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Memories of Clifford Truesdell

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Below is a shortened version of the text of a talk given at the *Meeting in Memory of Clifford Truesdell* held in Pisa in November of 2000 and at the *Symposium on Recent Advances and New Directions in Mechanics, Continuum Thermodynamics, and Kinetic Theory* held in Blacksburg in June of 2002. Appended to that text is the Curriculum Vita of Professor Truesdell as he himself kept it up-to-date until October 1993, at which time, with his approval, I had it transcribed into its present format.

Clifford Truesdell and Thermodynamics

I consider myself to have been among the most fortunate of men: I have had a teacher and friend, indeed, more than a friend, in effect, an elder brother, who was the leading scholar in my science and who gave me encouragement, sound advice, and every type of help that I might need, even when I did not know that I needed it. Most important of all, he taught me that careful scholarship and the persistent search for insight and understanding are far more important than facile skill in the use of contemporary techniques for the solution of currently popular problems.

Clifford Ambrose Truesdell III was born in Los Angeles, February 18, 1919. In his 23rd and 24th years he received, from the California Institute of Technology, the B.S. Degree in Mathematics, the B.S. Degree in Physics, and the M.S. Degree in Mathematics, and, in addition, from Brown University, a Certificate in Mechanics. In his 25th year he received, from Princeton University, the Ph.D. Degree in Mathematics.

In the course of his career he received numerous awards and prizes, among which are: the Euler medal of the USSR Academy of Sciences, which was received twice, in 1958 and 1983, the Bingham Medal of the Society of Rheology, the Panetti Prize and Gold Medal of the Accademia di Scienze di Torino, the Birkhoff Prize of the American Mathematical Society and the Society for Industrial and Applied Mathematics, and the Ordine del Cherubino of the Università di Pisa. He received honorary doctorates from five universities and was awarded membership in twelve international academies of science; among them is the illustrious Italian Accademia Nazionale dei Lincei.

Although I was an undergraduate student at Indiana University from February 1948 to June 1951, and hence my stay in Bloomington Indiana did overlap, albeit partially, that of Clifford and Charlotte Truesdell, we first met years later, in the Spring of 1958, at a scientific meeting in Lancaster Pennsylvania on the subject of rheology. The meeting was followed by an exchange of letters about thermodynamics, which was in turn followed by a one-week visit with Clifford and Charlotte Truesdell at their house in Bloomington in the winter of 1958 and not long after that by his two week visit to the Mellon Institute. If you bear with me, I should like to tell you about events of that period from the point of view of one whose subsequent view of science, the arts, and life itself were completely changed by his interaction with Clifford Truesdell.

In the summer of 1957 I left a position in the chemical industry to become a Senior Fellow of the Mellon Institute in Pittsburgh, and soon after my arrival I started to attend courses given by Walter Noll on continuum mechanics and related branches of mathematics. Before the academic year was over, we both went to the rheology meeting in Lancaster. The list of speakers for that meeting included Clifford Truesdell, Walter Noll, Jerry Ericksen, and Ronald Rivlin. At a luncheon that was held there, Walter Noll and I were sitting at a table with several persons other than those just mentioned, and I expressed the view that although we were all told in school that thermodynamics is a closed subject whose general principles are known and pertain to only equilibrium states or to processes that stay so close to equilibrium that all departures from equilibrium are governed by linear constitutive relations, I could not believe that such is the case, and I felt that our knowledge of what the science of thermodynamics could be was in some way analogous to what the cultivators of mechanics knew about their subject at the time of the publication of Newton's Principia and the early work of the Basel School. All within hearing, with the exception of Walter Noll, agreed with each other that I was wrong. Walter agreed with me and suggested that I read certain papers of Clifford Truesdell and that we talk more when we were back in Pittsburgh.

We did talk more, much more, and I, with my eyes open wide with excitement, read whatever I could of Clifford Truesdell's writings on thermodynamics.

There were papers that carried forward Maxwell's idea that a properly formulated theory of diffusion of mass in fluid mixtures should account, as Fick's Law does not, for balance of linear and angular momentum.

There were passages decrying the vagueness that rendered nearly empty, at least for mathematicians, the text-book versions of the Second Law of Thermodynamics. Among these was a footnote to a discussion of classical thermodynamics in his paper, *The Mechanical Foundations of Elasticity and Fluid Dynamics*, published in 1952 in Volume 1 of the Journal for Rational

Mechanics and Analysis. The footnote urges the rational student "to cleave the stinging fog of pseudo-philosophical mysticism" hiding the mathematics behind a certain formulation of the Second Law. It was clear that he saw that thermodynamics, far from being a closed subject, was in a terrible state.

Today we know that he was then doing research that would supply the key to setting things straight. In that paper of 1952 there appears a preliminary version of what he, with great generosity, called *the Clausius-Duhem inequality*, and which appeared in its present form in *The Classical Field Theories of Mechanics*, by Clifford Truesdell and Richard Toupin, published in 1960 in Volume III of the *Handbuch der Physik*:

$$\frac{d}{dt} H \geq - \int_{\partial \mathcal{P}} \frac{\mathbf{q} \cdot \mathbf{n}}{\theta} da + \int_{\mathcal{P}} \frac{r}{\theta} dm,$$

$$H = \int_{\mathcal{P}} \eta dm.$$

Here H is the total entropy of the part \mathcal{P} , θ is the thermodynamical temperature, \mathbf{q} is the inward directed heat flux, r is the supply of heat from external sources, and \mathbf{n} is the outward directed unit normal vector.

On reading those two works one sees that before 1960 it was clear to Clifford Truesdell that that inequality is the correct mathematical form of the second-law of thermodynamics for the materials or systems such that the total entropy H is an integral over \mathcal{P} of an entropy density η , and nearly all the thermodynamical systems that we consider in continuum physics have that property. The question that seemed open at the time was the following: How does one use the inequality? Is it a restriction on the process, or a relation to be obeyed by all processes?

In the early 1960's Walter Noll put to me the idea, as if it should be obvious to every one, that the inequality is a restriction on all processes that are admissible in the material of which the body is composed, and, because one defines each material by giving a set of constitutive relations, the Clausius-Duhem inequality, as it must hold for all processes compatible with those relations, becomes a *restriction on constitutive relations*. In another act of great generosity, Walter suggested that we develop the idea together. It took awhile to sort the argument out and to present it in a way that would convince the wary. The paper was written while he and I were on sabbatical leave and were guests of Clifford Truesdell at Hopkins.

Shortly thereafter, I used this approach to the Clausius-Duhem inequality to render mathematical ideas I had been struggling to express for years about thermodynamical restrictions on materials with gradually fading memory.

Many of the people in this room have done research on the Clausius-Duhem inequality, in the study of its implications for new classes of constitutive relations, in the study of its implications for the theory of the evolution of singular surfaces, or in the study of its logical relation to other mathematically precise statements of the second law. I am certain that I do not exaggerate when I say that every one of them feels a deep debt of gratitude to Clifford Truesdell for finding the tool to cleave the fog that once obscured the science of thermodynamics.¹ But we have even greater debts to him.

I should like to return to the time of that rheology meeting in Lancaster and elaborate on my own debt to him. A few months after that meeting, I received a letter from Clifford in which he said that he heard from Walter Noll that I had studied at Yale, had read some of the works of J. Willard Gibbs, and knew some things about thermodynamics. He then asked if I could clarify some passages in Gibb's paper on *The Equilibrium of Heterogeneous Substances*. With Walter's help I studied those passages for months and finally sent off a long letter in which Clifford's questions were answered but issues were raised which for decades affected my work on the stability of thermodynamical systems. In his reply he invited me to visit him and Charlotte in Bloomington. Many years later, in the summer of 1993, I wrote to him about that period and with your indulgence I shall read from the letter. I know there are others here who could say similar things about our beloved friend, and when I have finished you will see what I mean about our greater debts to him. What I read now are three brief consecutive paragraphs out of a long letter.

"My correspondence with you about Gibbs' conditions for the stability of fluid phases occurred in this happy period. I visited your house in Bloomington for a week in, I believe, the winter of 58-59. That visit had a major influence on my view of what is important. As if struck by lightning, like the one Christians call Paul, I suddenly saw clearly something for which I was ready by instinct. In my case it was not a new religion, but a way to get out of a rut, by seeking to study the languages, the writings, the art, the customs, the lives, and the music and diversions of the ages in which our science originated and the works we admire were produced. Your example gave me the impetus to try to learn properly other languages. I became serious in my study of Italian. In later years I have tried to improve my French. (In my 62nd year, I started working on Attic and Homeric Greek, but was too old for such efforts.)

¹ The remark was appropriate to both the meeting in Pisa and symposium in Blacksburg.

"The influence of our friendship on my intellectual development has been too great to describe in a few phrases couched in generalities. A brief summary is impossible. Only examples will do, and there is space here for only one.

"That one concerns my behavior when I am writing something for publication. Invariably, upon completion of a passage I put down the pencil and ask myself: 'What would Clifford say if he saw what I have just written?' The subsequent imagined conversation is often such that I feel obliged to rewrite the passage."

Would that he were here now, to help us live up to the standards of scholarship and clarity that he set for us!

Curriculum Vita of Clifford Ambrose Truesdell III

Born in Los Angeles, California, February 18, 1919

Studies

European Travel and Private Study, 1936 - 1938.

California Institute of Technology: B.S. (Mathematics), 1941; B.S. (Physics), 1941;
M.S. (Mathematics), 1942.

Brown University: Certificate in Mechanics, 1942.

Princeton University: Ph.D. (Mathematics), 1943.

Primary Employment

California Institute of Technology:

Assistant in history, debating, and mathematics, 1940 - 1942.

Brown University:

Assistant in Mechanics, 1942.

Princeton University:

Instructor of Mathematics, 1942 - 1943.

University of Michigan:

Instructor of Mathematics, 1943 - 1944.

Radiation Laboratory, Massachusetts Institute of Technology:

Staff Member, 1944 - 1946.

U.S. Naval Ordnance Laboratory, White Oak, Maryland:

Chief, Theoretical Mechanics Subdivision, 1946 - 1948.

U.S. Naval Research Laboratory, Washington, D.C.:

Head, Theoretical Mechanics Section, 1948 - 1950.

Indiana University:

Professor of Mathematics, 1950 - 1961.

Johns Hopkins University:

Professor of Rational Mechanics, 1961 - 1989; Emeritus, 1989 -

Part-time, Temporary, and Visiting Appointments

University of Maryland, College Park:

Lecturer in Mathematics, 1946 - 1947.

Assistant Professor of Mathematics, 1947 - 1949.

Associate Professor of Mathematics, 1949 - 1950.

U.S. Naval Research Laboratory, Washington, D.C.:

Consultant, 1951 - 1955.

Universität Marburg an der Lahn:
 Gastprofessor, 1957.
 Mathematics Research Center, U.S. Army, University of Wisconsin, Madison:
 Member, 1958.
 Mellon Institute, Pittsburgh:
 Visitor, 1959.
 Socony-Mobil Research Laboratory, Dallas, Texas:
 Colloquium Lecturer, 1960.
 U.S. National Bureau of Standards, Washington, D.C.
 Consultant, 1950 - 1962.
 University of California at Los Angeles:
 Special Lecturer, 1963.
 Technische Universität Berlin-Charlottenburg:
 Gastprofessor, 1964.
 University of Washington, Seattle:
 Walker-Ames Professor, 1964.
 Australian Mathematical Society Summer Research Institute, Melbourne:
 Lecturer, 1965.
 Syracuse University, New York:
 Distinguished Visiting Professor, 1965.
 International School on Non-linear Problems in Physics, München:
 Lecturer, 1966.
 Università di Pisa:
 Visiting Lecturer, 1966, 1973, 1974, 1975, 1978, 1980, 1982, 1985, 1987.
 Sandia Corporation, Albuquerque, N.M.:
 Visitor, 1966.
 Drexel Institute of Technology, Philadelphia:
 Seventy-Fifth Anniversary Lecturer, 1966 - 67.
 Accademia dei Lincei, Roma:
 Professore Linceo, 1970, 1973.
 Universidade Federal do Rio de Janeiro:
 Lecturer for the Coordenação dos Programas de Pós-Graduação de Engenharia
 and the Instituto de Matemática, 1972.
 Georgia Institute of Technology, Atlanta:
 Consultant, 1973 - 1974.
 Scuola Normale Superiore, Pisa:
 Ospite Linceo, 1974.
 Brookhaven National Laboratories, Long Island:
 Consultant (Advanced Codes Review Committee, U.S. Nuclear Regulatory
 Commission), 1975 - 1983.

University of Delaware:

Bicentennial Scholar in Residence, 1976.

Instituto de Ingenieria Mecánica y Mecánica Teórica y Aplicada, Universidad Autónoma de Mexico, Mexico D.F.:

Lecturer, 1977.

Università di Bologna:

Professore Visitatore, 1978, 1987, 1988.

Université Catholique de Louvain:

Visiting Professor, 1979.

Institut des Hautes Études Scientifiques, Bures-sur-Yvette:

Visitor, 1981.

Cornell University:

First Distinguished Visiting Professor of Theoretical and Applied Mechanics, 1982.

Università di Firenze, Scuola di Architettura:

Professore a Contratto, 1985.

Scuola di Ingegneria Strutturale, Università di Roma "La Sapienza":

Visiting Professor, 1990.

Short Lecture Series and Named Single Lectures

University of Toronto, 1949.

Sorbonne, Paris, 1949, 1955.

State University of Iowa, 1956.

Indiana University, 1959.

Scuola Internazionale di Fisica, Varenna, 1960.

Università di Padova, 1961.

Università e Politecnico di Milano, 1961.

Midwest Mechanics Seminar Tour, 1962.

Academy of Sciences, Warsaw, 1963, 1964.

The Johns Hopkins University, 1965.

Gibson Lecturer in the History of Mathematics, University of Glasgow, 1965.

Distinguished Visiting Lecturer, Centennial of the University of Kentucky, 1965.

NSF Conference on Recent Developments in Continuum Mechanics, Virginia Polytechnic Institute, 1966, 1969.

Koerner Lecturer, Simon Fraser University, Burnaby, B.C., 1969.

Distinguished Lecturer in Chemical Engineering, University of Rochester, 1970.

International Centre of Mechanical Sciences, Udine, 1971.

Centennial Lecturer in Engineering Mechanics, Virginia Polytechnic Institute, 1971.

Section de Transferts Thermiques, Centre de Recherches Nucléaires, Grenoble, 1973.

Bajer Lecture, Princeton University, 1975.

Durelli Lecture, Catholic University of America, 1977.
 International Symposium on Continuum Mechanics and Partial Differential Equations, Universidade do Rio de Janeiro, 1977.
 University of Chicago, 1979.
 Thermofluids Lectures, Departments of Chemical and Mechanical Engineering, School of Mines, University of Arizona, Tucson, 1980.
 Ritt Lectures, Department of Mathematics, Columbia University, 1982.
 First MTU Lectures in Engineering Science, Michigan Technical University, Houghton, 1983.
 St. Andrews University, Scotland, 1983.
 Distinguished Scientist Lecture, Trinity University, San Antonio, Texas, 1984.
 Allen Lecture in Mathematical Sciences, Rensselaer Polytechnic Institute, 1985.
 Page-Barbour Lectures, University of Virginia, Charlottesville, 1985.
 Franklin Lecture, Auburn University, Auburn, Alabama, 1986.

Invited Single Lectures to Meetings and Symposia

American Mathematical Association (Baltimore, 1948).
 American Physical Society (Charlottesville, 1949; State College, Pennsylvania, 1953; San Diego, California, 1971).
 International Conference on Theoretical Fluid Mechanics, Harvard, 1950.
 Conference on Elasticity, University of Maryland, 1952.
 Sigma Xi (Indiana University, 1952; State University of Iowa, 1956; Illinois Institute of Technology, 1960; Georgia Institute of Technology (Monie A. Ferst Memorial Lecture), 1969; University of Tennessee, 1976; McGill University, 1976.
 Symposium on Ultrasonic Absorption and Dispersion in Fluids, Brown University, 1952.
 Discussion Meeting on the Second Viscosity of Fluids, The Royal Society, London, 1953.
 First Midwestern Conference on Solid Mechanics, University of Illinois, 1953.
 Symposium of the Office of Ordnance Research and the American Mathematical Society, Chicago, 1954.
 American Society for Engineering Education, Urbana, 1954.
 Gesellschaft für Angewandte Mathematik und Mechanik (General Lectures), Berlin, 1955; Hamburg, 1957.
 Sixth Conference on Hydraulics (General Lecture), Iowa City, 1955.
 Eulerfeier (Main Lecture), Basel, 1957.
 Washington Philosophical Society, 1958.
 Accademia Nazionale di Scienze, Lettere ed Arti (Inaugural Address), Modena, 1960.
 Celebrazioni Archimedee, Siracusa, 1961.
 I.U.T.A.M. Symposium on Second-order Effects in Elasticity, Plasticity, and Fluid Dynamics (General Lecture), Haifa, 1962.

Fourth U.S. National Congress of Applied Mechanics (General Lecture), Berkeley, 1962.
 Summer Conference on Non-ideal Mechanical Behavior, Princeton, 1962.
 American Society of Mechanical Engineers, Washington, 1962.
 Symposium on Hemodynamics and Hydrodynamics, Baltimore, 1962.
 International Congress of Rheology (Bingham Medal Address), Providence, 1963.
 Society for Natural Philosophy at Pittsburgh, 1963; Notre Dame, 1971; Seattle, 1972;
 Pisa, 1974, 1978; Williamsburg (Fifteenth Anniversary Lecture), 1978; Rolla,
 80; Brown, 1983; Baltimore, 1987; Pittsburgh (Walter Noll retirement
 symposium), 1993.
 Eleventh International Congress of Applied Mechanics, Munich, 1954.
 Philosophy of Science Seminar, University of Delaware, 1965.
 Convegno dei Meccanici Italiana, Modena, 1966.
 I.U.T.A.M. Symposium on Irreversible Thermodynamics in Continuous Media, Vienna,
 1966.
 Commemoration of Newton's *Annus Mirabilis*, Austin, 1966.
 First Canadian National Congress of Applied Mechanics (General Lecture), Quebec,
 1967.
 Third Buhl International Conference on Materials, Mellon Institute, 1968.
 Symposium on "The Interplay between Mathematics and Physics - The Rise of
 Mathematical Physics" at the University of Aarhus, 1970.
 Southwest Graduate Research Conference, Houston, Texas, 1971.
 Second Annual Meeting of the American Society for Eighteenth Century Studies, College
 Park, Maryland, 1971.
 Banquet address, meeting of the History of Science Society and Society for the History of
 Technology, Washington, 1972.
 Sectional address (History and Paedagogy), International Congress of Mathematicians,
 Vancouver, 1974.
 Address at the Engineering Commencement, Tulane University, New Orleans, 1976.
 Address on receipt of a Birkhoff Prize, Annual meeting of the American Mathematical
 Society and the Society for Industrial and Applied Mathematics, 1978.
 Euromech Colloquium, Pisa, 1978.
 Italo-American Co-operative Science Seminar, Venice, 1978.
 Organizer's address, Special Symposium on "Conceptual Analysis in Rational
 Thermomechanics", Summer meeting of the American Mathematical Society,
 Providence, 1978.
 Keynote address on Constitutive Relations, E.P.R.I. Workshop on Two-Phase Flow,
 Tampa, Florida, 1979.
 Colloquium on Continuum Thermodynamics, Society of Engineering Science,
 Northwestern University, Evanston, 1979.
 Celebration of the 75th anniversary of *Scientia*, Milano, 1980.

Plenary lecture, 8th International Congress of Rheology, Naples, 1980.

General Lecture, Society of Engineering Science, Atlanta, 1980.

Colloquium on the History of Mathematics, Winter meeting of the American Mathematical Society, San Francisco, 1981.

Keynote address, 11th Southeastern Conference on Theoretical and Applied Mechanics, Huntsville, Alabama, 1982.

Joint Session on the History of Mathematics, meetings of the American Mathematical Society and American Mathematical Association, Toronto, 1982.

Festakt Daniel Bernoulli (Main Lecture), Basel, 1982.

Leonardo e l'età della ragione (congress organized by *Scientia* and the governing bodies of Milano and Lombardy), Milano, 1982.

25th British Theoretical Mechanics Colloquium, Manchester, 1983.

International Symposium, "The Codex Hammer in Context", Walters Art Gallery, Baltimore, 1983.

Workshop on the Laws and Structure of Continuum Thermomechanics, Institute for Mathematics and its Applications, University of Minnesota, Minneapolis, 1983.

Convegno sul tema "Termoelasticità finita", Accademia Nazionale dei Lincei, Rome, 1985.

International Conference on Non-linear Mechanics, Shanghai, 1985.

900th Anniversary celebrations, University of Bologna, 1987, 1988.

300 Years of Gravitation, University of Cambridge, England, 1987.

International Conference dedicated to the Tricentenary of the Publication of Newton's Principia, U.S.S.R. Academy of Sciences, Moscow, 1987.

First Plenary Lecture, 4th National Congress of Theoretical and Applied Mechanics, Coimbra, Portugal, 1987.

Celebration of the 300th anniversary of Newton's Principia, Technische Hochschule Darmstadt, 1988.

First Plenary Lecture, III International Workshop on Mathematical Aspects of Fluid and Plasma Dynamics, Salice Terme, Italy, 1988.

First Plenary Lecture, IX Congresso Nazionale dell'Associazione Italiana di Meccanica Teorica ed Applicata, Bari, 1988.

Imola Conference, Università degli Studi di Bologna, September 5 - 7, 1988.

Inaugural Charles E. Foster Lecture, School of Aerospace and Mechanical Engineering, University of Oklahoma, Norman, 1990.

Convegno Internazionale "I Riccati e la cultura della Marca nel Settecento Europeo", Castelfranco Veneto, 1990.

First Rutgers Conference on Theoretical Mechanics: The Dynamics of Rods, August 24 - 27, 1990, Rutgers University, New Brunswick.

Convegno Internazionale in Memoria di Vito Volterra, Accademia Nazionale dei Lincei, October 8 - 11, 1990.

Editorial Positions

- Co-founder and Co-editor, *Journal of Rational Mechanics and Analysis*, 1952 - 1956.
 Editor or Co-editor, *Leonhardi Euleri Opera Omnia*, Series II, Vols. 10 - 13, 18 - 19, 1952 - 1971.
- Co-editor, *Handbuch der Physik*, (Springer) Vols. 8/I, 8/II, 9 and 6a/1 - 6a/4, 1956 - 1974.
- Founder and Editor, *Archive for Rational Mechanics and Analysis*, 1957 - 1967, Co-editor, 1967 - 1985; Editor, 1985 - 1989.
- Editor, Reihe für Mechanik, *Ergebnisse der Angewandten Mathematik*, 1957 - 1962.
- Founder and Editor, *Archive for History of Exact Sciences*, 1960 - .
- Founder and Editor, *Springer Tracts in Natural Philosophy*, 1962 - 1966; Co-editor, 1967 - 1978; Editor, 1979 - .
- Co-editor, *Studies in the Foundations, Methodology and Philosophy of Science*, 1966 - 1970.
- Member of the Editorial Board, *Rendiconti del Circolo Matematico di Palermo*, 1971 - .
- Member of the Editorial Board, *Annali della Scuola Normale Superiore*, Pisa, 1974 - .
- Member of the Editorial Board, *Meccanica*, 1974 - .
- Member of the International Editorial Board, *Il Nuovo Cimento B*, 1979 - 1981; *Il Nuovo Cimento D*, 1982 - 1987.
- Member of the Editorial Council, *Bollettino di Storia delle Scienza Matematiche*, Unione Matematica Italiana, 1979 - .
- Member of the Editorial Board, *Speculations in Science and Technology*, 1980 - 1987.
- Member of the Editorial Board, *Ganita-Bharati*, 1981 - .
- Member of the Editorial Board, *Stability and Applied Analysis of Continuous Media*, 1991 - .

Organizational Positions

- U.S. Correspondent, *International Mathematical News (Austria)*, 1952 - 1956.
- Member, Committee on Applied Mathematics, U.S. National Research Council, 1954 - 1956.
- Sponsor for Elasticity, American Society for Mechanical Engineers, 1956 - 1958.
- General Chairman, Conference on the Foundations of Mechanics and Thermodynamics, National Bureau of Standards, 1959.
- Member of organizing committee, International Conference on Rarefied Gas Dynamics, Berkeley, California, 1960.
- Member of organizing committee, International Congress of Logic and the Philosophy of Science, Stanford, 1960.
- Member of organizing committee, I.U.T.A.M. Conference on Second-order Effects in Elasticity, Plasticity, and Fluid Mechanics, Haifa, 1962.

Co-founder, Society for Natural Philosophy, 1963; Director, 1963 - 1984; Secretary, 1963 - 1965, 1970 - 1971, 1980 - 1981; Chairman, 1967 - 1968, 1983 - 1984; Member of the Program Committee, 1975 - 1976.

Co-chairman of the local committee and Chairman of the Round-table Discussion, meetings of the Society for Natural Philosophy at Baltimore, 1963, Bressanone, 1965, Chairman of a Round-table Discussion at the meetings at Chicago, 1966; Cincinnati, 1970; Cincinnati, 1977; Madison, 1984. Co-chairman of the local committee for the meeting at Baltimore, 1965.

Coordinator, C.I.M.E. Course on Non-Linear Continuum Theories, Bressanone, 1965.

Co-Chairman, First Joint Italian-American Cooperative Science Seminar, Udine, 1971.

Member of the Scientific Committee, Symposium on Problems of Plasticity, Polish Academy of Sciences, Warsaw, 1972.

Co-Chairman, Italian-American Cooperative Science Seminar, Udine, 1974.

Organizer of Special Symposium "Conceptual Analysis in Rational Thermomechanics", Summer Meeting, American Mathematical Society, Providence, 1978.

Member of the Steering Committee, International Conference on Non-Linear Mechanics, Shanghai, 1985.

Honorary Doctorates

dott.ing.h.c. in Mechanical Engineering (Fluid Mechanics and History of Science), Centenary of the Politecnico di Milano, 1965.

D.Sc. (Engineering), Tulane University, 1976.

Fil. D. h.c. (Physics), Uppsala University, 1979.

Dr. Phil. h.c. (Sciences), University of Basel, 1979.

dott. mat. h.c. (Mathematics), University of Ferrara, 1992.

Memberships in National or International Academies of Science, etc.

Socio Onorario dell'Accademia Nazionale di Scienze, Lettere ed Arti, Modena, from 1960.

Membre Correspondent de l'Académie Internationale d'Histoire des Sciences, Paris, 1961 - 1968. Membre Effectif from 1968.

Membro Straniero dell'Istituto Lombardo Accademia di Scienze e Lettere, from 1968.

Socio Corrispondente Straniero dell'Istituto Veneto di Scienze, Lettere ed Arti, from 1969.

Accademico Corrispondente Straniero dell'Accademia delle Scienze dell'Istituto di Bologna, from 1971.

Socio Straniero dell'Accademia Nazionale dei Lincei Rome, from 1972.

Membre Titulaire de l'Académie Internationale de Philosophie des Sciences, Bruxelles, from 1974.

Socio Straniero dell'Accademia delle Scienze, Torino, from 1978.

Membro Corrispondente, Academia Brasileira de Ciências, from 1981.

Honorary Foreign Member, Polish Society for Theoretical and Applied Mechanics, from 1985.

Membrum Ordinarium, Regia societas scientiarum Upsaliensis, from 1987.

Fellow, American Academy of Arts and Sciences, from 1991.

Awards, Prizes

California Institute of Technology, Institute Scholar and LaVerne Noyes Scholar, 1938 - 1941; Conger Peace Prize, 1940, 1941.

Fellow of the John Simon Guggenheim Memorial Foundation, 1957.

Euler medal of the USSR Academy of Sciences, 1958, 1983.

Senior Post-Doctoral Fellow, U.S. National Science Foundation, 1960 - 1961.

Bingham Medal of the Society of Rheology, 1963.

Gold Medal and International Prize "Modesto Panetti" (applied mechanics), Accademia di Scienze di Torino, 1967.

Birkhoff Prize (applied mathematics), American Mathematical Society and Society for Industrial and Applied Mathematics, 1978.

Ordine del Cherubino, University of Pisa, 1978.

Visiting Research Scholar, Japan Society for the Promotion of Science, Kyoto, 1980.

Senior U.S. Scientist Award (Humboldtpreis), West Germany, 1985.