Int. J. Entomol. Res. 02 (02) 2014. 47-57

Available Online at ESci Journals
International Journal of Entomological Research
ISSN: 2310-3906 (Online), 2310-5119 (Print)
http://www.escijournals.net/IJER

USE OF INDUCTIVELY COUPLED PLASMA-MASS SPECTROMETRY, ICP-MS, IN ENTOMOLOGY

Hassan Nasirian*, Zahra Nasirian, Sayyed M.T. Sadeghi
Department of Medical Entomology and Vector Control, School of Public Health, Tehran University of Medical Sciences, Tehran, Islamic Republic of Iran.

A B S T R A C T

Applications of the inductively coupled plasma-mass spectroscopy (ICP-MS) in various fields with emphasis on entomology are reviewed. Examples of the using a broad spectrum of ICP-MS in entomology including ecotoxicology, physiology, disease treatments, bioremediation, bioindication, homeostasis, and immune system, and determining and removing environmental contaminations are discussed and summarized.

Keywords: Application, entomology, ICP-MS, inductively coupled plasma, mass spectrometry.

INTRODUCTION

Inductively coupled plasma-mass spectroscopy (ICP-MS) was created in the late 1980's to incorporate the easy sample introgression and rapid analysis with the exact and very low exploration limits of a mass spectrometer. ICP-MS is able to measuring the trace multi elements, often at the part per trillion levels. The instrument has been applied widely in a number of different fields including drinking water, wastewater, natural water systems, geology, soil science, mining, food sciences and medicine over the years (Sadeghi, 1999; Worley and Kvech, 2000; Wang *et al*., 2010).

Inductively coupled plasma-mass spectroscopy is a method of breaking chemical samples down to their component atoms and ions. Peripheral plasma has a neutral state that is formed by atoms in the equilibrium between the neutral state (1-2%) and electrons (10^{18} cm^{-3}) and is considered as the fourth state of matter. ICP was made upon the same principles exploited in the atomic emission spectrometry. Samples are broken up to neutral elements in the high temperature argon plasma and assayed based on their mass to charge ratios. It have four main processes, including sample loading and aerosol production, ionization, mass discrimination, and the detection phase (Worley and Kvech, 2000; Sadeghi, 2011). One of the great advantages of ICP-MS that typically was used for measuring many trace and ultra-trace metals and some nonmetals at extremely low detection limits for wide range of elements from ^{6}Li to ^{238}U. Many elements can be detected down to part per quadrillion levels while most can be assayed at part per trillion levels (Worley and Kvech, 2000).

Principles with very detailed knowledge and all sequence of processes including instrument description and theory, sample introduction, argon plasma, sample ionization, mass spectrometer (MS), detector and detection limits are described and well-illustrated (Worley and Kvech, 2000). In this paper, applications of ICP-MS in various fields with emphasis on entomology are discussed and reviewed. Examples of the use of a broad spectrum of ICP-MS in entomology including ecotoxicology, physiology, disease treatments, bioremediation, bioindication, homeostasis, immune system, and determining and removing environmental contaminations are summarized.

MATERIAL AND METHODS

ICP-MS APPLICATIONS

General Application of ICP-MS: ICP-MS is typically used for measure the many trace and ultra-trace metals, and some nonmetals in various fields for wide range of elements from ^{6}Li to ^{238}U that are: Li, Be Sc, V, Cr, Co, Ni, Cu, Zn, Ga, Rb, Y, Zr, Nb, Mo, Cd, Sn, Sb , Cs, Ba, Hf, Ta, W, Re, Tl, Pb, Th, U and rare earth elements (Sadeghi, 2011).

* Corresponding Author:
Email: hanasirian@yahoo.com

The most popular its applications are in the field of animal and plant biological sciences (Truong *et al*., 2010; Mao *et al*., 2010; Tang *et al*., 2010; Garcia *et al*., 2010), environmental sciences (Inouye *et al*., 2007; Eeva and Penttinen *et al*., 2009; Vermeulen *et al*., 2009), geological sciences (Martínez-Fernández *et al*., 2011; Malsy and Klemmb, 2010; Stafilov *et al*., 2010; Silva *et al*., 2010; Jamshidi *et al*., 2010), archaeology (Thornton *et al*., 2002), immunology (Goenaga-Infante *et al*., 2010), diets and dietary nutritional supplements (Ghaedi *et al*., 2007), public health sciences (Lewen, 2010; Groessl *et al*., 2010; Qin *et al*., 2010), forensic medicine (Roeterdink *et al*., 2004; Ma *et al*., 2010), industry, toxicology studies (Boulassel *et al*., 2010; Yoshimura *et al*., 2010; Judy *et al*., 2010; Hariri *et al*., 2010), studies of metabolism, cancer researches (Hanada *et al*., 1998; Lunoe *et al*., 2010; Faucher *et al*., 2010; Zhou *et al*., 2010), chemistry (Ryan *et al*., 2011; Hansen *et al*., 2010; Banerjee *et al*., 2010; Judd *et al*., 2010; Berg *et al*., 2010), bacteriology (Sun *et al*., 2010; Galiová *et al*., 2010; Hansen *et al*., 2010) and construction (Bassioni *et al*., 2010).

Using ICP-MS for quantification of proteins and biomolecules: An increasing trend of applications would have been exist for ICP-MS in the speciation analysis which regularly utilize in chromatography with elemental selective detectors. For example, ICP-MS may be incorporated with size exclusion chromatography and quantitative preparative native continuous polyacrylamide gel electrophoresis for recognizing and quantifying the native metal cofactor of proteins in the biofluids. Also the phosphorylation condition of the proteins can be identified and analyzed (Yoshimura *et al*., 2010; Qiao *et al*., 2010; Engelhard, 2010; Leufroy *et al*., 2011; Milliard *et al*., 2011; Chen *et al*., 2011). However, the insect sensitivity level and insecticide resistance mechanisms can be determined by bioassay methods (Nasirian *et al*., 2006a-f; Nasirian, 2007; Nasirian, 2008; Nasirian, 2010), but integrated ICP-MS with a variety methods of chromatography can be used for determination of pesticide residues.

Applications of ICP-MS in Entomology: Inductively coupled plasma-mass spectroscopy has been used in various entomology branches such as ecotoxicology, bioremediation, physiology, treatment of diseases, hemostasis, immune system, forensic medicine and environmental pollution studies or in any its subject related.

Many studies have been showed that ICP-MS has a various application in the entomology. For example, lead through human activity has been a dangerous environmental neurotoxin, recognized to affect activity levels, attention and both sensory and cognitive function in children. Lead study would be simplified by having an animal model such as *Drosophila melanogaster* that could be administrated easily and quickly. Human will be expected from further studies with *Drosophila melanogaster* to realize better how lead affects the developing nervous system, and thus ultimately its effects on children (Hirsch *et al*., 2003).

Bee venom has pharmacological properties used in treatment of arthritis, rheumatism, pain, cancerous tumors, and skin diseases. However, in a study metals of honeybee venom were determined due to human contamination (Kokot and Matysiak, 2008). Also, Royal jelly from *Apis mellifera*, whose demonstrates homeostatic adjustment as mammalian and human breast milk, is a highly active natural biological matter and is probably one of the most interesting raw substances in the natural product chemistry. Trace elements perform a key role in the biomedical activities affiliated with royal jelly, as these elements have a multitude of known and unknown biological functions (Stocker *et al*., 2005).

The common treatment of human visceral leishmaniasis requires the use of pentavalent antimony (SbV) which its mechanism of action is unknown because of the limited information available about intracellular antimony metabolism and about the genes that adjust these processes. Here, flow injection ICP-MS, flow injection hydride generation ICP-MS, and ion chromatography ICP-MS were applied to assay antimony (Ulrich *et al*., 2000; Shaked-Mishan *et al*., 2001; Miekeley *et al*., 2002; Neves *et al*., 2009; Séby *et al*., 2012).

Concern about the environmental pollution effects on the immune function in both humans and wildlife is increasing and practically nothing is known about this impact on terrestrial invertebrates, even though they are known to easily accumulate contaminants. The effect of industrial heavy metal pollution on *Formica aquilonia* immune defense, were investigated. The *Formica aquilonia* encapsulation response was increased in moderate whereas suppressed in high heavy metal levels suggesting higher risk for infections in heavily contaminated areas (Sorvari *et al*., 2007). Environmental pollution from heavy metals has become a matter of great concern in many countries. Heavy metal contents in the mineralised dental tissues are indicators of the contact of their mineral phase to heavy metals during the time of the dental tissue formation and tooth development. Teeth whose accurately reflect the environmental or dietary contact of animals and humans to heavy metals have been used as bioindicators. The bank vole (*Clethrionomys glareolus*) teeth heavy metal content was investigated as a contact indicator of environmental contamination (Gdula-Argasińska *et al*., 2004).

RESULTS AND DISCUSSION

Examples of the use of a broad spectrum of ICP-MS in entomology including ecotoxicology, physiology, disease treatments, determining and removing environmental contaminations, homeostasis, and immune system are summarized in tables 1-4.

Table 1. Selected recent and specific examples to illustrate the range of applications of ICP-MS in ecotoxicology studies related to entomology

Heavy metal	Arthropod	Measure	Reference
Lead	*Drosophila melanogaster* (Tephritidae)	Behavioral (courtship, fecundity, locomotor activity) effects of chronic exposure	Hirsch *et al*., 2003
Cadmium	Wolfspiders (*Pardosa saltans*: Lycosidae)	Effects of experimental exposure on metallothionein-like protein levels from polluted and reference populations	Eraly *et al*., 2010
Cadmium, lambda-cyhalothrin	*Daphnia magna* (Daphniidae)	Binary mixtures of toxic substances: pharmacological versus ecotoxicological modes of action	Barata *et al*., 2007
Zinc	*Daphnia magna* (Daphniidae)	Bioaccumulation by waterborne and dietary exposure	Balcaen *et al*., 2008
Mg, K, Na, Zn, Fe, Al, Cu, Sr, Ba, Mn, Ti, Se, Mo, Ag, Cd, Co, Li, Ce	*Oxidusgracilis* (Polydesmida: Paradoxosomatidae)	Distribution and relation to environmental habitats	Nakamura and Taira, 2005
Cadmium, copper, lambda-cyhalothrin, deltamethrin	*Daphnia magna* (Daphniidae)	Toxicity of binary mixtures of metals and pyrethroid insecticides, implications for multi-substance risks assessment	Barata *et al*., 2006
Cr, Co, Fe, Mg, Mn, Ni, Se, Na, Zn	Tobacco budworm (*Heliothis virescens*: Lepidoptera: Noctuidae)	Uptake of dietary micronutrients from artificial diets	Popham and Shelby, 2006
Na, K, Mg, Ca, Cu, Zn	*Bombyx mori* (Bombycidae)	Effect of metallic ions on silk formation	Zhou *et al*., 2005
Arsenic	*Stenopsyche marmorata* (Trichoptera: Stenopsychidae)	Rapid determination of arsenic species	Miyashita *et al*., 2009
Arsenic	*Cherax destructor* (Parastacidae)	Arsenic speciation	Williams *et al*., 2009
Arsenic	Terrestrialinvertebrates	Arsenic speciation	Moriarty *et al*., 2009
Arsenic	*Mya arenaria*	Speciation analysis	Yang *et al*., 2009
Cd, Cu, Zn	*Penaeus semisulcatus* (Penaeidae), *Penaeus merguiensis* (Penaeidue)	Distribution of trace elements in tissues of two shrimp species from the Persian Gulf and roles of metallothionein in their redistribution	Pourang and Dennis, 2005

In addition to the application of inductive coupled plasma-mass spectrometry in the various sciences, the use of this method of analysis can be used to determine most trace and ultra-trace metals, and some nonmetals, tracking of elements in biological samples and various studies that will be done on arthropods or related subjects to entomology such as ecotoxicology, physiology, disease treatments, determining and removing environmental contaminations, homeostasis, and immune system. Based on principles, ICP-MS device is similar to the atomic emission spectroscopy method that can be used as a prominent, efficient, and very special tool in the process of various samples analysis. Inductively coupled plasma-mass spectroscopy can be coupled with devices such as mass spectrometers, chromatography, or polyacrylamide gel electrophoresis for identifying and quantifying of the native metal cofactor of proteins and their phosphorylation in biofluids, determination of pesticides residues, etc.

Table 2. Selected recent and specific examples to illustrate the range of applications of ICP-MS in physiology and bioindication studies related to entomology.

Heavy metals	**Arthropod**	**Measure**	**Reference**
Iron	*Aedes aegypti* larvae	Regulation of cell ferritin	Geiser *et al*., 2007
Iron	*Aedesaegypti*larvae	Secreted ferritin: mosquito defense against iron overload	Geiser *et al*., 2006
Cu, Zn	*Drosophila melanogaster*	Metallothioneins (MTO): the second member of a *Drosophila* dual copper-thionein system	Domenech *et al*., 2003
Ferrihemeproteinnitrophorin-7	*Rhodnius prolixus* (Reduviidae)	Overexpression in *Escherichia coli* (Enterobacteriaceae) and functional reconstitution of the liposome binding ferriheme protein nitrophorin-7	Knipp *et al*., 2007
		Bioindication	
Finnish Cu-Ni smelter	Oribatid mites (*Chamobates cuspidatus*: Oribatidae)	Leg deformities of oribatid mites as an indicator of environmental pollution	Eeva and Penttinen, 2009
As, Cd, Cu, Pb, Zn	Earthworms, beetles and woodlice	Habitat type-based bioaccumulation and risk assessment of metal and As contamination	Vermeulen *et al*., 2009
La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu	*Paramoera walkeri* (Eusiridae, Amphipoda)	Baseline metal concentrations	Palmer *et al*., 2006
Cd, Cu, Zn, Pb, As	Red swamp crayfish (*Procambarus clarkia*: Cambaridae)	Indicator of the bioavailability of heavy metals in environmental monitoring in the River Guadiamar (SW, Spain)	Alcorlo *et al*., 2006
As, Cd, Co, Cr, Cu, Fe, Hg, Mn, Pb, Zn	Insects	Heavy metal contamination survey	Nasirian, 2013

Table 3. Selected recent and specific examples to illustrate the range of applications of ICP-MS in human treatment disease studies related to entomology.

Heavy metal	Arthropod, disease treatment/ agent	Measure	Reference
Microelements (Al, Co, Cu, Zn, Mn, Mo, B, V, Sr, Ni); Macro-elements (Ca, Mg, K, Na); Toxic metals (As, Ba, Pb, Cd, Sb, Cr)	Honeybee (*Apis mellifera*: Apidae)	Determination of metals in honeybee venom	Kokot and Matysiak, 2008
Cisplatin	*Drosophila melanogaster*	DNA adducts induced by cisplatin and their correlation with genotoxic damage	García *et al*., 2008
Iron	*Trypanosoma brucei brucei*	Purification and kinetic characterization of recombinant alternative oxidase	Kido *et al*., 2010
Antimony	Treatment of leishmaniasis	Speciation of antimony in injectable drugs used for leishmaniasis treatment	Seby *et al*., 2012
Antimony	Treatment of leishmaniasis	Antimony in plasma and skin of patients with cutaneous leishmaniasis-relationship with side effects	Neves *et al*., 2009
Antimony	Treatment of leishmaniasis	Monitoring of total antimony and its species in biological samples from patients	Miekeley *et al*., 2002
Antimony	Treatment of leishmaniasis	Speciation of antimony (III) and antimony (V) in cell extracts	Ulrich *et al*., 2000
Antimony	*Leishmania donovani*	Novel Intracellular SbV reducing activity correlates with antimony susceptibility	Shaked- Mishan *et al*., 2001

Table 4. Selected recent and specific examples to illustrate the range of applications of ICP-MS in miscellaneous studies related to entomology.

Heavy metals	Organism	Measure	Reference
	Bioremediation		
Selenium	*Cotesia marginiventris (Hymenoptera: Braconidae)*, parasitizing the beet armyworm (*Spodoptera exigua*: Noctuidae), feeding on alfalfa (*Medicago sativa*)	Biotransformations in an insect ecosystem: effects of insects on phytoremediation	Vickerman *et al*., 2004
	Hemostasis		
Al, Ba, Sr, Bi, Cd, Hg, Pb, Sn, Te, Tl, W, Sb, Cr, Ni, Ti, V, Co, Mo, P, S, Ca, Mg, K, Na, Zn, Fe, Cu, Mn	Royal jelly from *Apis mellifera*	Trace and mineral elements in royal jelly and homeostatic effects	Stocker *et al*., 2005

Insect immune system			
As, Cd, Cu, Ni, Pb	Free-living wood ant (*Formica aquilonia*: Hymenoptera: Formicidae)	Immune response disturbance	Sorvari *et al*., 2007
Metalloprotein	*Ostrinia furnacalis* (Lepidoptera: Pyralidae) larvae	Purification and characterization of hemolymph prophenoloxidase	Feng *et al*., 2008
Forensic medicine			
Pb, Ba, Sb	Forensically important blowfly *Calliphora dubia* (Diptera: Calliphoridae)	Extraction of gunshot residues from the larvae	Roeterdink *et al*., 2004
Environmental pollution			
Lead	Western fence lizards (*Sceloporus occidentalis*: Phrynosomatidae), *Acheta domestica* (Gryllidae), *Tenebrio molitor* (Tenebrionidae) larvae, *Porcellio scaber* (Porcellionidae)	Assessment of lead uptake in reptilian prey species	Inouye *et al*., 2007
Selenium, arsenic, copper, cadmium	Eastern mosquitofish (*Gambusia holbrooki*: Poeciliidae)	Respiratory and reproductive characteristics	Staub *et al*., 2004
Mn, Cd, Pb	Bank vole (*Clethrionomys glareolus*: Cricetidae)	Heavy metal of teeth as an indicator of environmental pollution	Gdula-Argasińska *et al*., 2004
Bioindication			
As, Cd, Co, Cr, Cu, Fe, Hg, Mn, Pb, Zn	*Gambusia affinis* (Poeciliidae)	Heavy metal bioconcentration	Nasirian *et al*., 2013

ACKNOWLEDGEMENTS

This study is a preparing preliminary PhD thesis of the first author's in Medical Entomology and Vector Control from Department of Medical Entomology and Vector Control, School of Public Health, supported by Tehran University of Medical Sciences, Tehran, Iran. The authors would like to thank professor Yavar Rassi for truly support to carry out this research.

REFERENCES

Alcorlo, P., M. Otero, M. Crehuet, A. Baltanás and C. Montes 2006. The use of the redswampcrayfish (*Procambarus clarkii*, Girard) as indicator of the bioavailability of heavymetals in environmental monitoring in the River Guadiamar (SW, Spain). *Sci. Total. Environ.* 366(1): 380-90.

Balcaen, L.I., K.A. De Schamphelaere, C.R. Janssen, L. Moens and F. Vanhaecke 2008. Development of a method for assessing the relative contribution of waterborne and dietary exposure to zinc bioaccumulation in *Daphnia magna* by using isotopically enriched tracers and ICP-MS detection. *Anal. Bioanal. Chem.* 390(2): 555-69.

Banerjee, D., S.J. Kim, H. Wu, W. Xu, L.A. Borkowskiand, J. Li and J.B. Parise 2010. Anionic Gallium-based metal-organic framework and its sorption and ion-exchange properties. *Inorg. Chem.* Dec 8.

Barata, C., D.J. Baird, A.J. Nogueira, A.M. Soares and M.C. Riva 2006. Toxicity of binary mixtures of metals and pyrethroid insecticides to *Daphnia magna* Straus. Implications for multi-substance risks assessment. *Aquat. Toxicol.* 78(1): 1-14.

Barata, C., D.J. Baird, A.J. Nogueira, A.R. Agra and A.M. Soares 2007. Life-history responses of *Daphnia magna* Straus to binary mixtures of toxic substances: pharmacological versus ecotoxicological modes of action. *Aquat. Toxicol.* 84(4): 439-49.

Bassioni, G., A.E. Pillay, M. El Kadi, F. Fegali, S.C. Fok and S. Stephen 2010. Tracking traces of transition metals present in concrete mixtures by inductively-coupled plasma mass spectrometry studies. *Eur. J. Mass. Spectrom. (Chichester, Eng).* 16(6): 679-92.

Berg, J. M., S. Ho, W. Hwang, R. Zebda, K. Cummins, M.P. Soriaga, R. Taylor, B. Guo and C.M. Sayes 2010. Internalization of Carbon Black and Maghemite Iron Oxide nanoparticle mixtures Leads to oxidant production. *Chem. Res. Toxicol.* Nov 10.

Boulassel, B., N. Sadeg, O. Roussel, M. Perrin and H. Belhadj-Tahar 2010. Fatal poisoning by vanadium. *Forensic Sci. Int.* Dec 2.

Chen, B., M. He, X. Mao, R. Cui, D. Pang and B. Hu 2011. Ionic liquids improved reversed-phase HPLC on-line coupled with ICP-MS for selenium speciation.*Talanta,* 83(3): 724-31.

Domenech, J., O. Palacios, L. Villarreal, P. Go

nzález-Duarte, M. Capdevila, S. Atrian and F.E.B.S. Lett 2003. MTO: the second member of a *Drosophila* dual copper-thionein system. *FEBS Lett.* 533(1-3): 72-8.

Eeva, T. and R. Penttinen 2009. Leg deformities of oribatid mites as an indicator of environmental pollution. *Sci. Total Environ.* 407(16): 4771-6.

Engelhard, C. 2010. Inductively coupled plasma mass spectrometry: recent trends and developments. *Anal. Bioanal. Chem.* Oct 29.

Eraly, D., F. Hendrickx, L. Bervoets and L. Lens 2010. Experimental exposure to cadmium affects metallothionein-like protein levels but not survival and growth in wolf spiders from polluted and reference populations. *Environ. Pollut.* Apr 1.

Faucher, L., A.A. Guay Bégin, J. Lagueux, M.F. Cote, E. Petitclerc and M.A. Fortin 2010. Ultra-small Gadolinium oxide nanoparticles to image brain cancer cells in vivo with MRI. *Contrast Media Mol. Imaging,* December 1.

Feng, C., Q. Song, W. Lü and J. Lu 2008. Purification and characterization of hemolymph prophenoloxidase from *Ostrinia furnacalis* (Lepidoptera: Pyralidae) larvae. *Comp. Biochem. Physiol. B. Biochem. Mol. Biol.* 151(2): 139-46.

Galiová, M., J. Kaiser, K. Novotný, M. Hartl, R. Kizek and P. Babula 2010. Utilization of laser-assisted analytical methods for monitoring of lead and nutrition items distribution in fresh and dried *Capsicum annuum* L. leaves. *Microsc. Res. Tech.* December 16.

Garcia, M. H., D.H. Moreno, F.S. Rodriguez, A.L. Beceiro, L.E. Alvarez and M.P. Lopez 2010. Sex-and age-dependent accumulation of heavy metals (Cd, Pb and Zn) in liver, kidney and muscle of roe deer (*Capreolus capreolus*) from NW Spain. *J. About. Sci. Health. A. Tox. Hazard. Subst. About. Eng.* 46(2): 109-116.

García, S.D., M. Montes-Bayón, L. Aguado Ortiz, E. González- Blanco, M. Sierra and A. Sanz-Medel 2008. In vivo detection of DNA adducts induced by cisplatin using capillary HPLC-ICP-MS and their correlation with genotoxic damage in *Drosophila melanogaster*. *Anal. Bioanal. Chem.* 390(1): 37-44.

Gdula-Argasińska, J., J. Appleton, K. Sawicka-Kapusta and B. Spence 2004. Further investigation of the heavy metal content of the teeth of the bank vole as an exposure indicator of environmental pollution in Poland. *Environ. Pollut.* 131(1): 71-9.

Geiser, D.L., J.D. Zhang and J. Winzerling 2006. Secreted ferritin: mosquito defense against iron overload? *Insect Biochem. Mol. Biol.* 36(3): 177-87.

Geiser, D.L., J.J.J. Mayo and J. Winzerling 2007. The unique regulation of *Aedes aegypti* larval cell ferritin by iron. Insect Biochem. *Mol. Biol.* 37(5): 418-29.

Ghaedi, M., F. Ahmadi and A. Shokrollahi 2007. Simultaneous preconcentration and determination of copper, nickel, cobalt and lead ions content by flame atomic absorption spectrometry. *J. Hazard Mater.* 142(1-2): 272-8.

Goenaga-Infante, H., S. Kassam, E. Stokes, C. Hopley and S.P. Joel 2010. Capabilities of HPLC with APEX-Q nebulisation ICP-MS and ESI MS/MS to compare selenium uptake and speciation of non-malignant B cell lymphoma with different lines. *Anal. Bioanal. Chem.* December 8.

Groessl, M., M. Terenghi, A. Casini, L. Elviri, R. Lobinski and P.J. Dyson 2010. Reactivity of anticancer metallodrugs with serum proteins: new insights from size exclusion chromatography-ICP-MS and ESI-MS. *J. Anal. At. Spectrom.* 25(3): 305-313.

Hanada, T., H. Isobe, T. Saito, S. Oguraand, H. Takekawa, K. Yamazaki, Y. Tokuchi and Y. Kawakami 1998. Intracellular accumulation of thallium as a marker of cisplatin cytotoxicity in nonsmall cell lung carcinoma: an application of inductively coupled plasma mass spectrometry. *Cancer,* 83(5): 930-5.

Hansen, C., B. Schmidt, E.H. Larsen, B. Gammelgaard, S. Stürup and H.R. Hansen 2010. Quantitative HPLC-ICP-MS analysis of antimony redox speciation in complex sample matrices: new insights into the Sb-chemistry causing poor chromatography recoveries. *Analyst,* December 14.

Hariri, G., M.S. Wellons, W.H. Morris, C.M. Lukehart and D.E. Hallahan 2010. Multifunctional FePt nanoparticles for radiation-guided targeting and imaging of cancer. *Ann. Biomed. Eng.* December 4.

Hirsch, H. V., J. Mercer, H. Sambaziotis, M. Huber, D.T. Stark, T. Torno-Morley, K. Hollocher, H. Ghiradella and D.M. Ruden 2003. Behavioral effects of chronic exposure to low levels of lead in *Drosophila melanogaster*. *Neurotoxicol.* 24(3): 435-42.

Inouye, L. S., L.J. Yoo, L.G. Talent, J.U. Clarke, R.P. Jones, J.A. Steevens and R.E. Boyd 2007. Assessment of lead uptake in reptilian prey species. *Chemosphere,* 68(8): 1591-6.

Jamshidi Badr, M., F. Masoudi, A.S. Collinsand and G. Cox 2010. Dating of precambrian metasedimentary rocks and timing of their metamorphism metamorphic complex in the Soursat (NW IRAN): Using LA-ICPMS U-Pb Dating of Zircon and Monazite. *J. Scien. Islamic Repub. Iran.* 21(4): 311-319.

Judd, C.D. and K. Swami 2010. ICP-MS determination of lead isotope ratios in legal and counterfeit cigarette tobacco samples. *Isotopes Environ. Health. Stud.* 46(4):484-94.

Judy, J.D., J.M. Unrine and P.M. Bertsch 2010. Evidence for biomagnification of gold nanoparticles within a terrestrial food chain. *Environ. Sci. Technol.* Dec 3.

Kido, Y., K. Sakamoto, K. Nakamura, M. Harada, T. Suzuki, Y. Yabu, H. Saimoto, F. Yamakura, D. Ohmori, A. Moore, S. Harada and K. Kita 2010. Purification and kinetic characterization of recombinant alternative oxidase from *Trypanosoma brucei brucei*. *Biochim. Biophys. Acta.* 1797(4): 443-50.

Knipp, M., H. Zhang, R.E. Berry and F.A. Walker 2007. Overexpression in *Escherichia coli* and functional reconstitution of the liposome binding ferriheme protein nitrophorin 7 from the bloodsucking bug *Rhodnius prolixus*. *Protein Expr. Purif.* 54(1): 183-91.

Kokot, Z. J. and J. Matysiak 2008. Inductively coupled plasma mass spectrometry determination of metals in honeybee venom*. J. Pharm. Biomed. Anal.* 48(3): 955-9.

Leufroy, A., L. Noël, V. Dufailly, D. Beauchemin and T. Guérin 2011. Determination of seven arsenic species in seafood by ion exchange chromatography coupled to inductively coupled plasma-mass spectrometry following microwave assisted extraction: Method validation and occurrence data. *Talanta,* 83(3): 770-9.

Lewen, N. 2010. The use of atomic spectroscopy in the pharmaceutical industry for the determination of trace elements in pharmaceuticals. *J. Pharm. Biomed. Anal.* Nov 27.

Lunoe, K., C. Gabel-Jensen, S. Stürup, L. Andresen and S. Skov, and B. Gammelgaard 2010. Investigation of the selenium metabolism in cancer cell lines. *Metallomics,* Dec 16.

Ma, D., M. Shen, Y.W. Luo, J. Bo, C. Xu and X.Y. Zhuo 2010. (Determination of blue ballpoint pen ink by laser ablation inductively coupled plasma mass spectrometry). *Guang Pu. Xue. Yu. Guang Pu. Fen. Xi.* 30(10): 2816-9.

Malsy, A. and L. Klemmb 2010. Distinction of gem spinels from the Himalayan mountain belt. *Chimia (Aarau),* 64(10): 741-6.

Mao, X., B. Chen, C. Huang, M. He and B. Hu 2010. Titania immobilized polypropylene hollow fiber as a disposable coating for stir bar sorptive extraction-high performance liquid chromatography-inductively coupled plasma mass spectrometry speciation of arsenic in chicken tissues. *J. Chromatogr. A.* Nov 11.

Martínez-Fernández, M., M.C. Barciela-Alonso, A. Moreda-Piñeiro and B. Bermejo-Barrera 2011. Matrix solid phase dispersion-assisted BCR sequential extraction method for metal partitioning in surface estuarine sediments. *Talanta,* 83(3): 840-9.

Miekeley, N., S.R. Mortari and A.O. Schubach 2002. Monitoring of total antimony and its species by ICP-MS and on-line ion chromatography in biological samples from patients treated for leishmaniasis. *Anal. Bioanal. Chem.* 372(3): 495-502.

Milliard, A., M. Durand-Jézéquel and D. Larivière 2011. Sequential automated fusion/extraction chromatography methodology for the dissolution of uranium in environmental samples for mass spectrometric determination. *Anal. Chim. Acta.* 684(1-2): 31-7.

Miyashita, S., M. Shimoya, Y. Kamidate, T. Kuroiwa and O. Shikinoetal 2009. Rapid determination of arsenic species in freshwater organisms from the arsenic-rich Hayakawa River in Japan using HPLC-ICP-MS. *Chemosphere,* 75(8):1065-73.

Moriarty, M.M., I. Koch, R.A. Gordon and K.J. Reimer 2009. Arsenic speciation of terrestrial invertebrates. *Environ. Sci. Technol.* 43(13): 4818-23.

Nakamura, K. and Taira, J. 2005. Distribution of elements in the millipede, *Oxidus gracilis* C. L. Koch (Polydesmida: Paradoxosomatidae) and the relation to environmental habitats. *Biometals,* 18(6): 651-8.

Nasirian, H. 2007. Duration of fipronil and imidacloprid gel baits toxicity against *Blattella germanica* strains of Iran. Iran. J. Arthropod-Borne Dis. 1 (2): 40-47.

Nasirian, H. 2008. Rapid elimination of German Cockroach, *Blattella germanica*, by fipronil and imidacloprid gel baits. *Iran. J. Arthropod-Borne Dis.* 2(1): 37-43.

Nasirian, H. 2010. An overview of German Cockroach, *Blattella germanica*, studies conducted in Iran. *Pak. J. Biol. Sci.* 13(22): 1077-1084.

Nasirian, H. 2013. Using insects for heavy metal contamination survey in Shadegan wetland. Thesis for fulfillment of the PhD Degree in Medical Entomology and Vector Control, School of Public Health, Tehran University of Medical Sciences.

Nasirian, H., A.H. Mahvi, M. Hosseini, B. Vazirianzadeh, S.M.T. Sadeghi and S. Nazmara 2013. Study on the heavy metal bioconcentration of the Shadegan international wetland mosquitofish, *Gambusia affinis*, by inductively coupled plasma technique. *J. Environ. Health Sci. Eng.* 11: 22.

Nasirian, H., H. Ladonni, B. Davari, M. Shayeghi, M.R. Yaghoobi Ershadi and H. Vatandoost 2006a. Effect of fipronil on permethrin sensitive and resistant strains of *Blattella germanica*. *Sci. J. Kurdistan Univ. Med. Sci.* 11: 33-41. (In persion with English abstract).

Nasirian, H., H. Ladonni, H. Vatandoost, M. Shayeghei and A. Poudat 2006d. Laboratory performance of 0.05% fipronil and 2.15% imidacloprid gel baits against German cockroaches, *Blattella germanica*. *Hormozgan Med. J.* 10: 24-25. (In persion with English abstract).

Nasirian, H., H. Ladonni, M. Shayeghi, H. Vatandoost, M.R. Yaghoobi-Ershadi, R. Rassi, M. Abolhassani and M.R. Abaei 2006c. Comparison of permethrin and fipronil toxicity against German Cockroach (Dictyoptera: Blattellidae) strains. *Iran. J. Publ. Health.* 35: 63-67.

Nasirian, H., H. Ladonni, M. Shayeghi, H. Vatandoost, Y. Rassi, M.R. Yaghoobi Ershadi, J. Rafinejad and H.R. Basseri 2006b. Duration of fipronil WHO glass jar method toxicity against susceptible and feral German Cockroach strains. *Pak. J. Biol. Sci.* 9: 1955-1959.

Nasirian, H., H. Ladonni, M. Shayeghiand and M. Soleimani-Ahmadi 2006f. Iranian non-responding contact method German Cockroach permethrin resistance strains resulting from field pressure pyrethroid spraying. *Pak. J. Biol. Sci.* 12: 643-647.

Nasirian, H., H. Ladonni and H. Vatandoost 2006e. Duration of fipronil topical application toxicity in *Blattella germanica* field population strains. *Pak. J. Biol. Sci.* 9: 800-804.

Neves, D.B., E.D. Caldas and R.N. Sampaio 2009. Antimony in plasma and skin of patients with cutaneous leishmaniasis-relationship with side effects after treatment with meglumine antimoniate. *Trop. Med. Int. Health,* 14(12): 1515-22.

Palmer, A. S., I. Snape, J.S. Stark, G.J. Johnstone and A.T. Townsend 2006. Baseline metal concentrations in *Paramoera walkeri* from EastAntarctica. *Mar. Pollut. Bull.* 52(11): 1441-9.

Popham, H.J. and K.S. Shelby 2006. Uptake of dietary micronutrients from artificial diets by larval *Heliothis virescens*. *J. Insect Physiol.* 52(7): 771-7.

Pourang, N. and J.H. Dennis 2005. Distribution of trace elements in tissues of two shrimp species from the Persian Gulf and roles of metallothionein in their redistribution. *Environ. Int.* 31(3): 325-41.

Qiao, J., X. Hou, P. Roos and M. Miro 2010. High-throughput sequential injection method for simultaneous determination of Plutonium and Neptunium in environmental solids using macroporous anion-exchange chromatography, followed by inductively coupled plasma mass spectrometric detection. *Anal. Chem.* Dec 1.

Qin, Z., J.A. Caruso, B. Lai, A. Matusch and J.S. Becker 2010. Trace metal imaging with high spatial resolution: applications in biomedicine. *Metallomics,* Dec 7.

Roeterdink, E.M., I.R. Dadour and R.J. Watling 2004. Extraction of gunshot residues from the larvae of the forensically important blowfly *Calliphora dubia* (Macquart) (Diptera: Calliphoridae). *Int. J. Legal. Med.* 118(2): 63-70.

Ryan, R., E. McEvoy, D. Sheila, J. Power and K. Altria 2011. Recent developments in the methodology and application of MEEKC. *Electrophoresis,* 32(1): 184-201.

Sadeghi, S.M.T. 1999. Chemistry for environmental engineering. Sawyer CN, McCarty P. Translated by Sadeghi S.M.T. Tehran University of Medical Sciences press.

Sadeghi, S.M.T. 2011. Chemical analysis (Modern instrumental methods & techniques). Rouessac F, Rouessac A. Translated by Sadeghi S.M.T. Tehran University Press.

Séby, F., C. Gleyzes, O. Grosso, B. Plau and O.F. Donard 2012. Speciation of antimony in injectable drugs used for leishmaniasis treatment (Glucantime®) by HPLC-ICP-MS and DPP. *Anal. Bioanal. Chem.* 404(10): 2939-48.

Shaked-Mishan, P., N. Ulrich, M. Ephros and D. Zilberstein 2001. Novel intracellular SbV reducing activity correlates with antimony susceptibility in *Leishmania donovani*. *J. Biol. Chem.* 276 (6): 3971-6.

Silva, L. F., X. Querol, K.M. da Boit, S.F. Vallejuelo and J.M. Madariaga 2010. Brazilian coal mining residues and sulphide oxidation by Fenton's reaction: an accelerated weathering procedure to evaluate possible environmental impact. *J. Hazard. Mater.* Nov 13.

Sorvari, J., L.M. Rantala, M.J. Rantala, H. Hakkarainen and T. Eeva 2007. Heavy metal pollution disturbs immune response in wild ant populations. *Environ. Pollut.* 145(1): 324-8.

Stafilov, T., M. Aliu and R. Sajn 2010. Arsenic in surface soils affected by mining and metallurgical processing in K. Mitrovica region, Kosovo. *Int. J. Environ. Res. Public Health,* 7(11): 4050-61.

Staub, B.P., W.A. Hopkins, J. Novak and J.D. Congdon 2004. Respiratory and reproductive characteristics of eastern mosquitofish (*Gambusia holbrooki*) inhabiting a coal ash settling basin. *Arch. Environ. Contam. Toxicol.* 46(1): 96-101.

Stocker, A., P. Schramel, A. Kettrup and E. Bengsch 2005. Trace and mineral elements in royal jelly and homeostatic effects. *J. Trace. Elem. Med. Biol.* 19(2-3): 183-9.

Sun, J., M. Zborowski and J.J. Chalmers 2010. Quantification of both the presence, and oxidation state, of Mn in *Bacillus atrophaeus* spores and its imparting of magnetic susceptibility to the spores. *Biotechnol. Bioeng.* Dec 16.

Tang, J., L. Xiong, G. Zhou, S. Wang, J. Wang, L. Liu, J. Li, F. Yuan, S. Lu, Z. Wan, L. Chou and T. Xi 2010. Silver nanoparticles crossing through and distribution in the blood-brain barrier in vitro. *J. Nanosci. Nanotechnol.* 10(10): 6313-7.

Thornton, C.P., C.C. Lamberg-Karlovsky, M. Liezers and S.M. Young 2002. On pins and needles: tracing the evolution of copper-base alloying at Tepe Yahya, Iran, via ICP-MS analysis of common-place items. *J. Archaeol. Scien.* 29(12): 1451-1460.

Truong, L., I.S. Moody, D.P. Stankus, J.A. Nason, M.C. Lonergan and R.L. Tanguay 2010. Differential stability of lead sulfide nanoparticles influences biological responses in embryonic zebrafish. *Arch. Toxicol.* Dec 8.

Ulrich, N., P. Shaked and D. Zilberstein 2000. Speciation of antimony (III) and antimony (V) in cell extracts by anion chromatography/inductively coupled plasma mass spectrometry. *Fresenius J. Anal. Chem.* 368(1): 62-6.

Vermeulen, F., N.W. Van den Brink, H.D. 'Havé, V.K. Mubiana, R. Blust, L. Bervoets and W. De Coen 2009. Habitat type-based bioaccumulation and risk assessment of metal and as contamination in earthworms, beetles and woodlice. *Environ. Pollut.* 157(11): 3098-105.

Vickerman, D.B., J.T. Trumble, G.N. George, I.I. Pickering and H. Nichol 2004. Selenium biotransformations in an insect ecosystem: effects of insects on phytoremediation. *Environ. Sci. Technol.* 38(13): 3581-6.

Wang, J.P., X.X. Ma, G.Z. Fang, S. Wang and H.L. Yin 2010. (Determination of six heavy metals elements in drinking water by inductively coupled plasma mass spectrometry). *Guang Pu. Xue. Yu. Guang Pu. Fen. Xi.* 30(10): 2827-9.

Williams, G., J.M. West, I. Koch, K.J. Reimer and E.T. Snow 2009. Arsenic speciation in the freshwater crayfish, *Cherax destructor* Clark. *Sci. Total Environ.* 407(8): 2650-2658.

Worley, J. and S. Kvech, 2000. ICP-MS [Online]. Available at: http://www.cee.vt.edu/ewr/environmental/teach/smprimer/icpms/icpms.htm

Yang, G., J. Xu, J. Zheng, X. Xu, W. Wang, L., Xu, G. Chen and F. Fu 2009. Speciation analysis of arsenic in *Myaarenaria linnaeus* and Shrimp with capillary electrophoresis-inductively coupled plasma mass spectrometry. *Talanta,* 78(2):471-6.

Yoshimura, Y., Y. Endo, Y. Shimoda, K. Yamanaka and G. Endo 2010. Acute arsine poisoning confirmed by speciation analysis of arsenic compounds in the plasma and urine by HPLC-ICP-MS.J. *Occup. Health,* Nov 25.

Zhou, G., Y. Li, Y. Liu, C. Ge, W. Li, Y. Gao and C. Chen, 2010. Subcellular distribution of poly hydroxylated metallo fullerene GdC82(OH)22 in different tissues of tumor-bearing mice. *J. Nanosci. Nanotechnol.* 10(12): 8597-602.

Zhou, L., X. Chen, Z. Shao, Y. Huang and D.P. Knight 2005. Effect of metallic ions on silk formation in the Mulberry silkworm, *Bombyx mori*. *J. Phys. Chem. B.* 109(35): 16937-45.