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Source of lead pollution, its influence on public health and the countermeasures.

Rui Zhang[1], Vincent L. Wilson[1], Aixin Hou[1*], Ge Meng[2]

[1]*Department of Environmental Sciences, School of the Coast & Environment, Louisiana State University, USA*

[2]*School of Pharmacy, Xi'an Jiaotong University, China*

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CORRESPONDING AUTHOR

Aixin Hou

Department of Environemental Sciences, 1285 Energy, Coast & Environment Building, Louisiana State University, Baton Rouge, LA, 70803, USA

e-mail: ahou@lsu.edu
phone: +01 2255784294

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ABSTRACT.

Lead is a well-known toxic heavy metal, which can have serious public health hazards at very low levels, especially for young children. This report summarized the background information on lead and its applications, pollution sources, poisoning pathways, biomarkers of exposure and effects, toxicities, poisoning mechanisms, preventive actions, decontamination strategies, and detoxification methods.

1 Introduction

1.1 The discovery of lead

Lead is an abundant heavy metal in the Earth, about 14 parts per million by weight or 1 part per million by moles. It rarely occurs in pure form in nature. Lead is usually found in ores, mostly with copper, zinc and silver. The most common lead mineral is galena, which is lead sulfide (PbS). Other minerals include lead carbonate ($PbCO_3$) and lead sulfate ($PbSO_4$) (Holleman et al. 1985). Lead is usually extracted from PbS by heating and processing. It was discovered and used in prehistoric times. The ancient Romans used lead for plumbing and called it 'plumbum', which is what the symbol, Pb, represents.

1.2 The extraction of lead

The lead found in ore and other minerals, not in pure form. The separation of lead from other substances must go through a chemical refining process. The lead containing ore is first ground into small pieces, followed by dilution with water. Then the mixture is dumped into the flotation chamber to produce slurry of ground ore and water. Pine oil is added to the slurry to draw impurities. The slurry is continually stirred and shaken so that the ground ore can be separated from the impurities. Next the slurry is processed through a filter to remove liquids. The remaining substance was processed by smelting, initially removing sulfur by roasting (heating) in an oxidizing environment to produce lead oxide (PbO), which is then reduced to elemental lead (Avameg Inc 2014).

1.3 The physical and chemistry characteristics of lead

Lead is gray color, soft and ductile metal. Its density at 293 K (19.9 °C) is 11.34 g/cm^3 and it has a melting point of 621.5 °F (327.5 °C) and a boiling point of 3180 °F (1749 °C) (Lide 2004). It is insoluble in water but dissolves slowly in a weak acid solution. It has four isotopes (Rabinowitz et al. 1995; John et al. 1996). Lead is a member of carbon group in the periodical table and is defined as an inert metal. With heat, Pb will oxidize to produce PbO, and it will react with HNO_3 to produce $Pb(NO_3)_2$ (University of Sheffield and Web Elements Ltd 2014).

2 Application of lead

Batteries: The major use of lead is making rechargeable storage batteries. The grey negative electrode is made of Pb and the red colour on the positive electrode is PbO_2 in the battery. Airplanes, automobiles, electric vehicles, trucks, tanks, and broadcasting stations all use rechargeable storage batteries as the energy source for light. The manufacture of one battery requires dozens of kilograms of lead (Crompton 2000).

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Antiknock agent in gasoline: One of the most important organic compounds of Pb, tetraethyl lead (TEL, $(CH_3CH_2)_4Pb$) was invented as a very efficient and cheap antiknock additive to the gasoline by chemist Thomas Midgley, Jr., in 1921. The components of gasoline are complex, but the main constituents are C_4~C_{12} hydrocarbons. Various grades of gasoline have different compositions, so their physical and chemical characteristics are different. Commercial gasoline is rated by the octane numbers. The higher the octane number, the better the anti-knock capability of the gasoline. By adding a little TEL, the octane numbers can be enhanced significantly (Loeb 1995). From the 1920s to the 1970s, TEL was universally added to the gasoline. Following the discovery of the toxicities of Pb in TEL, its use in gasoline for automobile engines was phased out in the US. The time of cancellation of TEL use in gasoline in different countries was disparate. While most countries have banned or at least restricted the selling of commercial leaded gasoline, it is still used in countries such as Afghanistan and North Korea. In the US a small amount of TEL is still being used in marine and airplane engines.

Reaction tanks: Lead is usually a grey colour since it can be easily oxidized into PbO by oxygen in the air. PbO forms a dense film, covering the outside layer and preventing deeper layers of metal from being oxidized. This feature together with its stable chemistry makes lead resistant for degradation, so it is often used to make pipes and reaction tanks in the chemical industries. The famous "lead chamber process" for making sulphuric acid (H_2SO_4) was named due to the process of using a reaction tank made of lead (Zumdahl 2009).

Soldering: Soldering is used to join one or more metal pieces together such as in plumbing and other metal assemblies. Alloys commonly used for soldering include Tin and lead (Sn/Pb). Since the discovery of toxicity of lead, lead-free alloys have gradually replaced lead containing alloys used for soldering.

Wire and cable insulation and jacketing: Lead's ductility and extrusion ability, along with its corrosion resistance enabled lead alloys to be widely used for sheathing the high voltage cables.

Radiation shields: Lead's characteristic of being able to obstruct radioactive rays makes it a good material for shielding radiation. When patients in the hospitals are being diagnosed with X ray, a piece of lead plate is set in front of their chest to protect them (Bethesda 2004). Personnel working in atomic reactor also wear outfits containing lead to shield against radiation. Lead is also used in the glass of television and glass screens to shield the watcher from radiation.

Ammunitions: Lead is inexpensive and it has a low melting point, which makes casting easy. Its high density and weight can prevent bullets from being deflected by wind and air turbulence (Trinogga et al. 2013).

Stiffener in candle wicks: Lead was used as stiffener in some candles to ensure the candle burn longer and more even, although this kind of use has been banned in the US for many years (Nriagu and Kim 2000).

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Pigments: Many lead compounds have beautiful colours, so they were widely utilized as pigments. The white pigment lead carbonate ($PbCO_3$) was the most extensively used, while other lead pigments include yellow (lead chromate ($PbCrO_4$)), gold (lead iodide (PbI)) and black (lead sulphide (PbS)). As health hazards produced by lead-based pigments were discovered, most countries have remarkably curtailed the lead content of paints and colorants.

Others: Lead has also been used in other areas, including weights in sport instruments, water pipes, house and building roofs, various alloys, fuse wires, bearings, and lead crystal glassware (Beattie et al. 1972; Zietz et al. 2009).

3 Sources of lead pollution

Lead has become widely distributed in the environment since it was discovered and used by humans for a long time (Sturge and Barrie 1989; Sungmin et al. 1994; Ingemar et al. 2000; Branvall et al. 2001; Pompeani et al 2013). Natural lead pollution occurrs from volcanic explosions and forest fire. Non-natural sources were from human activities, mainly referring to the lead emission from the industry and transportation. Since the use of leaded gasoline, the auto vehicles were the main source of lead emissions to the air and several million tons of lead have been deposited in the soil in the United States. Efforts in removing lead from gasoline substantially lessened the emissions of lead into the air and environment. The major sources of lead emissions to the environment today are from ore and the processing of metals, as well as leaded aviation gasoline (Lin et al. 2011). The highest air lead levels occur close to lead smelters. Other sources are from manufacturing batteries, coal burning, typecasting, and in older houses and buildings (American Academy of Paediatrics Committee on Environmental Health 2005; Woof et al. 2007; Zhang et al. 2009). Since lead is not degraded by microbial activity, it is persistent in the environment and accumulates in soils, water bodies and sediments through deposition, leaching and erosion (Shotyk et al. 1998; Maja-Lena et al. 1999).

Apart from exposure to aerial lead released from legal industrial manufacturing, mining and smelting activities, other major exposure pathways also include intake of lead from consuming lead-contaminated water and food. As lead does not decompose, the longer fields have received effluent irrigation and fertilizer, the higher the level of lead accumulation in the soil. Cultured crops therefore often contain increased levels of lead due to uptake during the growing process. Importing food products from developing countries requires caution since lead contamination of food is more common in countries that do not have strict food standards. Food can become contaminated with lead due to the soil and water in the growing environment, or materials used in processing or cooking or the containers used in storage. Also, the lead concentration can be amplified through food chain. In addition, lead in dwellings is a well-known source of childhood lead exposure. It is common in lead-based paints, tap water, indoor and outdoor floor dust, and soil in and around old houses and buildings (Lucas et al. 2012). Other pathways include accidentally intake of lead from contaminated soil and dust, lead glazed ceramics, lead-based paint, lead acid batteries, electronic equipment with lead

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containing components, water from lead soldered plumbing, leaded Polyvinyl chloride (PVC) products, lead containing jewellery, toys, ammunition, lead contaminated herbal medicine, and cigarettes. Hand-to-mouth behaviour is an important mechanism of lead intake among small children (Day et al. 1975; Bruce and Klaus 1997).

4 Biomarkers of lead exposure and effect

Blood lead reflects soft tissue lead, representing the lead burden of body and the doses absorbed. Urine lead and plasma lead reflects recent lead exposure. Lead can interact with some enzymes responsible for heme synthesis, inhibiting δ-aminolevulinic acid dehydratase (ALAD). Variation in the concentrations of some metabolites such as δ-aminolevulinic acid in urine, blood or plasma, coproporphyrin in urine, and/or zinc protoporphyrin in blood can be used as the biomarkers for lead exposure. Since the heme precursors from ALAD genotype ALAD1 have higher affinity to lead than ALAD2, ALAD1 homozygotes are more susceptible to heme biosynthesis disturbance by lead than ALAD2 carriers. Decreased activities of pyrimidine nucleotidase and nicotinamide adenine dinucleotide synthetase in blood can also be used as the biomarkers for lead exposure effects (Sakai 2000).

5 Toxicities of lead

Since it cannot be degraded by microbial activity, lead is an environmentally persistent toxin, which accumulated upward the food chain. Once taken into the body, lead can distribute in the blood throughout the body and accumulate in the bones and soft tissues leading to chronic toxicity. Growing evidence supports the premise that no threshold exists for harmful effects from the lead exposure (Jasna and Gary 1988; Lanphear et al. 2005). Depending on the level of exposure, lead can cause neurological (Thomson and Parry 2006; Woof et al. 2007), hepatic (Singh et al. 1994), renal (Goyer and Rhyne 1973), hematological, circulatory, immunological, reproductive, developmental (Davis and Svendsgaard 1987), auditory (Stevens et al. 2013), gastrointestinal, and cardiovascular pathologies (Patrick 2006a, 2006b). Generally speaking, lead harms children more than adults. Infants and young children are especially sensitive to lower lead levels than adults, showing the lead poisoning effects such as neurological effects contributing to lowered intelligence quotient (IQ) (Hebert and Constantine 1990; David et al. 1992; Schwartz 1994; Richard et al. 2003; Lanphear et al. 2005, Bellinger 2008), learning deficits, cognitive deficits (Lanphear et al. 2000; Mostafa et al. 2009), lower vocabulary and grammatical-reasoning ability (Herbert et al. 1990), longer reaction time (Herbert et al. 1990), poorer hand-eye coordination (Herbert et al. 1990), deficits in psychological and classroom performance (Herbert et al. 1979), hyperactivity and behavioural problems (Oliver et al. 1972). The high lead poisoning prevalence in children may be caused by the facts that lead is efficiently absorbed and retained and the blood brain barrier is not fully developed in very young children (William et al. 1981; Ekhard et al. 1978). High bone lead levels are associated with increased risk of somatic complaints, attention problems, social problems, as well as anxious/depressed, aggressive and delinquent behaviours among children

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(Needleman et al. 1996). Chronic occupational exposure to lead was shown to increase the risk of Parkinson's disease (Gorell et al. 1999; Weisskopf et al. 2010). Chronic exposure to lead can also cause tooth loss and the damage of hard dental tissues (Cenic-Milosevic et al. 2013). In addition, lead can cross the placental barrier, leading the impacts on fetal development, especially the developing baby's nervous system. Lead may also cause abortion and stillbirths. Polluted ecosystems have adverse effects such as the losses in biodiversity, community components alteration, decreased pollen germination and seed viability, reduced growth and reproductive rates in plants and animals (Briggs 1972; Jens et al. 1979; Bull et al. 1983; Krishnayya and Bedi 1986; Myra et al. 2012; Magwedere et al. 2013).

Lead toxicity also affects farm animals such as cows and horses, as well as animal pets. In addition, hunting ammunition causes toxicity in wild bird populations since lead pellets (lead shot) is ingested by waterfowls such as ducks and swan. Predators consuming these lead contaminated birds are also at risk (Ferreyra et al. 2009). Lead shot has been banned for waterfowl hunting in several countries including US and Canada (Pokras and Kneeland 2008; Degernes 2008).

6 Mechanisms of lead poisoning

Lead readily interacts with proteins causing various toxic symptoms and pathologies (Goldstein 1990; Goering 1993). It has been well recognized that the presence of lead can affect the homeostasis and physiological function of essential metals. Lead may exert its toxicity via disturbing Ca-mediated cellular processes by simulating and replacing calcium at the binding sites of functional proteins like calmodulin (Pounds 1984; Jasna and Gary 1988; Goldstein 1993), directly interrupting calcium transportation or storage involving Ca2+ transport proteins or calcium gates, or by indirectly altering cell functions such as energy production and plasma membrane permeability (Pounds 1984). Interactions between Pb and high-affinity metal-binding proteins have been shown to play a role in the inhibition of Zn-containing enzymes and aminolevulinic acid dehydratase (Goering 1993). In return, the shortage or surplus of some necessary metals in human can modify the absorption and elimination of lead. For example, increased dietary zinc and calcium can reduce the severity of lead toxicity (Cerklewski and Forbes 1976). Other known proteins related to Pb toxicity include nucleic acid binding proteins, protein kinase, carbonic anhydrase and calmodulin (Goldstein 1990; Goering 1993). Lead also enhances oxidative reactions producing reactive oxygen species (ROS), which contribute to lead related diseases by inhibiting sulfhydryl antioxidants production, heme impair and DNA repair and inducing nucleic acid damage and peroxidation (Patrick 2006a, 2006b).

The toxicity of tetraethyl lead is 100 times higher than inorganic lead. Tetraethyl lead can induce poisoning by contact and absorption through intact skin, inhalation, or by ingestion. Following the combustion of leaded gasoline in the engine, 70% of TEL is released to the atmosphere in the form of fine particles, while the remaining will be accumulated in the engines. Forty percent of the lead particulates emitted to the air will fall to the ground quickly.

While TEL is suspended in the air, it can easily be inhaled into the lung through the human's respiratory system. The accumulation rate of the inhaled lead is as high as 50%. These lead particulates are not easily excreted and have a half-life of 25 years in the human body. Some of the absorbed lead will be transformed to triethyl lead, which can go through blood-brain barrier, damaging the central nervous system.

7 Preventive actions and decontamination strategies

Advancement of analytic technologies: Since lead toxicity has become well recognized, the main focus has shifted from high-dose effects of clinical symptoms to asymptomatic levels, specifically in young children. Many research studies have substantiated that even very low lead levels can cause brain development problems in children and no threshold has been identified for this effect. Children's blood lead concentration should be measured and the development of more advanced analytical technologies will help detect very low blood levles (Needleman 2004; American Academy of Pediatrics Committee on Environmental Health 2005; Maitreyi et al. 2011; McLaine et al. 2013).

Policies, regulations and supervisions: Although high dose lead poisoning has become rare globally, long-term exposure to low levels of lead remains an issue for public health. More policies, regulations and supervisions on environmental lead level should be developed to improve the environmental safety and eliminate the existing problems (Tong et al. 2000; David and Andrew 2006).

Lead-free technologies: Due to the harmful effects that lead can cause, replacement of the conventional lead-based materials by lead-free products was an inevitable trend. This trend includes the development of lead-free piezoelectric ceramics (Tadashi et al. 1997; Eric 2004; Yasuyoshi et al. 2004; Zang et al. 2006), lead-free solders (Mulugeta and Guna 2000; Katsuaki 2001), lead-free glass, and lead-free electronic assembly. Also, the development of new hydrometallurgical technologies significantly decreased the Pd pollution during lead recovering processes (Pan et al. 2013).

Industrial hygiene: Good industrial hygiene and close monitoring should be adopted in a timely manner to detect improper or excessive lead emission before it leads to environmental hazards and human health impacts (Thomson and Parry 2006).

Reduction of indoor lead pollution: Although the incidences of elevated blood lead levels in US children have decreased, a large number of children still dwell in old buildings with lead-based paint and are at risk of lead exposure with ensuing neurological damages (American Academy of Pediatrics Committee on Environmental Health 2005; Roberts et al. 2013). Remediation for removing these lead sources from children's home environments can help to reduce their lead exposure. Workers involved in lead remediation or working with lead containing materials should take frequent showers and change clothes following work

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activities before going home. Indoor dust should be removed regularly and frequently for people living near lead industrial areas.

Decontamination strategies: Phytoremediation is a more environmentally friendly improvement to the conventional chelating methodologies. Phytoremediation technologies use plants to absorb lead from contaminated soils are emerging with increased frequency (Huang et al. 1997; Huang and Cunningham 2006). Materials like apatite and carbon nanotubes can also be used for phytoextraction, such as to clean lead from contaminated water or soil systems (Ma et al. 1993; Li et al. 2002).

8 Lead detoxification

Taking chelating agents orally is a conventional therapy for acute lead intoxication (Patrick 2006a, 2006b; George et al. 2010). People who have developed the lead poisoning symptoms can take in food rich in protein, Fe, vitamin C, pectin, and/or garlicin to help detoxify and remove the lead. Fe can replace Pb to combine with the proteins in human, while protein can bind with lead to speed its metabolism and removal. Vitamin C can interact with Pb to produce water insoluble precipitates, which can be excreted through feces. Foods rich in Fe are greens and fruits such as spinach, celery, rape, radish, amaranth, shepherd's purse, tomatoes, oranges, peaches, plums, apricots, pineapples and red dates. Edible sources of good quality proteins include eggs, milk and lean meat. Vitamin C broadly exists in fruits, vegetables such as orange, lemon, dates, apple, strawberry, peppers, cabbage, garlic bolt, tomatoes and cauliflower. Additional foods or ingredients for detoxification include yogurt, which can stimulate intestinal peristalsis and decrease Pb absorption, pectin, which inhibits Pb absorption (Zhao et al. 2008), garlicin, which can bind with Pb to produce a nontoxic compound and antioxidants like vitamins B6, C and E, taurine, N-acetylcysteine, and α-lipoic acid, which are able to lower ROS generated cellular damages (Patrick 2006a, 2006b).

9 Conclusion

As a summary, lead has been applied in a wide range of fields on our planet for thousands of years. As its toxicities are gradually uncovered, policies and regulations should be taken to reduce or stop its use. Advanced strategies and technologies need to be developed to detect and cure the lead polluted environments.

References

Amal A.H., Manal M.Z., Manal A.A., Amal A.M., Raya A.S. 2010. Relation between anemia and blood levels of lead, copper, zinc and iron among children. BMC Research Notes. 3,133.

ISSN: 2283-3927

American Academy of Pediatrics Committee on Environmental Health. 2005. Lead exposure in children: prevention, detection, and management. Lead exposure in children: prevention, detection, and management. Pediatrics. 116(4), 1036-1046.

Avameg Inc. 2014. http://www.madehow.com/Volume-2/Lead.html

Beattie A.D., Moore M.R., Devenay W.T., Miller A.R., Goldberg A. 1972. Environmental Lead Pollution in an Urban Soft-water Area. Br Med J. 2(5812), 491-493.

Bellinger D.C. 2008. Very low lead exposures and children's neurodevelopment. Curr Opin Pediatr. 20(2), 172-177.

Bethesda M.D. 2004. Structural shielding design for medial X-ray imaging facilities. National Council on Radiation Protection and Measurement. 16-17.

Branvall M.L., Bindler R., Emteryd O., Renberg I. 2001. Four thousand years of atmospheric lead pollution in northern Europe: a summary from Swedish lake sediments. Journal of Paleolimnology. 25(4), 421-435.

Briggs D. 1972. Population Differentiation in Marchantia polymorpha L. in Various Lead Pollution Levels. Nature. 238, 166-167.

Bruce P.L., Klaus J.R. 1997. Pathways of Lead Exposure in Urban Children. Environ Res. 74(1), 67-73.

Bull K.R., Every W.J., Freestone P., Hall J.R., Osborn D., Cooke A.S., Stowe T. 1983. Alkyl lead pollution and bird mortalities on the Mersey Estuary, UK, 1979-1981. Environmental Pollution Series A, Ecological and Biological. 31(4), 239-259.

Cenic-Milosevic D., Mileusnic I., Kolak V., Pejanovic D., Ristic T., Jakovljevic A., Popovic M., Pesic D., Melih I. 2013. Environmental lead pollution and its possible influence on tooth loss and hard dental tissue lesions. Vojnosanitetski pregled. 70(8), 751-756.

Cerklewski F.L., Forbes R.M. 1976. The Journal of Nutrition. Influence of dietary zinc on lead toxicity in the rat. J Nutr. 106(5), 689-696.

Crompton T.R. 2000. Battery reference book. Oxford, England: Newnes. 18/2–18/4.

David C.B., Andrew M.B. 2006. Childhood lead poisoning: the torturous path from science to policy. J Clin Invest. 116(4), 853-857.

David C.B., Karen M.S., Herbert L.N. 1992. Low-Level Lead Exposure, Intelligence and Academic Achievement: A Long-term Follow-up. Pediatrics. 90(6), 855-61.

Davis J.M, Svendsgaard DJ. 1987. Lead and child development. Nature. 329(6137), 297-300.

Day J.P., Hart M., Robinson M.S. 1975. Lead in urban street dust. Nature. 253, 343-345.

Degernes L. 2008. Waterfowl toxicology: a review. The veterinary clinics of North America. Exotic animal practice 11(2), 283-300.

Ekhard E.Z., Barbara B.E., Robert L.J., Kathryn R.M., Samuel J.F. 1978. Absorption and retention of lead by infants. Pediatric Research. 12, 29-34.

Eric C. 2004. Lead-free at last. Nature. 432, 24-25.

ISSN: 2283-3927

Ferreyra H.R., Romano M., Uhart M. 2009. Recent and chronic exposure of wild ducks to lead in human-modified wetlands in Santa Fe Province, Argentina. Journal of wildlife diseases. 45(3), 823-827.

George D., George R., Christos H. 2010. Acute lead intoxication in a female battery worker: Diagnosis and management. J Occup Med Toxicol. 2010 Jul 7, 5-19.

Goering P.L. 1993. Lead-protein interactions as a basis for lead toxicity. Neurotoxicology. 14(2-3), 45-60.

Goldstein G.W. 1990. Lead poisoning and brain cell function. Environ Health Perspect. 89, 91-94.

Goldstein G.W. 1993. Evidence that lead acts as a calcium substitute in second messenger metabolism. Neurotoxicology. 14(2-3), 97-101.

Gorell J.M., Johnson C.C., Rybicki B.A., Peterson E.L., Kortsha G.X., Brown G.G., Richardson R.J. 1999. Occupational exposure to manganese, copper, lead, iron, mercury and zinc and the risk of Parkinson's disease. Neurotoxicology. 20(2-3), 239-247.

Goyer R.A., Rhyne B.C. 1973. Pathological effects of lead. Int Rev Exp Pathol. 12, 1-77.

Herbert L.N., Charles G., Alan L., Robert R., Henry P., Cornelius M., Peter B. 1979. Deficits in Psychologic and Classroom Performance of Children with Elevated Dentine Lead Levels. N Engl J Med. 300, 689-695.

Herbert L.N., Alan S., David B., Alan L., Elizabeth N.A. 1990. The Long-Term Effects of Exposure to Low Doses of Lead in Childhood. N Engl J Med. 322, 83-88.

Herbert L.N., Constantine A.G. 1990. Low-Level Lead Exposure and the IQ of Children: : A Meta-analysis of Modern Studies. JAMA. 263(5), 673-678.

Holleman A.F., Wiberg E., Wiberg Nils. 1985. Blei. Lehrbuch der Anorganischen Chemie (in German) (91-100 ed.). Walter de Gruyter. 801-810.

Huang J.W., Cunningham S.D. 2006. Lead phytoextraction: species variation in lead uptake and translocation. New Phytologist. 134(1), 75-84.

Huang W., Chen J.J., William R.B., Scott D.C. 1997. Phytoremediation of Lead-Contaminated Soils: Role of Synthetic Chelates in Lead Phytoextraction. Environ. Sci. Technol. 31(3), 800-805.

Ingemar R., Maja-Lena B., Richard B., Ove E. 2000. Atmospheric Lead Pollution History during Four Millennia (2000 BC to 2000 AD) in Sweden. A Journal of the Human Environment. 29(3), 150-156.

Jasna M., Gary W.G. 1988. Picomolar concentrations of lead stimulate brain protein kinase C. Nature. 334, 71-73.

Jens C., Tjell M.H., Hans M. 1979. Atmospheric lead pollution of grass grown in a background area in Denmark. Nature. 280: 425-426.

John G.F., Lorna J.E., Alex K., Bailey-Watts T.E. 1996. Stable Lead Isotope Record. 3080-3083.

Katsuaki S. 2001. Advances in lead-free electronics soldering. Current Opinion in Solid State and Materials Science. 5(1), 55-64.

Krishnayya N.S.R., Bedi S.J. 1986. Effect of automobile lead pollution on Cassia tora L. and Cassia occidentalis L. Environmental Pollution Series A, Ecological and Biological. 40(3), 221-226.

Lanphear B.P., Dietrich K., Auinger P., Cox C. 2000. Cognitive deficits associated with blood lead concentrations <10 microg/dL in US children and adolescents. Public Health Rep. 115(6), 521-529.

Lanphear B.P., Hornung R., Khoury J., Yolton K., Baghurst P., Bellinger D.C., Canfield R.L., Dietrich K.N., Bornschein R., Greene T., Rothenberg S.J., Needleman H.L., Schnaas L., Wasserman G., Graziano J., Roberts R. 2005. Low-level environmental lead exposure and children's intellectual function: an international pooled analysis. Environ Health Perspect. 113(7), 894-899.

Li Y.H., Wang S.G., Wei J.Q., Zhang X.F., Xu C.L., Luan Z.K., Wu D.H., Wei B.Q. 2002. Lead adsorption on carbon nanotubes. Chemical Physics Letter. 357(3-4), 263-266.

Lide D.R. 2004. CRC Handbook of Chemistry and Physics (84th ed.). Boca Raton (FL): CRC Press. ISBN 978-0-8493-0484-2.

Lin S., Wang X., Yu I.T., Tang W., Miao J., Li J., Wu S., Lin X. 2011. Environmental lead pollution and elevated blood lead levels among children in a rural area of China. Am J Public Health. 101(5), 834-841.

Loeb A.P. 1995. Birth of the Kettering Doctrine: Fordism, Sloanism and Tetraethyl Lead. Business and Economic History. 24(2).

Lucas J.P., Le B.B, Glorennec P., Etchevers A., Bretin P., Douay F., Sebille V., Bellanger L., Mandin C. 2012. Lead contamination in French children's homes and environment. Environ Res. 116, 58-65.

Ma Q.Y., Traina S.J., Logan T.J., Ryan J.A. 1993. In situ lead immobilization by apatite. Environmental Science & Technology. 27(9), 1803-1810.

Magwedere K., Shimwino J., Hemberger Y., Hoffman L.C., Midzi E.M., Dziva F. 2013. Lead and Cadmium Levels in Liver, Kidney and Muscle of Harvested Wild Springbok (Antidorcus marsupialis) Under Extensive Management in Southern and Southeastern Namibia. South African Journal of Wildlife Research. 43(1), 52-60.

McLaine P., Navas-Acien A., Lee R., Simon P., Diener-West M., Agnew J. 2013. Elevated Blood Lead Levels and Reading Readiness at the Start of Kindergarten. Pediatrics. 131(6), 1081-9.

Maitreyi M., David C.B., Matthew G., Kathleen A., Janine B., Herbert L.N. 2011. Low-level environmental lead exposure in childhood and adult intellectual function: a follow-up study. Environmental Health. 10, 24.

Maja-Lena B., Richard B., Ingemar R., Ove E., Jerzy B., Kjell B. 1999. The Medieval Metal Industry Was the Cradle of Modern Large-Scale Atmospheric Lead Pollution in Northern Europe. Environ. Sci. Technol. 33(24), 4391-4395.

Michael V.R., Andy D., Rosalind S., Steve E., Christopher M.S. 1996. Estimation of Lead and Arsenic Bioavailability Using a Physiologically Based Extraction Test. Environ. Sci. Technol. 30(2), 422-430.

ISSN: 2283-3927

Mostafa G.A., El-Shahawi H.H., Mokhtar A. 2009. Blood lead levels in Egyptian children from high and low lead-polluted areas: impact on cognitive function. Acta Neurol Scand. 120(1), 30-37.

Mulugeta A., Guna S. 2000. Lead-free Solders in Microelectronics. Materials Science and Engineering. 27(5-6), 95-141.

Myra E.F., Daniel F.D., Daniel G., Joe B., Joseph B., Molly C., Jesse G., Donald R.S. 2012. Lead poisoning and the deceptive recovery of the critically endangered California condor. Proc Natl Acad Sci USA. 109(28), 11449-54.

Needleman H. 2004. Lead poisoning. Annu Rev Med. 55, 209-22.

Needleman H.L., Riess J.A., Tobin M.J., Biesecker G.E., Greenhouse J.B. 1996. Bone lead levels and delinquent behavior. JAMA. 275(5), 363-369.

Nriagu J., Kim M.J. 2000. Emissions of lead and zinc from candles with metal-core wicks. The Science of the Total Environment. 250 (1-3), 37-41.

Oliver D., Julian C., Kytja V. 1972. Lead and hyperactivity. The lancet. 300(7783), 900-903.

Pan J.Q., Sun Y.Z., Li W., Knight J., Manthiram A. 2013. A green lead hydrometallurgical process based on a hydrogen-lead oxide fuel cell. Nature Communications. 4, 2178.

Patrick L. 2006a. Lead toxicity, a review of the literature. Altern Med Rev. 11(1), 2-22.

Patrick L. 2006b. Lead toxicity part II: the role of free radical damage and the use of antioxidants in the pathology and treatment of lead toxicity. Alternative Medicine Review: a Journal of Clinical Therapeutic. 11(2), 114-127.

Pokras M., Kneeland M., 2008. Lead poisoning: using transdisciplinary approaches to solve an ancient problem. EcoHealth. 5(3), 379-385.

Pompeani D.P., Abbott M.B., Steinman B.A., Bain D.J. 2013. Lake sediments record prehistoric lead pollution related to early copper production in North America. Environ Sci Technol 47(11), 5545-52.

Pounds J.G. 1984. Effect of lead intoxication on calcium homeostasis and calcium-mediated cell function: a review. Neurotoxicology. 5(3), 295-331.

Rabinowitz M.B. 1995. Stable isotopes of lead for source identification. J Toxicol Clin Toxicol 33(6), 649-655.

Richard L.C., Charles R., Henderson J., Deborah A.C., Christopher C., Todd A.J., Bruce P.L. 2003. Intellectual Impairment in Children with Blood Lead Concentrations below 10 μg per Deciliter. N Engl J Med. 348, 1517-1526.

Roberts J.R., Allen C.L., Ligon C., Reigart J.R. 2013. Are children still at risk for lead poisoning? Clin Pediatr (Phila). 52(2), 125-130.

Sakai T. 2000. Biomarkers of lead exposure. Ind Health. 38(2), 127-142.

Schwartz J. 1994. Low-Level Lead Exposure and Children' s IQ: A Metaanalysis and Search for a Threshold. Environ Res. 65(1), 42-55.

ISSN: 2283-3927

Shotyk W., Weiss D., Appleby P.G, Frei R., Gloor M., Kramers J.D., Reese S., Van Der Knaap W.O. 1998. History of Atmospheric Lead Deposition Since 12,370 14C yr BP from a Peat Bog, Jura Mountains, Switzerland. Science. 281(5383), 1635-1640.

Singh B., Dhawan D., Nehru B., Garg M.L., Mangal P.C., Chand B., Trehan P.N. 1994. Impact of lead pollution on the status of other trace metals in blood and alterations in hepatic functions. Impact of lead pollution on the status of other trace metals in blood and alterations in hepatic functions. Biological Trace Element Research. 40(1), 21-29.

Stevens M.H., Jacobsen T., Crofts A.K. 2013. Lead and the deafness of Ludwig van Beethoven. Laryngoscope. 123(11), 2854-2858.

Sturges W.T., Barrie L.A. 1989. Stable lead isotope ratios in arctic aerosols: evidence for the origin of arctic air pollution. Arctic Air Chemistry. 23(11), 2513-2519.

Sungmin H., Jean-Pierre C., Clair C.P., Claude F.B. 1994. Greenland Ice Evidence of Hemispheric Lead Pollution Two Millennia Ago by Greek and Roman Civilizations. Science. 265(5180), 1841-1843.

Tadashi T., Takeo O., Koichi T. 1997. Lead-free piezoelectric ceramics based on (Bi1/2Na1/2)TiO3-NaNbO3. Ferroelectrics. 196(1), 175-178.

Thomson R.M., Parry G.J. 2006. Neuropathies associated with excessive exposure to lead. Muscle Nerve. 33(6), 732-41.

Tong S., von Schirnding Y.E., Prapamontol T. 2000. Environmental lead exposure: a public health problem of global dimensions. Bull World Health Organ. 78(9), 1068-1077.

Trinogga A., Fritsch G., Hofer H., Krone O. 2013. Are lead-free hunting rifle bullets as effective at killing wildlife as conventional lead bullets? A comparison based on wound size and morphology. Sci Total Environ. 15(443), 226-232.

University of Sheffield and Web Elements Ltd. 2014. http://www.webelements.com/lead/chemistry.html

Weisskopf M.G., Weuve J., Nie H., Saint-Hilaire M.H., Sudarsky L., Simon D.K., Hersh B., Schwartz J., Wright R.O., Hu H. 2010. Association of cumulative lead exposure with Parkinson's disease. Environ Health Perspect. 118(11), 1609-1613.

William Y., Richard L., Ian B.M., Marie-Anne U. 1981. The Relationship between Blood Lead Concentrations, Intelligence and Attainment in a School Population: a Pilot Study. Dev Med Child Neurol. 23(5), 567-576.

Woolf A.D., Goldman R., Bellinger D.C. 2007. Update on the clinical management of childhood lead poisoning. Pediatr Clin North Am. 54(2), 271-294.

Yasuyoshi S., Hisaaki T., Toshihiko T., Tatsuhiko N., Kazumasa T., Takahiko H., Toshiatsu N., Masaya N. 2004. Lead-free piezoceramics. Nature. 432, 84-87.

Zang G.Z., JWang J.F., Chen H.C., Su W.B., Wang C.M., Qi P., Ming B.Q., Du J., Zheng L.M., Zhang S.J., Thomas R.S. 2006. Perovskite lead-free piezoceramics. Appl. Phys. Lett. 88, 212908.

ISSN: 2283-3927

Zhang Y., Wanga X., Chen H., Yang X., Chen J., Allen J.O. 2009. Source apportionment of lead-containing aerosol particles in Shanghai using single particle mass spectrometry. Chemosphere. 74, 501-507.

Zhao Z.Y., Liang L., Fan X., Yu Z., Hotchkiss A.T., Wilk B.J., Eliaz I. 2008. The role of modified citrus pectin as an effective chelator of lead in children hospitalized with toxic lead levels. Altern Ther Health Med. 14(6), 18.

Zietz B.P., Lass J., Dunkelberg H., Suchenwirth R. 2009. Lead pollution of drinking water in lower Saxonomy from corrosion of pipe materials. Gesundheitswesen. 71(5), 265-274.

Zumdahl S.S. 2009. Chemical Principles 6th Ed. Houghton Mifflin Company. p. A23. ISBN 0-618-94690-X.

  ISSN: 2283-3927