

## Nuclear microscopy of normal and necrotic skeletal muscle fibers: an intracellular elemental microanalysis

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### Abstract

The *in situ* total elemental composition and elemental concentrations present in mouse soleus (type I) and gastrocnemius (type IIA) muscle fibers were analyzed by using nuclear microscopy (NM). Elemental changes in necrotic fibers, induced by intramuscular injection with snake venom (*Pseustesichis australis*), were also studied 3 h post-injection. Nuclear microscopy is a new method based on nuclear technology that utilizes the interaction between a million-electron-volt nuclear particle beam and the muscle sample (in the case of the present study). Elemental analysis was done at the parts per million (ppm) level of sensitivity on unfixed, rapidly frozen and unstained single fast- and slow-twitch muscle fibers with imaging capabilities of  $\mu\text{m}$  spatial resolution and in multi-elemental mode. In total, 12 different intracellular elements were mapped, co-localized and analyzed in single normal and necrotic skeletal muscle fibers from mice. Elements such as potassium, sulfur, phosphorus, chlorine and sodium were found in concentrations from 1000 to 18 000 ppm. Unlike conventional electron-probe X-ray microanalysis, NM also detected and analyzed the trace elements such as magnesium, calcium, iron and zinc that were found in concentrations of 50 to 1000 ppm. Other elements — copper, manganese and rubidium — were also detected in concentrations of less than 50 ppm. The trace elements calcium, iron and zinc were more abundant in the soleus than the gastrocnemius (the level of iron was statistically significant). Calcium, sodium and chlorine were significantly elevated in venom-induced necrotic soleus muscle fibers. © 1999 Elsevier Science Ltd. All rights reserved.

**Keywords:** Nuclear microscopy; Fast and slow muscle; Trace element analysis; PIXE; Calcium; Necrotic fibers.

### 1. Introduction

Various elements in skeletal muscle play a role in normal biochemical processes of muscle function as well as in the pathological mechanisms of myonecrosis (Bowen, 1966; George, 1995; Gopalakrishnakone et al., 1997). Diseases like muscular dystrophy, hypokalemic periodic paralysis, myotonia congenita and malignant hyperpyrexia may be due to changes in intracellular and extracellular concentrations of ions such as  $\text{Ca}^{2+}$ ,  $\text{Na}^+$ ,  $\text{K}^+$  and  $\text{Cl}^-$  (George, 1995). The role of  $\text{Ca}^{2+}$ ,  $\text{Na}^+$ ,  $\text{K}^+$  and  $\text{Mg}^{2+}$  ions in the contraction and functioning of skeletal muscle has been reported extensively. Calcium is an important ion both in the physiology and the pathology of the cell. Calcium was also implicated in venom-induced myonecrosis (Gopalakrishnakone et al., 1997). The venom of *Pseustesichis australis* snake is rich in myotoxic phospholipase  $\text{A}_2$  fractions and is capable of inducing skeletal muscle necrosis in both man

and experimental animals (Rowlands et al., 1969; Chen et al., 1993; Ponraj and Gopalakrishnakone, 1995; Gopalakrishnakone et al., 1997).

Mammalian twitch muscle fibers are mainly classified as slow-twitch fibers (type I — e.g., soleus) and fast-twitch fibers (type IIA — e.g., fast oxidative gastrocnemius; and type IIB — e.g., fast glycolytic extensor digitorum longus). These two fibers not only differ functionally, but also have different structural, biochemical as well as histochemical properties (Ruegg, 1992). The slow-twitch soleus muscle is non-fatiguing and appears red owing to its high myoglobin and mitochondrial contents. It is low in lactic dehydrogenase, creatine kinase, T-system and sarcoplasmic reticulum, but rich in actomyosin ATPase, succinic dehydrogenase and carbonic anhydrase III (Zheng et al., 1992). The fast-twitch gastrocnemius muscle is white because of its low myoglobin and mitochondrial levels, and fatigues easily. The susceptibility to myonecrosis also differs between slow and fast muscles, the soleus muscle being more susceptible than gastrocnemius to animal venoms and toxins (Duchen, 1970, 1971).

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# Nuclear Microanalysis

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## **Nuclear Microanalysis:**

**Nuclear Microanalysis** Vlado Valković, 1977      *Nuclear Science Abstracts*, 1976-02      *Ion Beam Handbook for Material Analysis* James W. Mayer, E. Rimini, 2012-12-02 Ion Beam Handbook for Material Analysis emerged from the U S Italy Seminar on Ion Beam Analysis of Near Surface Regions held at the Baia Verde Hotel Catania June 17 20 1974 The seminar was sponsored by the National Science Foundation and the Consiglio Nazionale delle Ricerche under the United States Italy Cooperative Science Program The book provides a useful collection of tables graphs and formulas for those involved in ion beam analysis These tables graphs and formulas are divided into five chapters that cover the following topics energy loss and energy straggling backscattering spectrometry channeling applications of ion induced nuclear reactions and the use of ion induced X ray yields      Applications Of Nuclear Microprobes In The Life Sciences Yvan Llabador, Philippe Moretto, 1998-02-28 This book describes the capabilities of nuclear techniques for elemental microanalysis in the biological field A description of basic principles is given at the beginning with special emphasis on X ray Fluorescence Rutherford Backscattering Spectrometry Nuclear Reaction Analysis and Scanning Transmission Ion Microscopy The major part of the volume is devoted to the applications in the life sciences and presents a general review of the subjects investigated during the last fifteen years In addition technical aspects of nuclear microanalysis in living tissues including data processing and specimen preparation are detailed Examples of recent applications in cellular pharmacology cell physiology and biomedicine are presented The last part concerns the studies of unicellular micro organisms involved in pollution problems Postgraduate students and confirmed scientists will be able to find here basic information references and practical aspects of this new tool with in each case a comparison with other analytical techniques      **Material Characterization Using Ion Beams** J. Thomas, 2012-12-06 The extensive use of low energy accelerators in non nuclear physics has now reached the stage where these activities are recognized as a natural field of investigation Many other areas in physics and chemistry have undergone similarly spectacular development beam foil spectroscopy in atomic physics studies in atomic collisions materials implantation defects creation nuclear microanalysis and so on Now this most recent activity by itself and in its evident connection with the others has brought a new impetus to both the fundamental and the applied aspects of materials science A summer school on Material Characterization Using Ion Beams has resulted from these developments and the realization that the use of ion beams is not restricted to accelerators but covers a wide energy range in the developing technology The idea of the ion beam as a common denominator of many activities dealing with surface and near surface characterization was enthusiastically received by many scientists and a school on this subject received the positive endorsement of NATO The Advanced Study Institute on Materials Science has assumed for us the status of an institution leading to better contact among the many laboratories engaged in this field The fourth Institute in this series was held in Aleria Corsica between August 22 and September 12 1976      Scientific and Technical Aerospace Reports, 1975 Lists citations with abstracts for

aerospace related reports obtained from world wide sources and announces documents that have recently been entered into the NASA Scientific and Technical Information Database     *Energy Research Abstracts* ,1993 Semiannual with semiannual and annual indexes References to all scientific and technical literature coming from DOE its laboratories energy centers and contractors Includes all works deriving from DOE other related government sponsored information and foreign nonnuclear information Arranged under 39 categories e g Biomedical sciences basic studies Biomedical sciences applied studies Health and safety and Fusion energy Entry gives bibliographical information and abstract Corporate author subject report number indexes     Principles and Practice of Heterogeneous Catalysis John Meurig Thomas,W. John Thomas,1996-10-07 Catalysis occupies a pivotal position in the physical and biological sciences As well as being the mainstay of the chemical industry it is the means of effecting many laboratory syntheses and the root cause of all enzymatic processes This book is an eminently readable introduction to the fundamental principles of heterogeneous catalysis Written by world renowned experts it explains the vocabulary grammar and literature of catalysis from the laboratory oriented model study through to the operating plant Didactically skillful and using many lucidly designed figures the authors present an insightful exposition of all important concepts new developments and techniques in this rapidly advancing field     **Methods and Instrumentations: Results and Recent Developments** Arnold S. Marfunin,2013-03-09 All existing introductory reviews of mineralogy are written accord ing to the same algorithm sometimes called the Dana System of Mineralogy Even modern advanced handbooks which are cer tainly necessary include basic data on minerals and are essentially descriptive When basic information on the chemistry structure optical and physical properties distinguished features and para genesis of 200 400 minerals is presented then there is practically no further space available to include new ideas and concepts based on recent mineral studies A possible solution to this dilemma would be to present a book beginning where introductory textbooks end for those already famil iar with the elementary concepts Such a volume would be tailored to specialists in all fields of science and industry interested in the most recent results in mineralogy This approach may be called Advanced Mineralogy Here an attempt has been made to survey the current possibilities and aims in mineral mater investigations including the main characteristics of all the methods the most important problems and topics of mineralogy and related studies The individual volumes are composed of short condensed chap ters Each chapter presents in a complete albeit condensed form specific problems methods theories and directions of investigations and estimates their importance and strategic position in science and industry     Materials Sciences Programs United States. Department of Energy. Division of Materials Sciences,1992     *Fiscal Year 1986 Department of Energy Authorization (basic Research Programs)* United States. Congress. House. Committee on Science and Technology. Subcommittee on Energy Development and Applications,1985     *Surface Modification and Alloying* J.M. Poate,G. Foti,D.C. Jacobson,2013-11-21 This book is an outcome of the NATO institute on surface modification which was held in Trevi 1981 Surface modification and alloying by ion electron or laser beams is proving

to be one of the most burgeoning areas of materials science The field covers such diverse areas as integrated circuit processing to fabricating wear and corrosion resistant surfaces on mechanical components The common scientific questions of interest are the microstructures by the different energy deposition techniques and associated physical properties produced The chapters constitute a critical review of the various subjects covered at Trevi Each chapter author took responsibility for the overall review and used contributions from the many papers presented at the meeting each participant gave a presentation The contributors are listed at the start of each chapter We took this approach to get some order in a large and diverse field We are indebted to all the contributors in particular the chapter authors for working the many papers into coherent packages to Jim Mayer for hosting a workshop of chapter authors at Cornell and to Ian Bubb who did a sterling job in working over some of the manuscripts Our special thanks are due to the text processing center at Bell Labs who took on the task of assembling the book In particular Karen Lieb and Beverly Heravi typed the whole manuscript and had the entire book phototypeset using the Bell Laboratories UNIX<sup>TM</sup> system

**ERDA Energy Research Abstracts** ,1989 Fusion Energy Update ,1982

**Activation Analysis** Zeev Alfassi,1990-06-22 This timely publication covers prompt measurements as well as delayed activation measurements used in chemical analysis of the elements It describes the various possibilities of activation neutrons charged ions and photons Also discussed are the advantages and disadvantages of each activation method These volumes are important for those in geology archaeology biology analytical chemistry radioanalytical and nuclear chemistry the semiconductor industry and others

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**Backscattering Spectrometry** Wei-Kan Chu,2012-12-02

Backscattering Spectrometry reviews developments in backscattering spectrometry and covers topics ranging from instrumentation and experimental techniques to beam parameters and energy loss measurements Backscattering spectrometry of thin films is also considered and examples of backscattering analysis are given This book is comprised of 10 chapters and begins with an introduction to backscattering spectrometry what it can and what it cannot accomplish and some rules of thumb for interpreting or reading spectra The relative strengths and weaknesses of backscattering spectrometry in the framework of materials analysis are outlined The following chapters focus on kinematics scattering cross sections energy loss and energy straggling backscattering analysis of thin films of various degrees of complications the influence of beam parameters and mass and depth resolutions and their relationships to the mass and energy of projectiles Many examples of backscattering analysis are also presented to illustrate the capability and limitation of backscattering Backscattering applications when combined with channeling effects are considered as well The final chapter provides a list of references on the applications of backscattering spectrometry This monograph will be a useful resource for physicists

**Site Characterization and Aggregation of Implanted Atoms in Materials** A. Perez,R. Coussement,2012-12-06 Explosive developments in microelectronics interest in nuclear metallurgy and widespread applications in surface science

have all produced many advances in the field of ion implantation The research activity has become so intensive and so broad that the field has become divided into many specialized subfields An Advanced Study Institute covering the basic and common phenomena of aggregation seems opportune for initiating interested scientists and engineers into these various active subfields since aggregation usually follows ion implantation As a consequence Drs Perez Coussement Marest Cachard and I submitted such a proposal to the Scientific Affairs Division of NATO the approval of which resulted in the present volume For the physicist studying nuclear hyperfine interactions the consequences of aggregation of implanted atoms even at low doses need to be taken into account if the results are to be correctly interpreted For materials scientists and device engineers understanding aggregation mechanisms and methods of control is clearly essential in the tailoring of the end products     Electron Beam Microanalysis ,     **Catalog of National Bureau of Standards Publications, 1966-1976:**  
**Key word index** United States. National Bureau of Standards. Technical Information and Publications Division, 1978

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