and the Solar System M. N. VAHIA AND D. LAL	351
PART V: NUCLIDES IN THE SUN'S PLANETARY SYSTEM	359
Isotope Anomalies in Tellurium in Interstellar Diamonds R. MAAS, R. D. LOSS, K. J. R. ROSMAN, J. R. DE LAETER, U. OTT, R.S. LEWIS, G. R. HUSS, E. ANDERS, AND G. W. LUGMAIR	361
Isotope Abundance Anomalies in Meteorites: Clues to Yields of Individual Nucleosynthesis Processes ULRICH OTT	369
Variation of Molybdenum Isotopic Composition in Iron Meteorites QI LU AND AKIMASA MASUDA	385
Iron Meteorites and Paradigm Shifts E. CALVIN ALEXANDER, JR.	401
Chronology of Early Solar System Events: Dating with Short-lived Nuclides JITENDRA NATH GOSWAMI	407
Xenology, FUN Anomalies and the Plutonium-244 Story P. K. KURODA AND W. A. MYERS	431
Extinct ²⁴⁴ Pu: Chronology of Early Solar System Formation MARVIN W. ROWE	501

<i>Contents</i>	xxi
A Search for Natural Pu-244 in Deep-Sea Sediment: Progress Report K. SAKAMOTO, Y. HASHIMOTO AND T. NAKANISHI	511
Strange Xenon Isotope Ratios in Jupiter K. WINDLER	519
Abundances of Hydrogen and Helium Isotopes in Jupiter ADAM NOLTE AND CARA LIETZ	529
The Possible Role of PeP Weak Interactions in the Early History of the Earth THOMAS E. WARD	545
Ce-Nd-Sr Isotope Systematics of Eucrites and Lunar Rocks MASAHARU TANIMIZU AND TSUYOSHI TANAKA	555
PART VI: THE ORIGIN OF THE SOLAR SYSTEM	573
Abundance of ¹⁸² Hf and the Supernova Model of the Solar System S. RAMADURAI	575
Binary Origin of Solar System M. N. VAHIA	581
Origin of Elements in the Solar System O. MANUEL	589
Author Index	645

Supernova 1987A is a recent example of one of the stellar nucleosynthesis events that generated many of the nuclides in our solar system. (From NASA).

The cradle of the nuclides holds the products of nucleosynthesis. The more stable nuclides lie in the valley, those that are radioactive or readily consumed by fusion or fission occupy higher positions in the cradle. (From FCR, Inc.)