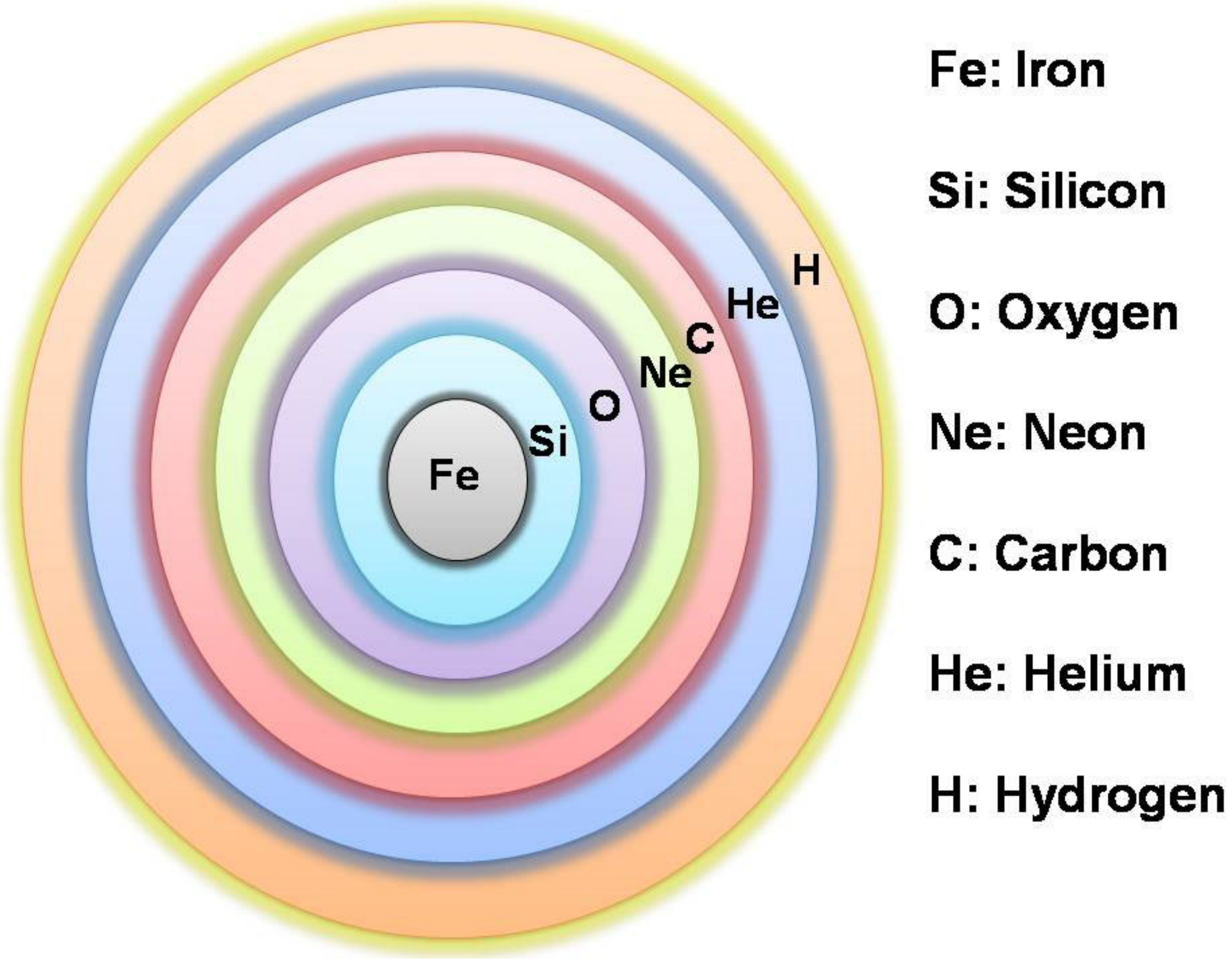
METALLOIDS 109

CONTINUING EDUCATION
PROFESSIONAL DEVELOPMENT COURSE



Technical
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College

Printing and Saving Instructions

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Adobe Acrobat DC reader is a free computer software program and you can find it at Adobe Acrobat's website.

You can complete the course by viewing the course on your computer or you can print it out. This course booklet does not have the assignment (the test). Please visit our website and download the assignment (the test).

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You can obtain a printed version from TLC for an additional $129.95 plus shipping charges.

Link to Assignment…
http://www.ABCTLC.com/downloads/PDF/Metalloids109ASS.pdf

State Approval Listing Link, check to see if your State accepts or has pre-approved this course. Not all States are listed. Not all courses are listed. Do not solely trust our list for it may be outdated. It is your sole responsibility to ensure this course is accepted for credit. No refunds.

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Contributing Editors

James L. Six Received a Bachelor of Science Degree in Civil Engineering from the University of Akron in June of 1976, Registered Professional Engineer in the State of Ohio, Number 45031 (Retired), Class IV Water Supply Operator issued by Ohio EPA, Number WS4-1012914-08, Class II Wastewater Collection System Operator issued by Ohio EPA, Number WC2-1012914-94

Joseph Camerata has a BS in Management with honors (magna cum laude). He retired as a Chemist in 2006 having worked in the field of chemical, environmental, and industrial hygiene sampling and analysis for 40 years.

James Bevan, Water Quality Inspector S.M.E. Twenty years of experience in the environmental field dealing with all aspects of water regulations on the federal, state, and local levels. Teacher and Proctor in Charge for Backflow Certification Testing at the ASETT Center in Tucson for the past 15 years and possess an Arizona Community College, Special Teaching Certificate in Environmental Studies.

Dr. Pete Greer S.M.E., Retired biology instructor, chemistry and biological review.

Jack White, Environmental, Health, Safety expert, City of Phoenix. Art Credits.

Some States and many employers require the final exam to be proctored.

Precept-Based Training CEU Course

This training course is made of "micro-content" or "precepts"– small chunks of information that can be easily digested. Using bite-size pieces of technical information is considered to be one of the most effective ways of teaching people new information because it helps the student to retain knowledge easier.

Micro-learning or precept-based training doesn't rely on the student to process a large amount of information before breaking it down. Our method includes short modules with clearly defined learning goals for each section. This method allows a student to hone in on a particular skill, then demonstrate their knowledge in the final assessment.

This course contains EPA's federal rule requirements. Please be aware that each state implements drinking water regulations that may be more stringent than EPA's regulations. Check with your state environmental agency for more information.

Important Information about this Manual

Disclaimer

This manual has been prepared to assist employees in the general awareness of arsenic and metal treatments and remediation process including: water distribution systems and groundwater production systems, complex pumping ideas, dangerous excavation techniques, water regulatory sampling and dealing with often-complex procedures and requirements for safely handling hazardous and toxic materials. The scope of the material is quite large, requiring a major effort to bring it under control. Employee health and safety, as well as that of the public, depend upon careful application of federal and state regulations and safe working procedures.

This manual will cover general laws, regulations, required procedures and work rules relating to water distribution and sampling. It should be noted, however, that the federal and state regulations are an ongoing process and subject to change over time. For this reason, a list of resources and hyperlinks is provided to assist in obtaining the most up-to-date information on various subjects. You can find these on our website or in this manual.

This manual may be a guidance document for employees who are involved with various metals like Arsenic treatment, handling, water quality and pollution control. It is not designed to meet the full requirements of the United States Environmental Protection Agency (EPA) or the Department of Labor-Occupational Safety and Health Administration (OSHA) rules and regulations.

This course manual will provide general guidance and should not be used as a preliminary basis for developing general water/wastewater sampling plans or water distribution safety plans or procedures. This document is not a detailed water/wastewater textbook or a comprehensive source book on water/wastewater/ safety rules and regulations.

Technical Learning College makes no warranty, guarantee or representation as to the absolute correctness or appropriateness of the information in this manual and assumes no responsibility in connection with the implementation of this information.

It cannot be assumed that this manual contains all measures and concepts required for specific conditions or circumstances. This document should be used for guidance and is not considered a legal document.

Individuals who are responsible for water distribution, production and/or sampling and the health and safety of workers at hazardous waste sites should obtain and comply with the most recent federal, state, and local regulations relevant to these sites and are urged to consult with OSHA, the EPA and other appropriate federal, state and local agencies.

Technical Learning College's Scope and Function

Welcome to the Program,

Technical Learning College (TLC) offers affordable continuing education for today's working professionals who need to maintain licenses or certifications. TLC holds several different governmental agency approvals for granting of continuing education credit.

TLC's delivery method of continuing education can include traditional types of classroom lectures and distance-based courses or independent study. TLC's distance-based or independent study courses are offered in a print - based distance educational format. We will beat any other training competitor's price for the same CEU material or classroom training.

Our courses are designed to be flexible and for you to finish the material at your convenience. Students can receive course materials through the mail or electronically. The CEU course or e-manual will contain all your lessons, activities and instruction to obtain the assignments. All of TLC's CEU courses allow students to submit assignments using e-mail or fax, or by postal mail. (See the course description for more information.)

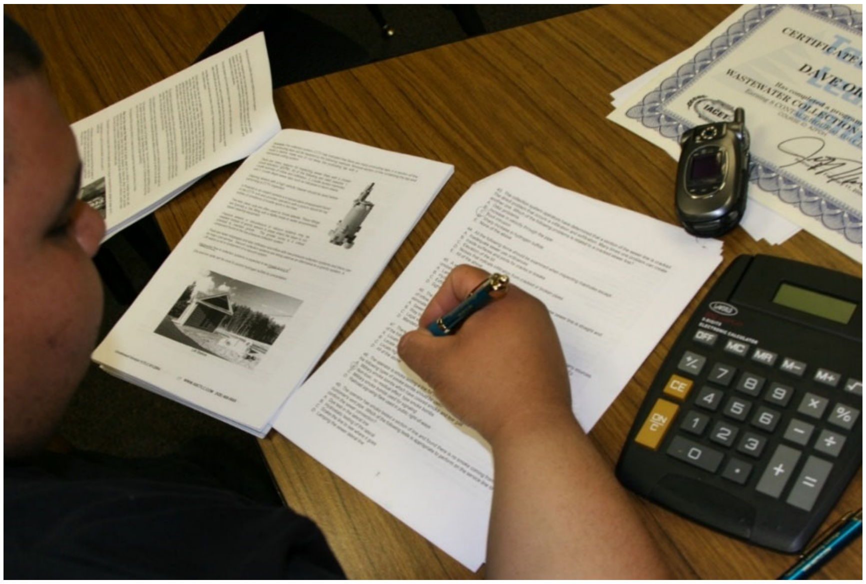
Students have direct contact with their instructor—primarily by e-mail or telephone. TLC's CEU courses may use such technologies as the World Wide Web, e-mail, CD-ROMs, videotapes and hard copies. (See the course description.) Make sure you have access to the necessary equipment before enrolling; i.e., printer, Microsoft Word and/or Adobe Acrobat Reader. Some courses may require proctored closed-book exams, depending upon your state or employer requirements.

Flexible Learning
At TLC, there are no scheduled online sessions or passwords you need contend with, nor are you required to participate in learning teams or groups designed for the "typical" younger campus - based student. You will work at your own pace, completing assignments in time frames that work best for you. TLC's method of flexible individualized instruction is designed to provide each student the guidance and support needed for successful course completion.

Course Structure
TLC's online courses combine the best of online delivery and traditional university textbooks. You can easily find the course syllabus, course content, assignments, and the post-exam (Assignment). This student-friendly course design allows you the most flexibility in choosing when and where you will study.

Classroom of One
TLC offers you the best of both worlds. You learn on your own terms, on your own time, but you are never on your own. Once enrolled, you will be assigned a personal Student Service Representative who works with you on an individualized basis throughout your program of study. Course specific faculty members (S.M.E.) are assigned at the beginning of each course providing the academic support you need to successfully complete each course. Please call or email us for assistance.

Satisfaction Guaranteed
We have many years of experience, dealing with thousands of students. We assure you, our customer satisfaction is second to none. This is one reason we have taught more than 20,000 students.



We welcome you to do the electronic version of the assignment and submit the answer key and registration to us either by fax or e-mail.

If you need this assignment graded and a certificate of completion within a 48-hour turn around, prepare to pay an additional rush charge of $50.

Contact Numbers
Fax (928) 468-0675
Email Info@tlch2o.com
Telephone (866) 557-1746

CEU Course Description

Metalloids 109 Course Description

Arsenic, boron, silicon, germanium, antimony and tellurium are commonly classified as metalloids. One or more from among selenium, polonium or astatine are sometimes added to the list. Boron is sometimes excluded from the list, by itself or together with silicon. Tellurium is sometimes not regarded as a metalloid. The inclusion of antimony, polonium and astatine as metalloids has also been questioned. A metalloid is a chemical element with properties that are in-between or a mixture of those of metals and nonmetals, and which is considered to be difficult to classify unambiguously as either a metal or a nonmetal.

Audience

Attention Pretreatment Operators, Laboratory Technicians, Water Distribution, Well Drillers, Pump Installers, and Water and Wastewater Treatment Operators. The target audience for this course is the person interested in working in a water/wastewater treatment or distribution facility and wishing to maintain CEUs for certification license, meet education needs for promotion, or to learn how to do the job more safely and effectively.

General Course Objectives

1. Understand and Describe Various EPA Water and Wastewater Metalloid Standards.
2. Understand and Describe Various Water and Wastewater inorganic chemicals.
3. Understand and Describe Various Chemical Processes.
4. Understand and Explain Various Chemical and Elemental Contaminants Factors.
5. Understand and Describe Various Chemical and Laboratory Techniques.
6. Understand and Describe Various Metalloids and the problems and applications connected with these contaminants.
7. Understand and Describe Allotropes associated with water and wastewater contamination.
8. Understand and Describe Various Point-of-Use and Conventional Contaminants Removal and Treatment Options for IOCs and Metalloids.
9. Understand and Describe EPA Arsenic Treatment and Waste Disposal.

Prerequisites: None

Course Procedures for Registration and Support

All of Technical Learning College's distance learning courses have complete registration and support services offered. Delivery of services will include e-mail, web site, telephone, fax and mail support. TLC will attempt immediate and prompt service.

When a student registers for a correspondence course, he/she is assigned a start date and an end date. It is the student's responsibility to note dates for assignments and keep up with the course work. If a student falls behind, he/she must contact TLC and request an end date extension in order to complete the course. It is the prerogative of TLC to decide whether to grant the request. All students will be tracked by a unique computer generated number assigned to the student.

Disclaimer and Security Notice

The student shall understand that it their responsibility to ensure that this CEU course is either approved or accepted in my State for CEU credit. The student shall understand and follow State laws and rules concerning distance learning courses and understand these rules change on a frequent basis and will not hold Technical Learning College responsible for any changes. The student shall understand that this type of study program deals with dangerous conditions and will not hold Technical Learning College, Technical Learning Consultants, Inc. (TLC) liable for any errors or omissions or advice contained in this CEU education training course or for any violation or injury caused by this CEU education training course material. The student shall contact TLC if they need help or assistance and double-check to ensure my registration page and assignment has been received and graded.

Final Examination for Credit

Opportunity to pass the final comprehensive examination is limited to three attempts per course enrollment.

Security and Integrity

All students are required to do their own work. All lesson sheets and final exams are not returned to the student to discourage sharing of answers. Any fraud or deceit and the student will forfeit all fees and the appropriate agency will be notified. A random test generator will be implemented to protect the integrity of the assignment.

Instructions for Written Assignments

The Metalloid 109 CEU training course uses multiple choice and true/false questions. Answers may be written on the assignment answer key or typed out on a separate answer sheet. TLC prefers that students type out and e-mail their answer sheets to info@tlch2o.com, but they may be faxed to (928) 468-0675.

Feedback Mechanism (Examination Procedures)

A feedback form is included in the front of each study packet.

Environmental Terms, Abbreviations, and Acronyms

TLC provides a glossary in the rear of this manual that defines, in non-technical language, commonly used environmental terms appearing in publications and materials, as well as abbreviations and acronyms used throughout the EPA and other governmental agencies.

Record Keeping and Reporting Practices

TLC keeps all student records for a minimum of five years. It is the student’s responsibility to give the completion certificate to the appropriate agencies.

ADA Compliance

TLC will make reasonable accommodations for persons with documented disabilities. Students should notify TLC and their instructors of any special needs. Course content may vary from this outline to meet the needs of these particular students.

DISCLAIMER NOTICE

I understand that it is my responsibility to ensure that this CEU course is either approved or accepted in my State for CEU credit. I understand State laws and rules change on a frequent basis and I believe this course is currently accepted in my State for CEU or contact hour credit, if it is not, I will not hold Technical Learning College responsible. I also understand that this type of study program deals with dangerous conditions and that I will not hold Technical Learning College, Technical Learning Consultants, Inc. (TLC) liable for any errors or omissions or advice contained in this CEU education training course or for any violation or injury caused by this CEU education training course material. I will call or contact TLC if I need help or assistance and double-check to ensure my registration page and assignment has been received and graded.

AFFIDAVIT OF EXAM COMPLETION

I affirm that I personally completed the entire text of the course. I also affirm that I completed the exam without assistance from any outside source. I understand that it is my responsibility to file or maintain my certificate of completion as required by the state or by the designation organization.

Note to Students

Keep a copy of everything that you submit! If your work is lost, you can submit your copy for grading. If you do not receive your certificate of completion or other results within two to three weeks after submitting it, please contact your instructor.

Educational Mission

The educational mission of TLC is:

To provide TLC students with comprehensive and ongoing training in the theory and skills needed for the environmental education field,

To provide TLC students opportunities to apply and understand the theory and skills needed for operator certification and environmental education,

To provide opportunities for TLC students to learn and practice environmental educational skills with members of the community for the purpose of sharing diverse perspectives and experience,

To provide a forum in which students can exchange experiences and ideas related to environmental education,

To provide a forum for the collection and dissemination of current information related to environmental education, and to maintain an environment that nurtures academic and personal growth.

Table of Contents

List of Acronyms and Abbreviation

AA: Activated alumina
AC: Activated carbon
ASR: Annual Status Report
As(III): Trivalent arsenic, common inorganic form in water is arsenite, H_3AsO_3
As(V): Pentavalent arsenic, common inorganic form in water is arsenate, H_2AsO_4
BDAT: best demonstrated available technology
BTEX: Benzene, toluene, ethylbenzene, and xylene
CCA: Chromated copper arsenate
CERCLA: Comprehensive Environmental Response, Compensation, and Liability Act
CERCLIS 3: CERCLA Information System
CLU-IN: EPA’s CLeanUp INformation system
CWS: Community Water System
cy: Cubic yard
DDT: Dichloro-diphenyl-trichloroethane
DI: Deionized
DOC: Dissolved organic carbon
DoD: Department of Defense
DOE: Department of Energy
EDTA: Ethylenediaminetetraacetic acid
EPA: U.S. Environmental Protection Agency
EPT: Extraction Procedure Toxicity Test
FRTR: Federal Remediation Technologies Roundtable
ft: feet
gpd: gallons per day
gpm: gallons per minute
HTMR: High temperature metals recovery
MCL: Maximum Contaminant Level (enforceable drinking water standard)
MF: Microfiltration
MHO: Metallurgie-Hoboken-Overpelt
mgd: million gallons per day
mg/kg: milligrams per kilogram
mg/L: milligrams per Liter
NF: Nanofiltration
NPL: National Priorities List
OCLC: Online Computer Library Center
ORD: EPA Office of Research and Development
OU: Operable Unit
PAH: Polycyclic aromatic hydrocarbons
PCB: Polychlorinated biphenyls
POTW: Publicly owned treatment works
PRB: Permeable reactive barrier
RCRA: Resource Conservation and Recovery Act
Redox: Reduction/oxidation
RO: Reverse osmosis
ROD: Record of Decision
SDWA: Safe Drinking Water Act
SMZ: surfactant modified zeolite
SNAP: Superfund NPL Assessment Program

S/S: Solidification/Stabilization
SVOC: Semivolatile organic compounds
TCLP: Toxicity Characteristic Leaching Procedure
TNT: 2,3,6-trinitrotoluene
TWA: Total Waste Analysis
UF: Ultrafiltration
VOC: Volatile organic compounds
WET: Waste Extraction Test
ZVI: Zero valent iron

A PDF version of *Arsenic Treatment Technologies for Soil, Waste, and Water*, is available for viewing or downloading from the Hazardous Waste Cleanup Information (**CLU-IN**) system web site at *http://clu-in.org/arsenic*.

A limited number of printed copies are available free of charge, and may be ordered via the web site, by mail or by facsimile from:

U.S. EPA/National Service Center for Environmental Publications (NSCEP)
P.O. Box 42419 Cincinnati, OH 45242-2419
Telephone: (513) 489-8190 or (800) 490-9198 Fax: (513) 489-8695

Definitions

As used in 40 CFR 141, the term:

Best available technology **(BAT)** means the best technology, treatment techniques, or other means which the Administrator finds, after examination for efficacy under field conditions and not solely under laboratory conditions, are available (taking cost into consideration). For the purposes of setting MCLs for synthetic organic chemicals, any BAT must be at least as effective as granular activated carbon.

Community water system **(CWS)** means a public water system which serves at least 15 service connections used by year-round residents or regularly serves at least 25 year-round residents.

Compliance cycle means the nine-year calendar year cycle during which public water systems must monitor. Each compliance cycle consists of three three-year compliance periods.

Compliance period means a three-year calendar year period within a compliance cycle. Each compliance cycle has three three-year compliance periods.

Contaminant means any physical, chemical, biological, or radiological substance or matter in water.

Maximum contaminant level **(MCL)** means the maximum permissible level of a contaminant in water which is delivered to any user of a public water system.

Maximum contaminant level goal **(*MCLG)*** means the maximum level of a contaminant in drinking water at which no known or anticipated adverse effect on the health of persons would occur, and which allows an adequate margin of safety. Maximum contaminant level goals are nonenforceable health goals.

Non-transient non-community water system **(NTNCWS)** means a public water system that is not a community water system and that regularly serves at least 25 of the same persons over 6 months per year.

Point-of-entry treatment device **(POE)** is a treatment device applied to the drinking water entering a house or building for the purpose of reducing contaminants in the drinking water distributed throughout the house or building.

Point-of-use treatment device **(POU)** is a treatment device applied to a single tap used for the purpose of reducing contaminants in drinking water at that one tap.

Public water system **(PWS)** *means* a system for the provision to the public of water for human consumption through pipes or, after August 5, 1998, other constructed conveyances, if such system has at least fifteen service connections or regularly serves an average of at least twenty-five individuals daily at least 60 days out of the year. Such term includes: any collection, treatment, storage, and distribution facilities under control of the operator of such system and used primarily in connection with such system; and any collection or pretreatment storage facilities not under such control which are used primarily in connection with such system. Such term does not include any "*special irrigation district*."

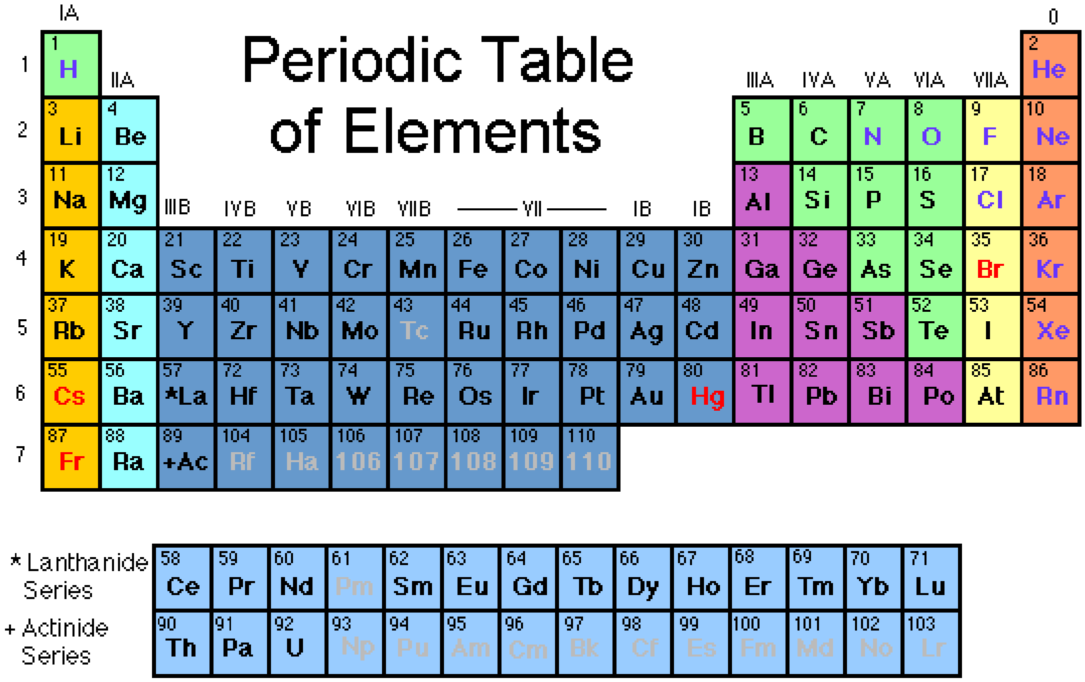
A public water system is either a "community water system" or a "noncommunity water system."

State means the agency of the State or Tribal government which has jurisdiction over public water systems. During any period when a State or Tribal government does not have primary enforcement responsibility pursuant to section 1413 of the Act, the term "State" means the Regional Administrator, U.S. Environmental Protection Agency.

Surface water means all water which is open to the atmosphere and subject to surface runoff.

Ion Exchange Units

Ion exchange technology is one method to remove Arsenic from drinking water



Periodic Table of Elements

	IA	IIA	IIIB	IVB	VB	VIB	VIIB	VII			IB	IB	IIIA	IVA	VA	VIA	VIIA	0
1	1 H																	2 He
2	3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
3	11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
4	19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
5	37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
6	55 Cs	56 Ba	57 *La	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
7	87 Fr	88 Ra	89 +Ac	104 Rf	105 Ha	106 106	107 107	108 108	109 109	110 110								

* Lanthanide Series	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu
+ Actinide Series	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr

How is the Periodic Table Organized?

The periodic table is organized with eight principal vertical columns called groups and seven horizontal rows called periods (the groups are numbered I to VIII from left to right, and the periods are numbered 1 to 7 from top to bottom).

All the metals are grouped together on the left side of the periodic table, and all the nonmetals are grouped together on the right side of the periodic table. Semimetals are found in between the metals and nonmetals.

What are the Eight Groups of the Periodic Table?

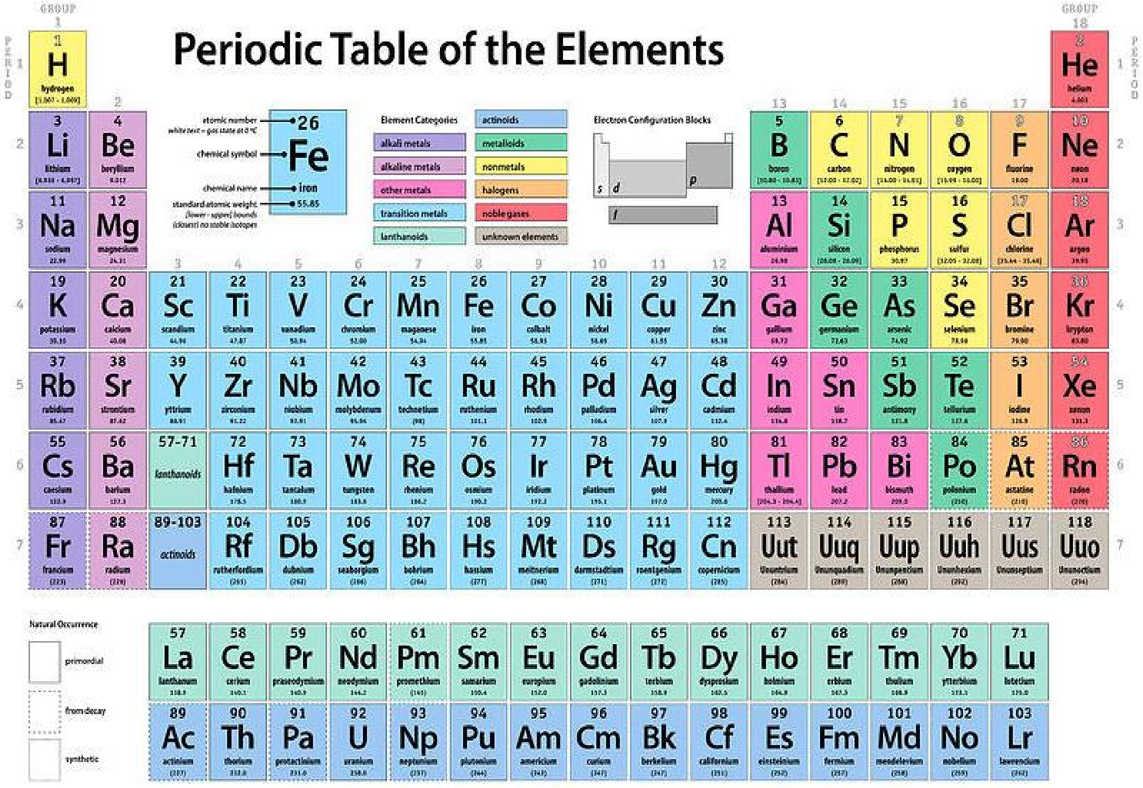
- **Group I: Alkali Metals - Li, Na, K, Rb, Cs, Fr**
  known as alkali metals
  most reactive of the metals
  react with all nonmetals except the noble gases
  contain typical physical properties of metals (i.e., shiny solids and good conductors of heat and electricity)
  softer than most familiar metals; can be cut with a knife
- **Group II: Alkaline Earth Metals-Be, Mg, Ca, Sr, Ba, Ra**
  known as alkaline earth metals
  react with nonmetals, but more slowly than the Group I metals
  solids at room temperature
  have typical metallic properties
  harder than the Group I metals
  higher melting points than the Group I metals

- **Group III: B, Al, Ga, In, Tl**
  boron is a semimetal; all the others are metals
- **Group IV: C, Si, Ge, Sn, Pb**
  carbon is a nonmetal; silicon and germanium are semimetals; tin and lead are metals
- **Group V: N, P, As, Sb, Bi**
  nitrogen and phosphorus are nonmetals; arsenic and antimony are semimetals; bismuth is a metal
- **Group VI: O, S, Se, Te, Po**
  oxygen, sulfur, and selenium are nonmetals; tellurium and polonium are semimetals
- **Group VII: Halogens-F, Cl, Br, I, At**
  very reactive nonmetals
- **Group VIII: Noble Gases-He, Ne, Ar, Kr, Xe, Rn**
  very unreactive

Properties of Metals
Solids at room temperature
Conduct heat very well
Have electrical conductivities that increase with decreasing temperature
Have a high flexibility and a shiny metallic luster
Are malleable-can be beaten out into sheets or foils
Are ductile-can be pulled into thin wires without breaking
Emit electrons when they are exposed to radiation of sufficiently high energy or when They are heated (known as photoelectric effect and thermionic effect)

Properties of Nonmetals
May be gases, liquids, or solids at room temperature
Poor conductors of heat
Are insulators-very poor conductors of electricity
Do not have a high reflectivity or a shiny metallic appearance
In solid form generally brittle and fracture easily under stress
Do not exhibit photoelectric or thermionic effects

Metalloids Section



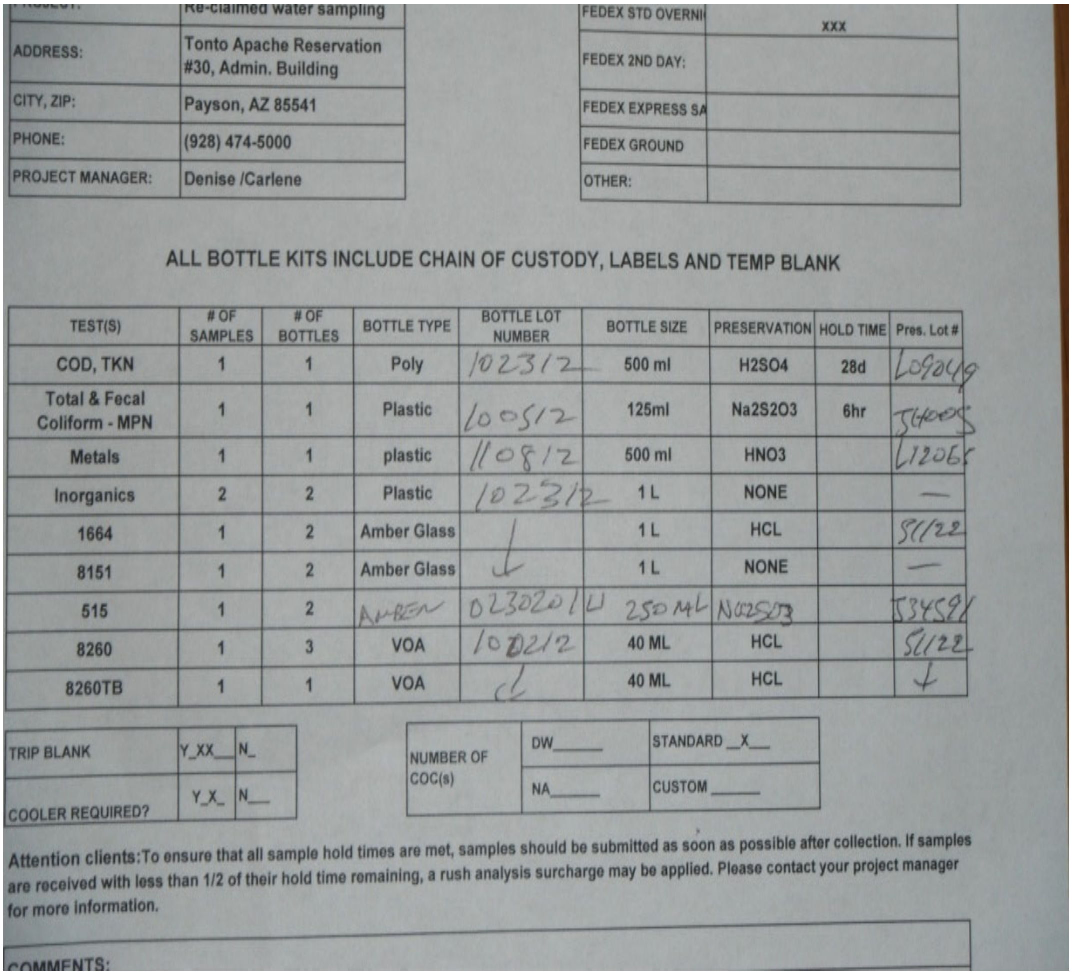
Periodic Table of the Elements

Period	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	1 H																	2 He
2	3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
3	11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
4	19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
5	37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
6	55 Cs	56 Ba	57-71 lanthanoids	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
7	87 Fr	88 Ra	89-103 actinoids	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Cn	113 Uut	114 Uuq	115 Uup	116 Uuh	117 Uus	118 Uuo

57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu
89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr

Germanium, left and Boron, right

There are several reasons why sampling occurs such as meeting state and federal regulations, process control and quality assurance programs. Once identified request are made to a certified lab. In rural areas the lab will deliver the samples in a secure box or ice chest as shown above. Notice the custody seal on the outside of the ice chest. Below, the lab will also provide a chain of custody form along with a form that shows which bottle is used for the sample application.



	Re-claimed water sampling
ADDRESS:	Tonto Apache Reservation #30, Admin. Building
CITY, ZIP:	Payson, AZ 85541
PHONE:	(928) 474-5000
PROJECT MANAGER:	Denise /Carlene

FEDEX STD OVERNI	XXX
FEDEX 2ND DAY:	
FEDEX EXPRESS SA	
FEDEX GROUND	
OTHER:	

ALL BOTTLE KITS INCLUDE CHAIN OF CUSTODY, LABELS AND TEMP BLANK

TEST(S)	# OF SAMPLES	# OF BOTTLES	BOTTLE TYPE	BOTTLE LOT NUMBER	BOTTLE SIZE	PRESERVATION	HOLD TIME	Pres. Lot #
COD, TKN	1	1	Poly	102312	500 ml	H2SO4	28d	L09049
Total & Fecal Coliform - MPN	1	1	Plastic	100512	125ml	Na2S2O3	6hr	J4005
Metals	1	1	plastic	110812	500 ml	HNO3		L12065
Inorganics	2	2	Plastic	102312	1 L	NONE		—
1664	1	2	Amber Glass	↓	1 L	HCL		SI/22
8151	1	2	Amber Glass	↓	1 L	NONE		—
515	1	2	AMBER	0230201U	250 ML	Na2SO3		J34591
8260	1	3	VOA	102212	40 ML	HCL		SI/22
8260TB	1	1	VOA	↓	40 ML	HCL		↓

TRIP BLANK	Y_XX__	N_
COOLER REQUIRED?	Y_X_	N__

NUMBER OF COC(s)	DW_____	STANDARD __X__
	NA_____	CUSTOM _____

Attention clients:To ensure that all sample hold times are met, samples should be submitted as soon as possible after collection. If samples are received with less than 1/2 of their hold time remaining, a rush analysis surcharge may be applied. Please contact your project manager for more information.

COMMENTS:

Metalloid Introduction

Drinking water contaminants that can cause health effects after continuous long-term exposure at levels greater than the maximum contaminant level (MCL) are considered “chronic” contaminants. Examples of chronic drinking water contaminants regulated by EPA include inorganic contaminants like arsenic, cadmium, and copper; organic contaminants such as pesticides and industrial chemicals; and radiological contaminants like radium and uranium.

If your water system has installed some form of inorganic contaminant or arsenic treatment, keep in mind that the treatment you installed may change the water quality in other ways. It might cause the water to react differently in the distribution system. Depending on the kind of treatment you’ve installed, consider what distribution system problems might result.

A change in the taste, odor or appearance of the water at customers’ taps may be the first indication of a problem. Some water quality parameters to consider monitoring, depending on your arsenic treatment technology, include iron, pH, manganese, alkalinity, and aluminum.

In contrast, “acute” contaminants can cause short-term health effects within hours or days of exposure. Microbes such as *E. coli* and *Cryptosporidium* are examples of contaminants that can cause an acute health risk. Some chronic-type contaminants can also fall in this category if they are present at high enough concentrations to cause immediate health effects. For example, nitrate levels over the MCL can cause “blue-baby” syndrome in children less than 6 months.

Arsenic, boron, silicon, germanium, antimony and tellurium are commonly classified as metalloids. One or more from among selenium, polonium or astatine are sometimes added to the list. Boron is sometimes excluded from the list, by itself or together with silicon. Tellurium is sometimes not regarded as a metalloid. The inclusion of antimony, polonium and astatine as metalloids has also been questioned

A metalloid is a chemical element with properties that are in-between or a mixture of those of metals and nonmetals, and which is considered to be difficult to classify unambiguously as either a metal or a nonmetal. There is no standard definition of a metalloid nor is there agreement as to which elements are appropriately classified as such. Despite this lack of specificity the term continues to be used in the chemistry literature.

Some authors do not classify elements bordering the metal-nonmetal dividing line as metalloids noting that a binary classification can facilitate the establishment of some simple rules for determining bond types between metals and/or nonmetals. Other authors, in contrast, have suggested that classifying some elements as metalloids 'emphasizes that properties change gradually rather than abruptly as one moves across or down the periodic table. Alternatively, some periodic tables distinguish elements that are metalloids in the absence of any formal dividing line between metals and nonmetals. Metalloids are instead shown as occurring in a diagonal fixed band or diffuse region, running from upper left to lower right, centered around arsenic.

The six elements commonly recognized as metalloids are boron, silicon, germanium, arsenic, antimony and tellurium. They are metallic-looking brittle solids, with intermediate to relatively good electrical conductivities, and each having the electronic band structure of either a semiconductor or a semimetal.

Chemically, they mostly behave as (weak) nonmetals, have intermediate ionization energy and electronegativity values, and form amphoteric or weakly acidic oxides. Being too brittle to have any structural uses, the metalloids and their compounds instead find common use in glasses, alloys and semiconductors. The electrical properties of silicon and germanium, in particular, enabled the establishment of the semiconductor industry in the 1950s and the development of solid state electronics from the early 60s onwards.

Other elements less commonly recognized as metalloids include carbon, aluminum, selenium, polonium and astatine. On a standard periodic table these elements, as well as the elements commonly recognized as metalloids, occur in or near a diagonal region of the p-block, having its main axis anchored by boron at one end and astatine at the other. Some periodic tables include a dividing line between metals and nonmetals and it is generally the elements adjacent to this line or, less frequently, one or more of the elements adjacent to those elements, which are identified as metalloids.

The term *metalloid* was first popularly used to refer to nonmetals. It’s more recent meaning as a category of elements with intermediate or hybrid properties did not become widespread until the period 1940–1960. Metalloids are sometimes called semimetals, a practice which has been discouraged. This is because the term *semimetal* has a different meaning in physics, one which more specifically refers to the electronic band structure of a substance rather than the overall classification of a chemical element.

There is no universally agreed or rigorous definition of a metalloid. The feasibility of establishing a specific definition has also been questioned, noting anomalies can be found in several such attempted constructs. Classifying any particular element as a metalloid has been described as 'arbitrary'.

The generic definition set out at the start of this article is based on metalloid attributes consistently cited in the literature. Illustrative definitions and extracts include:

- 'In chemistry a metalloid is an element with properties intermediate between those of metals and nonmetals.'
- 'Between the metals and nonmetals in the periodic table we find elements…[that] share some of the characteristic properties of both the metals and nonmetals, making it difficult to place them in either of these two main categories.'
- 'Chemists sometimes use the name metalloid…for these elements which are difficult to classify one way or the other.'
- 'Because the traits distinguishing metals and nonmetals are qualitative in nature, some elements do not fall unambiguously in either category. These elements…are called metalloids…'.

More Broadly, Metalloids have also been referred to as:

- 'elements that…are somewhat of a cross between metals and nonmetals' or
- 'weird in-between elements.'

The criterion that metalloids are difficult to unambiguously classify one way or the other is a key tenet. In contrast, elements such as sodium and potassium 'have metallic properties to a high degree' and fluorine, chlorine and oxygen 'are almost exclusively nonmetallic.'

Although most other elements have a mixture of metallic and nonmetallic properties most such elements can also be classified as either metals or nonmetals according to which set of properties are regarded as being more pronounced in them. It is only the elements at or near the margins, ordinarily those that are regarded as lacking a sufficiently clear preponderance of metallic or nonmetallic properties, which are classified as metalloids.

Which Elements are Metalloids?

There is no universally agreed or rigorous definition of the term metalloid. So the answer to the question "Which elements are metalloids?" can vary, depending on the author and their inclusion criteria. Emsley, for example, recognized only four: germanium, arsenic, antimony and tellurium. James et al., on the other hand, listed twelve: boron, carbon, silicon, germanium, arsenic, selenium, antimony, tellurium, bismuth, polonium, ununpentium and livermorium. As of 2011 the list of metalloid lists recorded an average of just over seven elements classified as metalloids, per list of metalloids, based on a sample size of 194 lists.

The absence of a standardized division of the elements into metals, metalloids and nonmetals is not necessarily an issue. There is a more or less continuous progression from the metallic to the nonmetallic. A specified subset of this continuum can potentially serve its particular purpose as well as any other. In any event, individual metalloid classification arrangements tend to share common ground (as described above) with most variations occurring around the indistinct margins, as surveyed later.

How Are Chronic Contaminants Regulated?

In 1974, Congress passed the Safe Drinking Water Act (SDWA) to give EPA the authority to set standards to ensure the safety of drinking water provided by public water systems. The SDWA, which was amended in 1986 and 1996, directs EPA to establish non-enforceable health goals called maximum contaminant level goals (MCLGs) which reflect the level at which no adverse health effects are expected from a particular contaminant.

Once an MCLG is established, EPA sets enforceable standards for contaminants called maximum contaminant levels (MCLs). MCLs are set as close to the health goals as possible considering cost, benefits, and the ability of public water systems to detect and remove contaminants using appropriate treatment technologies. When there is no reliable method to measure a contaminant that is economically and technically feasible, EPA develops a treatment technique requirement rather than an MCL. EPA continues to assess the occurrence of unregulated contaminants through the Unregulated Contaminant Monitoring Regulation (UCMR). Information about the UCMR can be found at http://www.epa.gov/safewater/ucmr/.

What Are Some Best Practices for Effective Communication About Chronic Contaminants?

If you expect that your public water system will exceed EPA's standard for a contaminant or that the costs of compliance may require public funding, communicate early and often.

The most effective communication efforts follow these simple steps:
- Provide simple, straightforward, *and consistent* messages;
- Describe potential adverse health effects and populations at risk;
- Describe actions you are taking to correct the situation and when you anticipate it will be resolved;
- Describe actions the consumer can take such as using alternate water supplies and when to seek medical help;
- Provide links to useful information resources such as EPA's Web site.
- Use graphics, photographs, maps, charts, and drawings to illustrate your messages;
- Assume that consumers will only read the top half of the notice or what can be read in ten seconds;
- Display important elements in bold and/or large type in the top half of the notice;
- Communicate in multiple languages to meet the needs of your non-English speaking consumers; and Include contact information for further information in *all* communications.

Near Metalloids

The concept of a class of elements intermediate between metals and nonmetals is sometimes extended to include elements that most chemists, and related science professionals, would not ordinarily recognize as metalloids. In 1935, Fernelius and Robey allocated carbon, phosphorus, selenium, and iodine to such an intermediary class of elements, together with boron, silicon, arsenic, antimony, tellurium and polonium. They also included a placeholder for the missing element 85 (astatine), five years ahead of its synthesis in 1940.

They excluded germanium from their considerations as it was still then regarded as a poorly conducting metal. In 1954, Szabó & Lakatos counted beryllium and aluminum in their list of metalloids, as well as boron, silicon, germanium, arsenic, antimony, tellurium, polonium and astatine. In 1957, Sanderson recognized carbon, phosphorus, selenium, and iodine as part of an intermediary class of elements with 'certain metallic properties', together with boron, silicon, arsenic, tellurium, and astatine. Germanium, antimony and polonium were classified by him as metals. More recently, in 2007, Petty included carbon, phosphorus, selenium, tin and bismuth in his list of metalloids, as well as boron, silicon, germanium, arsenic, antimony, tellurium, polonium and astatine.

Elements such as these are occasionally called, or described as, *near-metalloids,* or the like. They are located near the elements commonly recognized as metalloids, and usually classified as either metals or nonmetals. Metals falling into this loose category tend to show 'odd' packing structures, marked covalent chemistry (molecular or polymeric), and amphoterism. Aluminum, tin and bismuth are examples. They are also referred to as *(chemically) weak metals, poor metals, post-transition metals,* or *semimetals* (in the aforementioned sense of metals with incomplete metallic character). These classification groupings generally cohabit the same periodic table territory but are not necessarily mutually inclusive.

Nonmetals in the 'near-metalloid' category include carbon, phosphorus, selenium and iodine. They exhibit metallic luster, semiconducting properties and bonding or valence bands with delocalized character. This applies to their most thermodynamically stable forms under ambient conditions: carbon as graphite; phosphorus as black phosphorus; and selenium as grey selenium. These elements are alternatively described as being 'near metalloidal', showing metalloidal character, or having metalloid-like or some metalloid(al) or metallic properties.

Allotropes

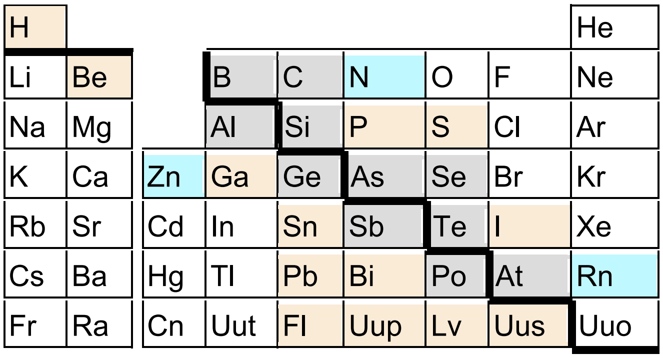
Some allotropes of the elements exhibit more pronounced metallic, metalloidal or nonmetallic behavior than others. For example, the diamond allotrope of carbon is clearly nonmetallic. The graphite allotrope however displays limited electrical conductivity more characteristic of a metalloid. Phosphorus, selenium, tin, and bismuth also have allotropes that display borderline or either metallic or nonmetallic behavior.

Categorization and Periodic Table Territory

Metalloids are generally regarded as a third category of chemical elements, alongside metals and nonmetals. They have been described as forming a (fuzzy) buffer zone between metals and nonmetals.

The make-up and size of this zone depends on the classification criteria being used. Metalloids are sometimes grouped instead with metals, regarded as nonmetals or treated as a sub-category of same.

Metalloid



H								He
Li	Be		B	C	N	O	F	Ne
Na	Mg		Al	Si	P	S	Cl	Ar
K	Ca	Zn	Ga	Ge	As	Se	Br	Kr
Rb	Sr	Cd	In	Sn	Sb	Te	I	Xe
Cs	Ba	Hg	Tl	Pb	Bi	Po	At	Rn
Fr	Ra	Cn	Uut	Fl	Uup	Lv	Uus	Uuo

Periodic table extract showing elements that have sometimes] been classified as metalloids:

Elements that appear commonly to rarely in the list of metalloid lists.

Elements that appear still less frequently.
Outlying elements showing that the metalloid net is sometimes cast very widely. Although they do not appear in the list of metalloids lists, isolated references to their designation as metalloids can be found in the literature.

Metalloids cluster on either side of the **dividing line between metals and nonmetals**. This can be found, in varying configurations, on some periodic tables (see mini-example, right). Elements to the lower left of the line generally display increasing metallic behavior; elements to the upper right display increasing nonmetallic behavior. When presented as a regular stair-step, elements with the highest critical temperature for their groups (Li, Be, Al, Ge, Sb, Po) lie just below the line.

The diagonal positioning of the metalloids represents somewhat of an exception to the phenomenon that elements with similar properties tend to occur in vertical columns. Going across a periodic table row, the nuclear charge increases with atomic number just as there is as a corresponding increase in electrons. The additional 'pull' on outer electrons with increasing nuclear charge generally outweighs the screening efficacy of having more electrons. With some irregularities, atoms therefore become smaller, ionization energy increases, and there is a gradual change in character, across a period, from strongly metallic, to weakly metallic, to weakly nonmetallic, to strongly nonmetallic elements.

Going down a main group periodic table column, the effect of increasing nuclear charge is generally outweighed by the effect of additional electrons being further away from the nucleus. With some irregularities, atoms therefore become larger, ionization energy falls, and metallic character increases.

The combined effect of these competing horizontal and vertical trends is that the location of the metal-nonmetal transition zone shifts to the right in going down a period.

A related effect can be seen in other diagonal similarities that occur between some elements and their lower right neighbors, such as lithium-magnesium, beryllium-aluminum, carbon-phosphorus, and nitrogen-sulfur.

Other Metalloids

Given there is no agreed definition of a metalloid, some other elements are occasionally classified as such. These elements include hydrogen, beryllium, nitrogen, phosphorus, sulfur, zinc, gallium, tin, iodine, lead, bismuth and radon. The term metalloid has also been used to refer to:

- Elements that exhibit metallic luster and electrical conductivity, and that are also amphoteric. Arsenic, antimony, vanadium, chromium, molybdenum, tungsten, tin, lead and aluminum are examples.
- Elements that are otherwise sometimes referred to as poor metals.
- Nonmetallic elements (for example, nitrogen; carbon) that can form alloys with, or modify the properties of, metals.

Heavy Metals

A heavy metal is a member of a loosely defined subset of elements that exhibit metallic properties. It mainly includes the transition metals, some metalloids, lanthanides, and actinides. Many different definitions have been proposed—some based on density, some on atomic number or atomic weight, and some on chemical properties or toxicity. The term *heavy metal* has been called a "misinterpretation" in an IUPAC technical report due to the contradictory definitions and its lack of a "coherent scientific basis". There is an alternative term *toxic metal*, for which no consensus of exact definition exists either.

As discussed below, depending on context, heavy metal can include elements lighter than carbon and can exclude some of the heaviest metals. Heavy metals occur naturally in the ecosystem with large variations in concentration. In modern times, anthropogenic sources of heavy metals, i.e. pollution, have been introduced to the ecosystem. Waste-derived fuels are especially prone to contain heavy metals, so heavy metals are a concern in consideration of waste as fuel.

Motivations for controlling heavy metal concentrations in gas streams are diverse. Some of them are dangerous to health or to the environment (e.g. mercury, cadmium, lead, chromium), some may cause corrosion (e.g. zinc, lead), some are harmful in other ways (e.g. arsenic may pollute catalysts). Within the European community the eleven elements of highest concern are arsenic, cadmium, cobalt, chromium, copper, mercury, manganese, nickel, lead, tin, and thallium, the emissions of which are regulated in waste incinerators. Some of these elements are actually necessary for humans in minute amounts (cobalt, copper, chromium, manganese, nickel) while others are carcinogenic or toxic, affecting, among others, the central nervous system (manganese, mercury, lead, arsenic), the kidneys or liver (mercury, lead, cadmium, copper) or skin, bones, or teeth (nickel, cadmium, copper, chromium).

Heavy metal pollution can arise from many sources but most commonly arises from the purification of metals, e.g., the smelting of copper and the preparation of nuclear fuels. Electroplating is the primary source of chromium and cadmium. Through precipitation of their compounds or by ion exchange into soils and muds, heavy metal pollutants can localize and lay dormant.

Unlike organic pollutants, heavy metals do not decay and thus pose a different kind of challenge for remediation. Currently, plants or microrganisms are tentatively used to remove some heavy metals such as mercury.

Plants which exhibit hyper accumulation can be used to remove heavy metals from soils by concentrating them in their bio matter. Some treatment of mining tailings has occurred where the vegetation is then incinerated to recover the heavy metals.

One of the largest problems associated with the persistence of heavy metals is the potential for bioaccumulation and biomagnification causing heavier exposure for some organisms than is present in the environment alone. Coastal fish (such as the smooth toadfish) and seabirds (such as the Atlantic Puffin) are often monitored for the presence of such contaminants.

Living organisms require varying amounts of "heavy metals". Iron, cobalt, copper, manganese, molybdenum, and zinc are required by humans. Excessive levels can be damaging to the organism. Other heavy metals such as mercury, plutonium, and lead are toxic metals that have no known vital or beneficial effect on organisms, and their accumulation over time in the bodies of animals can cause serious illness. Certain elements that are normally toxic are, for certain organisms or under certain conditions, beneficial. Examples include vanadium, tungsten, and even cadmium.

Toxic Metals

Toxic metals are metals that form poisonous soluble compounds and have no biological role, i.e. are not essential minerals, or are in the wrong form. Often heavy metals are thought as synonymous, but lighter metals also have toxicity, such as beryllium, and not all heavy metals are particularly toxic, and some are essential, such as iron. The definition may also include trace elements when considered in abnormally high, toxic doses. A difference is that there is no beneficial dose for a toxic metal with no biological role.

Toxic metals sometimes imitate the action of an essential element in the body, interfering with the metabolic process to cause illness. Many metals, particularly heavy metals are toxic, but some heavy metals are essential, and some, such as bismuth, have a low toxicity. Most often the definition includes at least cadmium, lead, mercury and the radioactive metals. Metalloids (arsenic, polonium) may be included in the definition.

Radioactive metals have both radiological toxicity and chemical toxicity. Metals in an oxidation state abnormal to the body may also become toxic: chromium (III) is an essential trace element, but chromium (VI) is a carcinogen.

Toxicity is a function of solubility. Insoluble compounds as well as the metallic forms often exhibit negligible toxicity. The toxicity of any metal depends on its ligands.
In some cases, organometallic forms, such as dimethyl mercury and tetraethyl lead, can be extremely toxic. In other cases, organometallic derivatives are less toxic such as the cobaltocenium cation.

Decontamination for toxic metals is different from organic toxins: because toxic metals are elements, they cannot be destroyed. Toxic metals may be made insoluble or collected, possibly by the aid of chelating agents.

Toxic metals can bioaccumulate in the body and in the food chain. Therefore, a common characteristic of toxic metals is the chronic nature of their toxicity.

This is particularly notable with radioactive heavy metals such as thorium, which imitates calcium to the point of being incorporated into human bone, although similar health implications are found in lead or mercury poisoning. The exceptions to this are barium and aluminum, which can be removed efficiently by the kidneys.

Toxic Heavy Metals

- Antimony (a metalloid)
- Arsenic is a metalloid
- Barium
- Beryllium
- Cadmium - cadmium poisoning
- Lead - lead poisoning
- Mercury - mercury poisoning
- Osmium
- Thallium
- Vanadium
- Radioactive metals:
    - Actinium

  - Thorium
  - Uranium
  - Radium
  - The transuraniums, such as plutonium, americium, etc.
  - Polonium
  - Radioactive isotopes of metallic elements not otherwise strongly toxic, e.g. cobalt-60 and strontium-90.

Aluminum has no biological role and its classification into toxic metals is controversial. Significant toxic effects and accumulation to tissues have been observed in renally impaired patients. However, individuals with healthy kidneys can be exposed to large amounts of aluminum with no ill effects. Thus, aluminum is not considered dangerous to persons with normal elimination capacity.

Trace Elements with Toxicity

- Chromium as hexavalent Cr(VI)
- Nickel – nickel salts are carcinogenic
- Copper – copper toxicity
- Zinc - zinc toxicity
- Iron – iron poisoning
- Fluorine-fluoride poisoning

Nonmetals

Some heavy nonmetals may be erroneously called "metals", because they have some metallic properties.

- Selenium – a nonmetal; essential element
- Tellurium

Atomic Spectrometry

Atomic spectrometry converts each metal in the water sample to a particulate emission that can then be weighed. Extrapolations are made to determine each metal concentration in each water sample taken. The complicated analysis requires preserving the sample with acid, heating the sample to convert to a particulate emission and then identifying each metal and its weight.

A simple analogy is to capture the steam from a pot of water, separate every atom in the steam, identify each atom, weigh each atom and then apply these numbers back to the original volume of water contained in the pot. The result is an accurate picture of what is in the water.

Heavy Metals in Water

High heavy metals concentrations can be naturally occurring. Every geologic formation contains a certain amount of heavy metal. Mine operations extract and process these metals in areas with the highest concentrations. Water in these areas may have high metal concentrations due to the combination of naturally occurring deposits and mine waste.

Water samples are usually taken randomly within a contaminated area and offsite to identify the source of contamination and the pathway it travels, into the drinkable groundwater system or away from potable water sources. Accurate determination of heavy metal contamination is important to identify cumulative risks to people drinking water derived from these areas.

Treating Heavy Metal Contamination in Water

Heavy metal water contamination is a difficult expensive problem to address. Most cleanup activities use a pump and treat system where contaminated groundwater is pumped out of the ground, treated with activated carbon to remove contaminants and then replaced into the groundwater system.

Because large volumes of water must be pumped and treated over long time periods, associated operation and maintenance systems are very expensive. There are some new technologies being developed that actually treat the water in the ground which operate more efficiently and quickly, decreasing costs.

If groundwater is contaminated with heavy metals, an alternative source of drinking water must be used to prevent harmful health effects, until the water is treated to meet standards protective of human health and the environment

Health Significance of Metals in the Environment

The metallic elements can be categorized into two groups. The heavy metals are those having densities five times greater than water, and the light metals, those having lesser densities. Well-known examples of heavy metallic elements are iron, lead, and copper. Examples of light metals are sodium, magnesium, and potassium. Humans consume metallic elements through both water and food.

Some metals such as sodium, potassium, magnesium, calcium, and iron are found in living tissue and are essential to human life-biological anomalies arise when they are depleted or removed. Probably less well known is that currently no less than six other heavy metals including molybdenum, manganese, cobalt, copper, and zinc, have been linked to human growth, development, achievement, and reproduction (Vahrenkamp, 1979; Friberg and others, 1979).

Even these metals, however, can become toxic or aesthetically undesirable when their concentrations are too great. Several heavy metals, like cadmium, lead, and mercury, are highly toxic at relatively low concentrations, can accumulate in body tissues over long periods of time, and are nonessential for human health. Table 1 lists metals according to their toxicities.

No specific health guidelines for heavy metals associated with suspended or bed sediments have been established by the U.S. Environmental Protection Agency. This lack of national guidelines based on concise scientific criteria causes' difficulty when evaluating the environmental effects of heavy metals in sediments. Several different criteria have been defined, primarily on the basis of observed effects on aquatic life (Lyman and others, 1987). Table 2 lists criteria for open-water disposal of polluted sediments that can be used for comparison purposes.

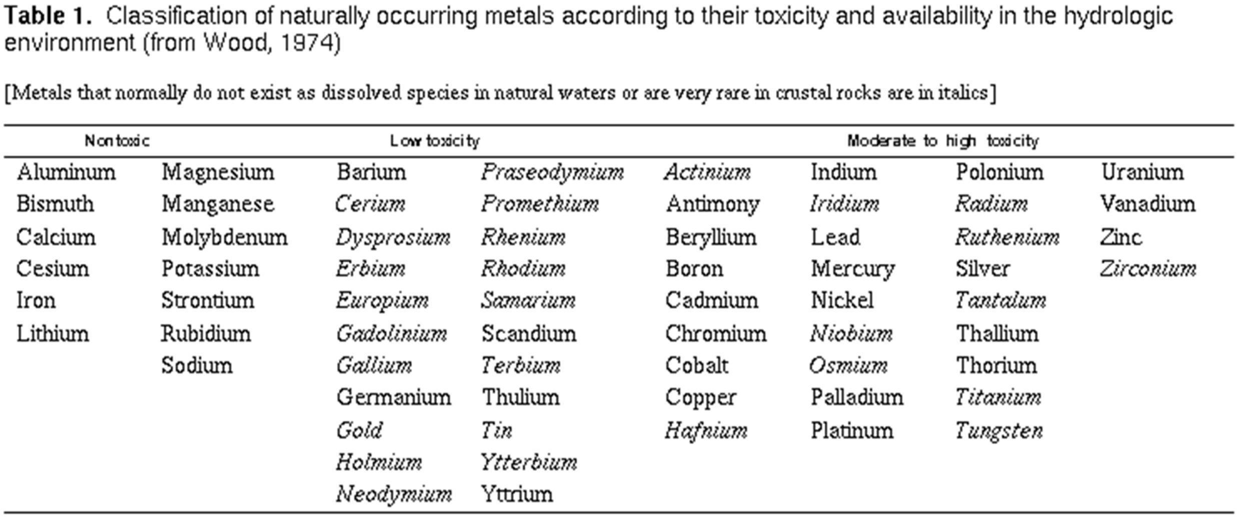


Table 1. Classification of naturally occurring metals according to their toxicity and availability in the hydrologic environment (from Wood, 1974)

[Metals that normally do not exist as dissolved species in natural waters or are very rare in crustal rocks are in italics]

Nontoxic		Low toxicity		Moderate to high toxicity			
Aluminum	Magnesium	Barium	*Praseodymium*	*Actinium*	Indium	Polonium	Uranium
Bismuth	Manganese	*Cerium*	*Promethium*	Antimony	*Iridium*	*Radium*	Vanadium
Calcium	Molybdenum	*Dysprosium*	*Rhenium*	Beryllium	Lead	*Ruthenium*	Zinc
Cesium	Potassium	*Erbium*	*Rhodium*	Boron	Mercury	Silver	*Zirconium*
Iron	Strontium	*Europium*	*Samarium*	Cadmium	Nickel	*Tantalum*	
Lithium	Rubidium	*Gadolinium*	Scandium	Chromium	*Niobium*	Thallium	
	Sodium	*Gallium*	*Terbium*	Cobalt	*Osmium*	Thorium	
		Germanium	Thulium	Copper	Palladium	*Titanium*	
		Gold	*Tin*	*Hafnium*	Platinum	*Tungsten*	
		Holmium	*Ytterbium*				
		Neodymium	Yttrium				

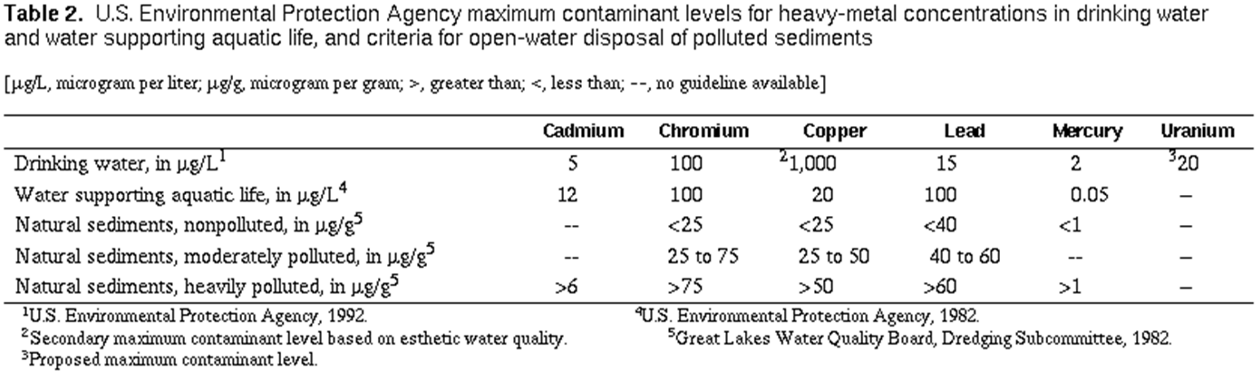


Table 2. U.S. Environmental Protection Agency maximum contaminant levels for heavy-metal concentrations in drinking water and water supporting aquatic life, and criteria for open-water disposal of polluted sediments

[µg/L, microgram per liter; µg/g, microgram per gram; >, greater than; <, less than; --, no guideline available]

	Cadmium	Chromium	Copper	Lead	Mercury	Uranium
Drinking water, in µg/L[1]	5	100	[2]1,000	15	2	[3]20
Water supporting aquatic life, in µg/L[4]	12	100	20	100	0.05	–
Natural sediments, nonpolluted, in µg/g[5]	--	<25	<25	<40	<1	–
Natural sediments, moderately polluted, in µg/g[5]	--	25 to 75	25 to 50	40 to 60	--	–
Natural sediments, heavily polluted, in µg/g[5]	>6	>75	>50	>60	>1	–

[1] U.S. Environmental Protection Agency, 1992.

[2] Secondary maximum contaminant level based on esthetic water quality.

[3] Proposed maximum contaminant level.

[4] U.S. Environmental Protection Agency, 1982.

[5] Great Lakes Water Quality Board, Dredging Subcommittee, 1982.

Antimony - Inorganic Contaminant 0.006 mg/L MCL Metalloid

Antimony is a toxic chemical element with symbol **Sb** and atomic number 51. A lustrous gray metalloid, it is found in nature mainly as the sulfide mineral stibnite (Sb_2S_3). Antimony compounds have been known since ancient times and were used for cosmetics; metallic antimony was also known, but it was erroneously identified as lead. It was established to be an element around the 17th century.

For some time, China has been the largest producer of antimony and its compounds, with most production coming from the Xikuangshan Mine in Hunan. The industrial methods to produce antimony are roasting and subsequent carbothermal reduction or direct reduction of stibnite with iron.

What are EPA's drinking water regulations for antimony?

In 1974, Congress passed the Safe Drinking Water Act. This law requires EPA to determine the level of contaminants in drinking water at which no adverse health effects are likely to occur. These non-enforceable health goals, based solely on possible health risks and exposure over a lifetime with an adequate margin of safety, are called maximum contaminant level goals (MCLG). Contaminants are any physical, chemical, biological or radiological substances or matter in water.

The MCLG for antimony is 0.006 mg/L or 6 ppb. EPA has set this level of protection based on the best available science to prevent potential health problems. EPA has set an enforceable regulation for antimony, called a maximum contaminant level (MCL), at 0.006 mg/L or 6 ppb. MCLs are set as close to the health goals as possible, considering cost, benefits and the ability of public water systems to detect and remove contaminants using suitable treatment technologies. In this case, the MCL equals the MCLG, because analytical methods or treatment technology do not pose any limitation.

The Phase V Rule, the regulation for antimony, became effective in 1994. The Safe Drinking Water Act requires EPA to periodically review the national primary drinking water regulation for each contaminant and revise the regulation, if appropriate. EPA reviewed antimony as part of the Six Year Review and determined that the 0.006 mg/L or 6 ppb MCLG and 0.006 mg/L or 6 ppb MCL for antimony are still protective of human health.

Applications

The largest applications for metallic antimony are as alloying material for lead and tin and for lead antimony plates in lead-acid batteries. Alloying lead and tin with antimony improves the properties of the alloys which are used in solders, bullets and plain bearings. Antimony compounds are prominent additives for chlorine- and bromine-containing fire retardants found in many commercial and domestic products. An emerging application is the use of antimony in microelectronics.

Antimony is in the nitrogen group (group 15) and has an electronegativity of 2.05. As expected by periodic trends, it is more electronegative than tin or bismuth, and less electronegative than tellurium or arsenic. Antimony is stable in air at room temperature, but reacts with oxygen if heated to form antimony trioxide, Sb_2O_3. Antimony is a silvery, lustrous gray metal that has a Mohs scale hardness of 3. Therefore, pure antimony is not used to make hard objects: coins made of antimony were issued in China's Guizhou province in 1931, but because of their rapid wear, their minting was discontinued. Antimony is resistant to attack by acids.

Four allotropes of antimony are known, a stable metallic form and three metastable forms, explosive, black and yellow. Metallic antimony is a brittle, silver-white shiny metal. When molten antimony is slowly cooled, metallic antimony crystallizes in a trigonal cell, isomorphic with that of the gray allotrope of arsenic. A rare explosive form of antimony can be formed from the electrolysis of antimony (III) trichloride. When scratched with a sharp implement, an exothermic reaction occurs and white fumes are given off as metallic antimony is formed; when rubbed with a pestle in a mortar, a strong detonation occurs.

Black antimony is formed upon rapid cooling of vapor derived from metallic antimony. It has the same crystal structure as red phosphorus and black arsenic; it oxidizes in air and may ignite spontaneously. At 100 °C, it gradually transforms into the stable form. The yellow allotrope of antimony is the most unstable. It has only been generated by oxidation of stibine (SbH_3) at −90 °C. Above this temperature and in ambient light, this metastable allotrope transforms into the more stable black allotrope.

Metallic antimony adopts a layered structure (space group R3m No. 166) in which layers consist of fused ruffled six-membered rings. The nearest and next-nearest neighbors form a distorted octahedral complex, with the three atoms in the same double-layer being slightly closer than the three atoms in the next. This relatively close packing leads to a high density of 6.697 g/cm^3, but the weak bonding between the layers leads to the low hardness and brittleness of antimony.

Isotopes

Antimony exists as two stable isotopes, ^{121}Sb with a natural abundance of 57.36% and ^{123}Sb with a natural abundance of 42.64%. It also has 35 radioisotopes, of which the longest-lived is ^{125}Sb with a half-life of 2.75 years. In addition, 29 metastable states have been characterized. The most stable of these is ^{124}Sb with a half-life of 60.20 days, which has an application in some neutron sources. Isotopes that are lighter than the stable ^{123}Sb tend to decay by β^+ decay, and those that are heavier tend to decay by β^- decay, with some exceptions.

Occurrence

The abundance of antimony in the Earth's crust is estimated at 0.2 to 0.5 parts per million, comparable to thallium at 0.5 parts per million and silver at 0.07 ppm. Even though this element is not abundant, it is found in over 100 mineral species. Antimony is sometimes found natively, but more frequently it is found in the sulfide stibnite (Sb_2S_3) which is the predominant ore mineral.

Antimony compounds are often classified into those of Sb(III) and Sb(V). Relative to its congener arsenic, the +5 oxidation state is more stable.

Oxides and hydroxides

Antimony trioxide (Sb_4O_6) is formed when antimony is burnt in air. In the gas phase, this compound exists as Sb_4O_6, but it polymerizes upon condensing. Antimony pentoxide (Sb_4O_{10}) can only be formed by oxidation by concentrated nitric acid. Antimony also forms a mixed-valence oxide, antimony tetroxide (Sb_2O_4), which features both Sb(III) and Sb(V). Unlike phosphorus and arsenic, these various oxides are amphoteric, do not form well-defined oxoacids and react with acids to form antimony salts.

Antimonous acid $Sb(OH)_3$ is unknown, but the conjugate base sodium antimonite ($[Na_3SbO_3]_4$) forms upon fusing sodium oxide and Sb_4O_6. Transition metal antimonites are also known. Antimonic acid exists only as the hydrate $HSb(OH)_6$, forming salts containing the antimonate anion Sb(OH)−6. Dehydrating metal salts containing this anion yields mixed oxides. Many antimony ores are sulfides, including stibnite (Sb_2S_3), pyrargyrite (Ag_3SbS_3), zinkenite, jamesonite, and boulangerite. Antimony pentasulfide is non-stoichiometric and features antimony in the +3 oxidation state and S-S bonds. Several thioantimonides are known, such as $[Sb_6S_{10}]^{2-}$ and $[Sb_8S_{13}]^{2-}$.

Halides

Antimony forms two series of halides, SbX_3 and SbX_5. The trihalides SbF_3, $SbCl_3$, $SbBr_3$, and SbI_3 are all molecular compounds having trigonal pyramidal molecular geometry. The trifluoride SbF_3 is prepared by the reaction of Sb_2O_3 with HF:

$$Sb_2O_3 + 6\ HF \rightarrow 2\ SbF_3 + 3\ H_2O$$

It is Lewis acidic and readily accepts fluoride ions to form the complex anions SbF−4 and SbF2−5. Molten SbF_3 is a weak electrical conductor. The trichloride $SbCl_3$ is prepared by dissolving Sb_2S_3 in hydrochloric acid:

$$Sb_2S_3 + 6\ HCl \rightarrow 2\ SbCl_3 + 3\ H_2S$$

The pentahalides SbF_5 and $SbCl_5$ have trigonal bipyramidal molecular geometry in the gas phase, but in the liquid phase, SbF_5 is polymeric, whereas $SbCl_5$ is monomeric. SbF_5 is a powerful Lewis acid used to make the super acid fluoroantimonic acid ("$HSbF_6$").

Oxyhalides are more common for antimony than arsenic and phosphorus. Antimony trioxide dissolves in concentrated acid to form oxoantimonyl compounds such as SbOCl and $(SbO)_2SO_4$.

Antimonides, hydrides, and organoantimony compounds

Compounds in this class generally are described as derivatives of Sb^{3-}. Antimony forms antimonides with metals, such as indium antimonide (InSb) and silver antimonide (Ag_3Sb). The alkali metal and zinc antimonides, such as Na_3Sb and Zn_3Sb_2, are more reactive. Treating these antimonides with acid produces the unstable gas stibine, SbH_3:

$$Sb^{3-} + 3\ H^+ \rightarrow SbH_3$$

Stibine can also be produced by treating Sb^{3+} salts with hydride reagents such as sodium borohydride. Stibine decomposes spontaneously at room temperature. Because stibine has a positive heat of formation, it is thermodynamically unstable and thus antimony does not react with hydrogen directly.

Organoantimony compounds are typically prepared by alkylation of antimony halides with Grignard reagents. A large variety of compounds are known with both Sb(III) and Sb(V) centers, including mixed chloro-organic derivatives, anions, and cations. Examples include $Sb(C_6H_5)_3$ (triphenylstibine), $Sb_2(C_6H_5)_4$ (with an Sb-Sb bond), and cyclic $[Sb(C_6H_5)]_n$. Pentacoordinated organoantimony compounds are common, examples being $Sb(C_6H_5)_5$ and several related halides.

History

Antimony(III) sulfide, Sb_2S_3, was recognized in predynastic Egypt as an eye cosmetic (kohl) as early as about 3100 BC, when the cosmetic palette was invented.

An artifact, said to be part of a vase, made of antimony dating to about 3000 BC was found at Telloh, Chaldea (part of present-day Iraq), and a copper object plated with antimony dating between 2500 BC and 2200 BC has been found in Egypt.

Austen, at a lecture by Herbert Gladstone in 1892 commented that "we only know of antimony at the present day as a highly brittle and crystalline metal, which could hardly be fashioned into a useful vase, and therefore this remarkable 'find' (artifact mentioned above) must represent the lost art of rendering antimony malleable."

Moorey was unconvinced the artifact was indeed a vase, mentioning that Selimkhanov, after his analysis of the Tello object (published in 1975), "attempted to relate the metal to Transcaucasian natural antimony" (i.e. native metal) and that "the antimony objects from Transcaucasia are all small personal ornaments." This weakens the evidence for a lost art "of rendering antimony malleable."

The first European description of a procedure for isolating antimony is in the book *De la pirotechnia* of 1540 by Vannoccio Biringuccio; this predates the more famous 1556 book by Agricola, *De re metallica*. In this context Agricola has been often incorrectly credited with the discovery of metallic antimony.

The book *Currus Triumphalis Antimonii* (The Triumphal Chariot of Antimony), describing the preparation of metallic antimony, was published in Germany in 1604. It was purported to have been written by a Benedictine monk, writing under the name Basilius Valentinus, in the 15th century; if it were authentic, which it is not, it would predate Biringuccio.

The first natural occurrence of pure antimony in the Earth's crust was described by the Swedish scientist and local mine district engineer Anton von Swab in 1783; the type-sample was collected from the Sala Silver Mine in the Bergslagen mining district of Sala, Västmanland, Sweden.

Arsenic
Arsenic- Inorganic Contaminant 0.010 mg/L MCL
Metalloid

Arsenic is a chemical element with symbol **As** and the atomic number is 33. Arsenic occurs in many minerals, usually in conjunction with sulfur and metals, and also as a pure elemental crystal. It was first documented by Albertus Magnus in 1250. Arsenic is a metalloid. It can exist in various allotropes, although only the gray form has important use in industry.

In 1974, Congress passed the Safe Drinking Water Act. This law requires EPA to determine the level of contaminants in drinking water at which no adverse health effects are likely to occur. These non-enforceable health goals, based solely on possible health risks and exposure over a lifetime with an adequate margin of safety, are called maximum contaminant level goals (MCLG). Contaminants are any physical, chemical, biological or radiological substances or matter in water.

The MCLG for arsenic is zero. EPA has set this level of protection based on the best available science to prevent potential health problems. Based on the MCLG, EPA has set an enforceable regulation for arsenic, called a maximum contaminant level (MCL), at 0.010 mg/L or 10 ppb. MCLs are set as close to the health goals as possible, considering cost, benefits and the ability of public water systems to detect and remove contaminants using suitable treatment technologies.

The Arsenic and Clarifications to Compliance and New Source Contaminants Monitoring Final Rule, the regulation for arsenic, became effective in 2002. The Safe Drinking Water Act requires EPA to periodically review and revise contaminants, if appropriate, based on new scientific data. The regulation for arsenic will be included in a future review cycle.

The main uses of metallic arsenic is for strengthening alloys of copper and especially lead (for example, in car batteries). Arsenic is a common n-type dopant in semiconductor electronic devices, and the optoelectronic compound gallium arsenide is the most common semiconductor in use after doped silicon. Arsenic and its compounds, especially the trioxide, are used in the production of pesticides (treated wood products), herbicides, and insecticides. These applications are declining, however.

Arsenic is notoriously poisonous to multicellular life, although a few species of bacteria are able to use arsenic compounds as respiratory metabolites. Arsenic contamination of groundwater is a problem that affects millions of people across the world.

Arsenic, a naturally occurring element, is found throughout the environment; for most people, food is the major source of exposure. Acute (short-term) high-level inhalation exposure to arsenic dust or fumes has resulted in gastrointestinal effects (nausea, diarrhea, abdominal pain); central and peripheral nervous system disorders have occurred in workers acutely exposed to inorganic arsenic. Chronic (long-term) inhalation exposure to inorganic arsenic in humans is associated with irritation of the skin and mucous membranes. Chronic oral exposure has resulted in gastrointestinal effects, anemia, peripheral neuropathy, skin lesions, hyperpigmentation, and liver or kidney damage in humans. Inorganic arsenic exposure in humans, by the inhalation route, has been shown to be strongly associated with lung cancer, while ingestion of inorganic arsenic in humans has been linked to a form of skin cancer and also to bladder, liver, and lung cancer. EPA has classified inorganic arsenic as a Group A, human carcinogen.

Contamination of Groundwater

Arsenic contamination of groundwater is often due to naturally occurring high concentrations of arsenic in deeper levels of groundwater. It is a high-profile problem due to the use of deep tubewells for water supply in the Ganges Delta, causing serious arsenic poisoning to large numbers of people. In addition, mining techniques such as hydraulic fracturing mobilize arsenic in groundwater and aquifers due to enhanced methane 28 transport and resulting changes in redox conditions, and inject fluid containing additional arsenic.

A 2007 study found that over 137 million people in more than 70 countries are probably affected by arsenic poisoning of drinking water. Arsenic contamination of ground water is found in many countries throughout the world, including the USA.

Approximately 20 incidents of groundwater arsenic contamination have been reported from all over the world. Of these, four major incidents were in Asia, including locations in Thailand, Taiwan, and Mainland China. In South America, Argentina and Chile are affected. There are also many locations in the United States where the groundwater contains arsenic concentrations in excess of the Environmental Protection Agency standard of 10 parts per billion adopted in 2001. Millions of private wells have unknown arsenic levels, and in some areas of the US, over 20% of wells may contain levels that are not safe.

Arsine

Arsine is a gas consisting of arsenic and hydrogen. It is extremely toxic to humans, with headaches, vomiting, and abdominal pains occurring within a few hours of exposure. EPA has not classified arsine for carcinogenicity.

Drinking water regulations require public water systems to monitor for arsenic at the entry point to the distribution system. There is no federal requirement for systems to monitor for arsenic within the distribution system. You may, however, want to test your distribution system water for arsenic to be sure that the water being delivered has arsenic levels below the MCL. If you decide to monitor your distribution system, consider testing for arsenic at locations where the settling and accumulation of iron solids or pipe scales are likely (i.e., areas with cast iron pipe, ductile iron pipe, or galvanized iron pipe).

If your water system has installed some form of arsenic treatment, keep in mind that the treatment you installed may change the water quality in other ways.

It might cause the water to react differently in the distribution system. Depending on the kind of treatment you've installed, consider what distribution system problems might result.

A change in the taste, odor or appearance of the water at customers' taps may be the first indication of a problem. Some water quality parameters to consider monitoring, depending on your arsenic treatment technology, include iron, pH, manganese, alkalinity, and aluminum.

The current drinking water standard or Maximum Contaminant Level (MCL) set by the U.S. Environmental Protection Agency (EPA) is 0.010 mg/L or parts per million (ppm). This is equivalent to 10 ug/L (micrograms per liter) or 10 ppb. In 2001, the U.S. Environmental Protection Agency (EPA) reduced the regulatory MCL from 50 ppb to 10 ppb on the basis on bladder and lung cancer risks. The MCL is based on the average individual consuming 2 liters of water a day for a lifetime. Long term exposure to drinking water containing arsenic at levels higher than 10 ppb increases the chances of getting cancer, while for lower arsenic water levels the chances are less.

If your water has arsenic levels above 10 ppb, you should obtain drinking water from another source or install a home treatment device. Concentrations above 10 ppb will increase the risk of long-term or chronic health problems, the higher the level and length of exposure, the greater the risk. It is especially important to reduce arsenic water concentrations if you have children or are pregnant. Children are at greater risk (to any agent in water) because of their greater water consumption on a per unit body weight basis.

Pregnant women may wish to reduce their arsenic exposures because arsenic has been found at low levels in mother's milk and will cross the placenta, increasing exposures and risks for the fetus. If your water has arsenic levels above 200 ppb, you should immediately stop drinking the water until you can either obtain water from another source or install and maintain treatment.

Physical Characteristics

The three most common arsenic allotropes are *metallic gray*, *yellow* and *black arsenic*, with gray being the most common. *Gray arsenic* (α-As, space group R3m No. 166) adopts a double-layered structure consisting of many interlocked ruffled six-membered rings. Because of weak bonding between the layers, gray arsenic is brittle and has a relatively low Mohs hardness of 3.5. Nearest and next-nearest neighbors form a distorted octahedral complex, with the three atoms in the same double-layer being slightly closer than the three atoms in the next. This relatively close packing leads to a high density of 5.73 g/cm^3. Gray arsenic is a semimetal, but becomes a semiconductor with a bandgap of 1.2–1.4 eV if amorphized. *Yellow arsenic* is soft and waxy, and somewhat similar to tetraphosphorus (P_4).

Both have four atoms arranged in a tetrahedral structure in which each atom is bound to each of the other three atoms by a single bond. This unstable allotrope, being molecular, is the most volatile, least dense and most toxic. Solid yellow arsenic is produced by rapid cooling of arsenic vapor, As_4. It is rapidly transformed into the gray arsenic by light. The yellow form has a density of 1.97 g/cm^3. *Black arsenic* is similar in structure to red phosphorus.

Isotopes

Naturally occurring arsenic is composed of one stable isotope, ^{75}As. As of 2003, at least 33 radioisotopes have also been synthesized, ranging in atomic mass from 60 to 92. The most stable of these is ^{73}As with a half-life of 80.3 days. Isotopes that are lighter than the stable ^{75}As tend to decay by β^+ decay, and those that are heavier tend to decay by β^- decay, with some exceptions.

At least 10 nuclear isomers have been described, ranging in atomic mass from 66 to 84. The most stable of arsenic's isomers is ^{68m}As with a half-life of 111 seconds.

Chemistry

When heated in air, arsenic oxidizes to arsenic trioxide; the fumes from this reaction have an odor resembling garlic. This odor can be detected on striking arsenide minerals such as arsenopyrite with a hammer. Arsenic (and some arsenic compounds) sublimes upon heating at atmospheric pressure, converting directly to a gaseous form without an intervening liquid state at 887 K (614 °C). The triple point is 3.63 MPa and 1,090 K (820 °C). Arsenic makes arsenic acid with concentrated nitric acid, arsenious acid with dilute nitric acid, and arsenic trioxide with concentrated sulfuric acid.

Compounds

Arsenic compounds resemble in some respects those of phosphorus, which occupies the same group (column) of the periodic table. Arsenic is less commonly observed in the pentavalent state, however. The most common oxidation states for arsenic are: −3 in the arsenides, such as alloy-like intermetallic compounds; and +3 in the arsenites, arsenates (III), and most organoarsenic compounds. Arsenic also bonds readily to itself as seen in the square As3−4 ions in the mineral skutterudite. In the +3 oxidation state, arsenic is typically pyramidal, owing to the influence of the lone pair of electrons.

Inorganic

Arsenic forms colorless, odorless, crystalline oxides As_2O_3 ("white arsenic") and As_2O_5, which are hygroscopic and readily soluble in water to form acidic solutions. Arsenic (V) acid is a weak acid. Its salts are called arsenates, which is the basis of arsenic contamination of groundwater, a problem that affects many people. Synthetic arsenates include Paris Green (copper(II) acetoarsenite), calcium arsenate, and lead hydrogen arsenate. The latter three have been used as agricultural insecticides and poisons.

The protonation steps between the arsenate and arsenic acid are similar to those between phosphate and phosphoric acid. Unlike phosphorus acid, arsenous acid is genuinely tribasic, with the formula $As(OH)_3$.

A broad variety of sulfur compounds of arsenic are known. Orpiment (As_2S_3) and realgar (As_4S_4) are somewhat abundant and were formerly used as painting pigments. In As_4S_{10}, arsenic has a formal oxidation state of +2 in As_4S_4, which features As-As bonds so that the total covalency of As is still three.

The trifluoride, trichloride, tribromide, and triiodide of arsenic (III) are well known, whereas only Arsenic pentafluoride (AsF_5) is the only important pentahalide. Again reflecting the lower stability of the 5+ oxidation state, the pentachloride is stable only below −50 °C.

Organoarsenic Compounds

A large variety of organoarsenic compounds are known. Several were developed as chemical warfare agents during World War I, including vesicants such as lewisite and vomiting agents such as adamsite. Cacodylic acid, which is of historic and practical interest, arises from the methylation of arsenic trioxide, a reaction that has no analogy in phosphorus chemistry.

Alloys

Arsenic is used as the group 5 element in the III-V semiconductors gallium arsenide, indium arsenide, and aluminum arsenide. The valence electron count of GaAs is the same as a pair of Si atoms, but the band structure is completely different, which results distinct bulk properties. Other arsenic alloys include the II-IV semiconductor cadmium arsenide.

Occurrence and Production

Minerals with the formula MAsS and MAs_2 (M = Fe, Ni, Co) are the dominant commercial sources of arsenic, together with realgar (an arsenic sulfide mineral) and native arsenic. An illustrative mineral is arsenopyrite (FeAsS), which is structurally related to iron pyrite. Many minor As-containing minerals are known. Arsenic also occurs in various organic forms in the environment. Inorganic arsenic and its compounds, upon entering the food chain, are progressively metabolized to a less toxic form of arsenic through a process of methylation.

Other naturally occurring pathways of exposure include volcanic ash, weathering of arsenic-containing minerals and ores, and dissolved in groundwater. It is also found in food, water, soil, and air. Arsenic is absorbed by all plants, but is more concentrated in leafy vegetables, rice, apple and grape juice, and seafood. An additional route of exposure is through inhalation.

In 2005, China was the top producer of white arsenic with almost 50% world share, followed by Chile, Peru, and Morocco, according to the British Geological Survey and the United States Geological Survey. Most operations in the US and Europe have closed for environmental reasons. The arsenic is recovered mainly as a side product from the purification of copper. Arsenic is part of the smelter dust from copper, gold, and lead smelters.

On roasting in air of arsenopyrite, arsenic sublimes as arsenic (III) oxide leaving iron oxides, while roasting without air results in the production of metallic arsenic. Further purification from sulfur and other chalcogens is achieved by sublimation in vacuum or in a hydrogen atmosphere or by distillation from molten lead-arsenic mixture.

Health Hazard Information

Arsenic

Arsenic is known to cause cancer, as well as many other serious health problems. Here we review the hazards of arsenic exposure and ways people can protect themselves from these hazards.

Arsenic is an element in the environment that can be found naturally in rocks and soil, water, air, and in plants and animals. It can also be released into the environment from some agricultural and industrial sources.

Arsenic has no taste or smell. Although sometimes found in its pure form as a steel grey metal, arsenic is usually part of chemical compounds. These compounds are divided into 2 groups:

- Inorganic compounds (combined with oxygen, iron, chlorine, and sulfur)
- Organic compounds (combined with carbon and other atoms)

Inorganic arsenic compounds are found in industry, in building products (in some "pressure-treated" woods), and in arsenic-contaminated water. This is the form of arsenic that tends to be more toxic and has been linked to cancer.

Organic arsenic compounds are much less toxic than the inorganic arsenic compounds and are not thought to be linked to cancer. These compounds are found in some foods, such as fish and shellfish.

While arsenic levels may fluctuate over time, what is most significant from the standpoint of cancer risk is long-term exposure.

For water systems in the 25 states that reported arsenic data to the EPA, we have calculated two estimates of average long-term levels: one is a very conservative estimate, the other our best estimate, based on what we believe to be the most reasonable analytical techniques (details on how we arrived at the estimates are included with the charts).

The table below shows the lifetime risks of dying of cancer from arsenic in tap water, based on the National Academy of Sciences' 1999 risk estimates.

Arsenic Level in Tap Water (in parts per billion, or ppb)	Approximate Total Cancer Risk (assuming 2 liters consumed/day)
0.5 ppb	1 in 10,000
1 ppb	1 in 5,000
3 ppb	1 in 1,667
4 ppb	1 in 1,250
5 ppb	1 in 1,000
10 ppb	1 in 500
20 ppb	1 in 250
25 ppb	1 in 200
50 ppb	1 in 100

Arsenic Diabetes

New research findings from the National Health and Nutrition Examination Survey suggest that exposure to levels of arsenic commonly found in drinking water may be a risk factor for type 2 diabetes. The findings suggest that millions of Americans may be at increased risk for type 2 diabetes based on the level of arsenic in their drinking water.

Data on the nearly 800 participants in the study for which urinary arsenic concentrations were available, indicated that urine levels of arsenic were significantly associated with the prevalence of type 2 diabetes. After splitting the subjects into 5 groups based on the level of arsenic in their urine, the researchers determined that those in the highest category were more than three and one-half times more likely to have diabetes. The strength of arsenic as a risk factor for diabetes is similar to other factors such as obesity.

Inorganic arsenic in drinking water at concentrations higher than 100 parts per million has been linked to type 2 diabetes in studies that took place in Taiwan, Mexico, and Bangladesh where drinking water is commonly contaminated with high levels of arsenic. The US drinking water standard is currently 10 parts per million, but most people on private wells have not had their water tested and aren't required to. The researchers estimate that about 13 million Americans live in areas where public water systems exceed the EPA standard for arsenic and this number does not included private wells and water systems.

Animal studies have shown that arsenic affects the production of glucose, insulin secretion and can cause insulin resistance. The current findings reinforce the need to evaluate the role of arsenic in diabetes development in prospective epidemiologic studies conducted in populations exposed to a wide range of arsenic levels.

Acute Effects:

Inorganic Arsenic

- Acute inhalation exposure of workers to high levels of arsenic dusts or fumes has resulted in gastrointestinal effects (nausea, diarrhea, abdominal pain), while acute exposure of workers to inorganic arsenic has also resulted in central and peripheral nervous system disorders.
- Acute oral exposure to inorganic arsenic, at doses of approximately 600 micrograms per kilogram body weight per day (µg/kg/d) or higher in humans, has resulted in death. Oral exposure to lower levels of inorganic arsenic has resulted in effects on the gastrointestinal tract (nausea, vomiting), central nervous system (CNS) (headaches, weakness, delirium), cardiovascular system (hypotension, shock), liver, kidney, and blood (anemia, leukopenia).
- Acute animal tests in rats and mice have shown inorganic arsenic to have moderate to high acute toxicity.

Arsine

- Acute inhalation exposure to arsine by humans has resulted in death; it has been reported that a half-hour exposure to 25 to 50 parts per million (ppm) can be lethal.
- The major effects from acute arsine exposure in humans include headaches, vomiting, abdominal pains, hemolytic anemia, hemoglobinuria, and jaundice; these effects can lead to kidney failure.
- Arsine has been shown to have extreme acute toxicity from acute animal tests.

Chronic Effects (Non-cancer):

Inorganic arsenic

- Chronic inhalation exposure to inorganic arsenic in humans is associated with irritation of the skin and mucous membranes (dermatitis, conjunctivitis, pharyngitis, and rhinitis).
- Chronic oral exposure to inorganic arsenic in humans has resulted in gastrointestinal effects, anemia, peripheral neuropathy, skin lesions, hyperpigmentation, gangrene of the extremities, vascular lesions, and liver or kidney damage.
- No chronic inhalation exposure studies have been performed in animals for any inorganic arsenic compound.
- Some studies have suggested that inorganic arsenic is an essential dietary nutrient in goats, chicks, and rats. However, no comparable data are available for humans. EPA has concluded that essentiality, although not rigorously established, is plausible.
- EPA has not established a Reference Concentration (RfC) for inorganic arsenic.
- The California Environmental Protection Agency (CalEPA) has established a chronic inhalation reference level of 0.00003 milligrams per cubic meter (mg/m^3) based on developmental effects in mice. The CalEPA reference exposure level is a concentration at or below which adverse health effects are not likely to occur. It is not a direct estimator of risk, but rather a reference point to gauge the potential effects. At lifetime exposures increasingly greater than the reference exposure level, the potential for adverse health effects increases.
- The Reference Dose (RfD) for inorganic arsenic is 0.0003 milligrams per kilogram body weight per day (mg/kg/d) based on hyperpigmentation, keratosis, and possible vascular complications in humans. The RfD is an estimate (with uncertainty spanning perhaps an order of magnitude) of a daily oral exposure to the human population (including sensitive subgroups) that is likely to be without appreciable risk of deleterious noncancer effects during a lifetime.
- EPA has medium confidence in the study on which the RfD for inorganic arsenic was based because, although an extremely large number of people were included in the assessment (>40,000), the doses were not well characterized and other contaminants were present. The supporting human toxicity database, while extensive, is somewhat flawed and, consequently, EPA has assigned medium confidence to the RfD.

Arsine

- No information is available on the chronic effects of arsine in humans.
- The RfC for arsine is 0.00005 mg/m^3 based on increased hemolysis, abnormal red blood cell morphology, and increased spleen weight in rats, mice, and hamsters.
- EPA has medium confidence in the RfC based on: (1) high confidence in the studies on which the RfC for arsine was based because the sample sizes were adequate, statistical significance was reported, concentration dose-response relationships were documented, three species were investigated, and both a no-observed-adverse-effect level (NOAEL) and a lowest-observed-adverse-effect level (LOAEL) were identified, and (2) medium confidence in the database because while there were three inhalation animal studies and a developmental/reproductive study, there were no data available on human exposure.

Reproductive/Developmental Effects:

Inorganic arsenic

- Several studies have suggested that women who work in, or live near, metal smelters may have higher than normal spontaneous abortion rates, and their children may exhibit lower than normal birth weights. However, these studies are limited because they were designed to evaluate the effects of smelter pollutants in general, and are not specific for inorganic arsenic.
- Ingested inorganic arsenic can cross the placenta in humans, exposing the fetus to the chemical.
- Oral animal studies have reported inorganic arsenic at very high doses to be fetotoxic and to cause birth defects.

Arsine

- Human studies have indicated higher than expected spontaneous abortion rates in women in the microelectronics industry who were exposed to arsine. However, these studies have several limitations, including small sample size and exposure to other chemicals in addition to arsine.

Cancer Risk:

Inorganic arsenic

- Human, inhalation studies have reported inorganic arsenic exposure to be strongly associated with lung cancer.
- Ingestion of inorganic arsenic in humans has been associated with an increased risk of nonmelanoma skin cancer and also to an increased risk of bladder, liver, and lung cancer.
- Animal studies have not associated inorganic arsenic exposure via the oral route with cancer, and no cancer inhalation studies have been performed in animals for inorganic arsenic.
- EPA has classified inorganic arsenic as a Group A, human carcinogen.
- EPA used a mathematical model, using data from an occupational study of arsenic-exposed copper smelter workers, to estimate the probability of a person developing cancer from continuously breathing air containing a specified concentration of inorganic arsenic. EPA calculated an inhalation unit risk estimate of $4.3 \times 10^{-3} (\mu g/m^3)^{-1}$. EPA estimates that, if an individual were to continuously breathe air containing inorganic arsenic at an average of 0.0002 µg/m^3 (2×10^{-7} mg/m^3) over his or her entire lifetime, that person would theoretically have no more than a one-in-a-million increased chance of developing cancer as a direct result of breathing air containing this chemical.

Similarly, EPA estimates that continuously breathing air containing 0.002 µg/m^3 (2 x 10^{-6} mg/m^3) would result in not greater than a one-in-a-hundred thousand increased chance of developing cancer, and air containing 0.02 µg/m^3 (2 x 10^{-5} mg/m^3) would result in not greater than a one-in-ten thousand increased chance of developing cancer. For a detailed discussion of confidence in the potency estimates, please see IRIS.

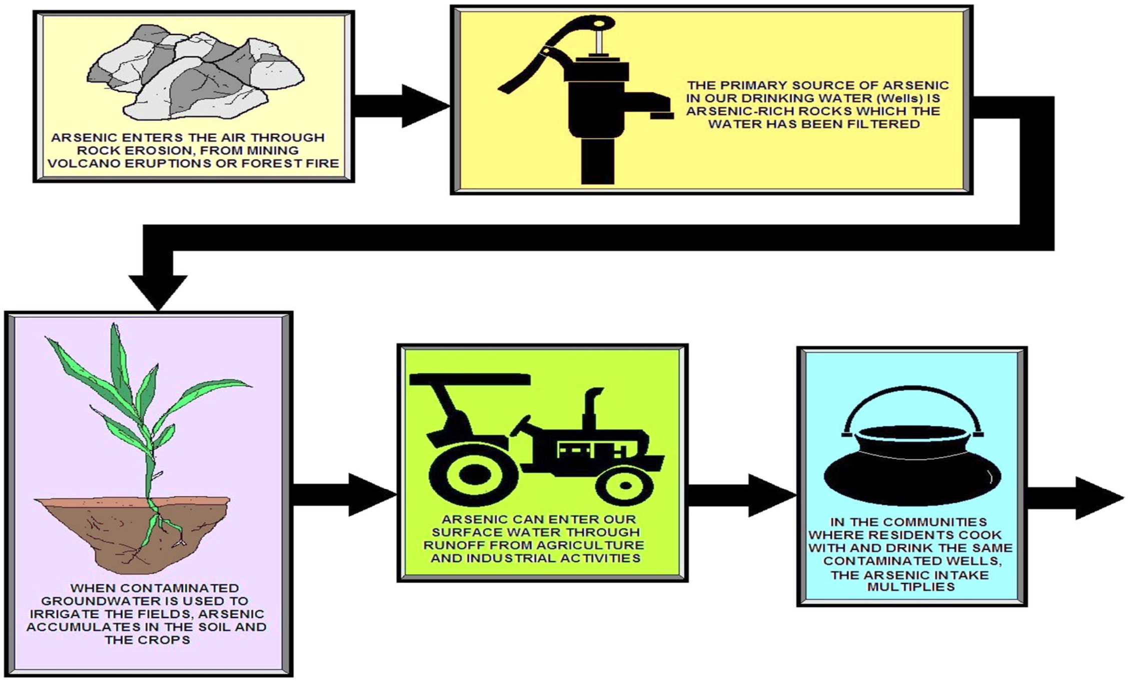
- EPA has calculated an oral cancer slope factor of 1.5 (mg/kg/d)$^{-1}$ for inorganic arsenic.

Arsine

- No cancer inhalation studies in humans or animals are available for arsine.
- EPA has not classified arsine for carcinogenicity.

Physical Properties

- Inorganic arsenic is a naturally occurring element in the earth's crust.
- Pure inorganic arsenic is a gray-colored metal, but inorganic arsenic is usually found combined with other elements such as oxygen, chlorine, and sulfur.
- The chemical symbol for inorganic arsenic is As, and it has an atomic weight of 74.92 g/mol.
- The chemical formula for arsine is AsH_3, and it has a molecular weight of 77.95 g/mol.
- Arsine is a colorless gas with a disagreeable garlic odor.
- Arsenic combined with elements such as oxygen, chlorine, and sulfur forms inorganic arsenic; inorganic arsenic compounds include arsenic pentoxide, arsenic trioxide, and arsenic acid. Arsenic combined with carbon and hydrogen forms organic arsenic; organic arsenic compounds include arsanilic acid, arsenobetaine, and dimethylarsinic acid.



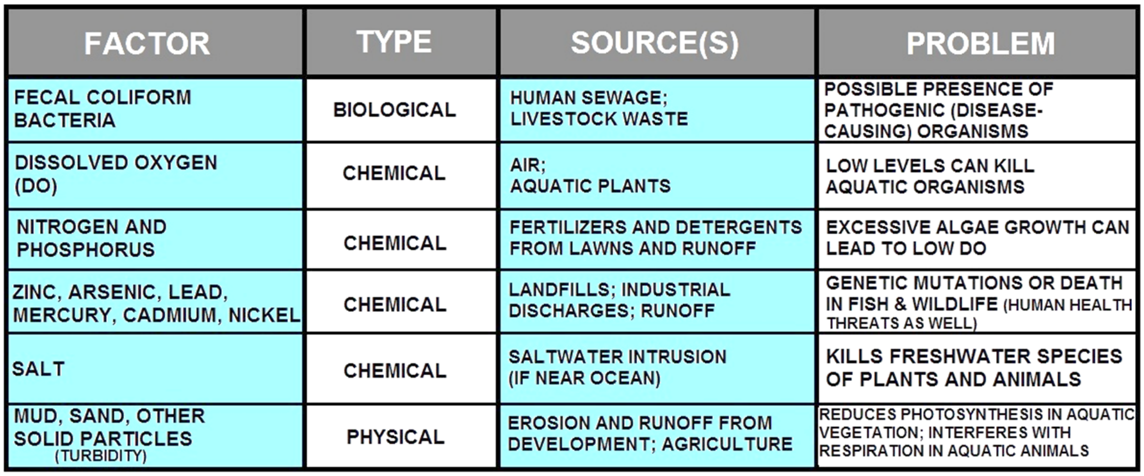
ARSENIC IN DRINKING WATER

Arsenic

History
The word “Arsenic“ was adopted in Latin *arsenicum* and Old French *arsenic,* from which the English word *arsenic* is derived. Arsenic sulfides (orpiment, realgar) and oxides have been known and used since ancient times. Zosimos (circa 300 AD) describes roasting *sandarach* (realgar) to obtain *cloud of arsenic* (arsenious oxide), which he then reduces to metallic arsenic. As the symptoms of arsenic poisoning were somewhat ill-defined, it was frequently used for murder until the advent of the Marsh test, a sensitive chemical test for its presence. (Another less sensitive but more general test is the Reinsch test.) Owing to its use by the ruling class to murder one another and its potency and discreetness, arsenic has been called the *Poison of Kings* and the *King of Poisons*.

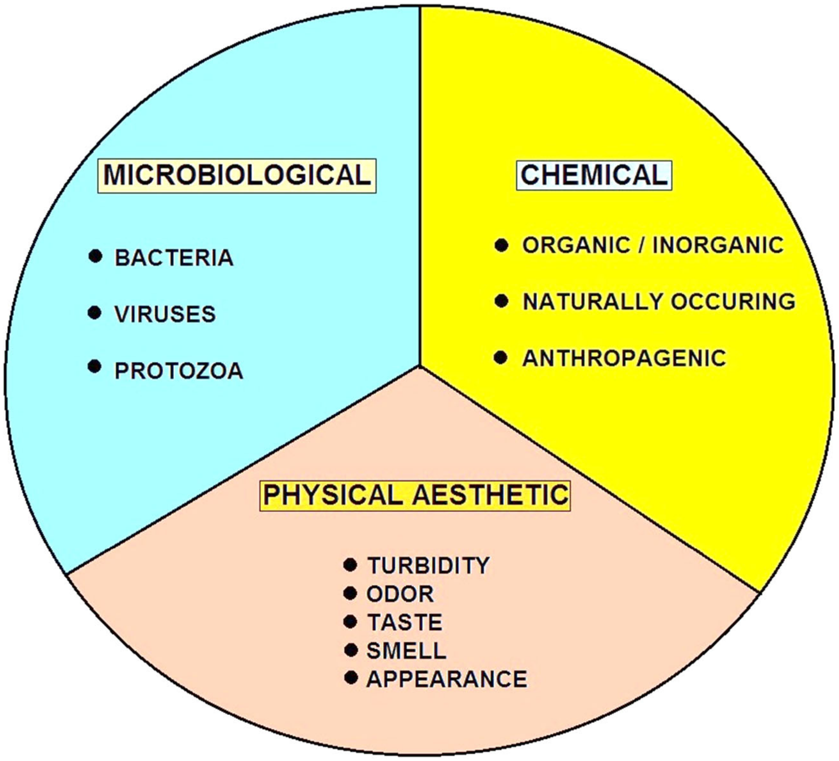
During the Bronze Age, arsenic was often included in bronze, which made the alloy harder (so-called "arsenical bronze"). Albertus Magnus (Albert the Great, 1193–1280) is believed to have been the first to isolate the element from a compound in 1250, by heating soap together with arsenic trisulfide. In 1649, Johann Schröder published two ways of preparing arsenic. Crystals of elemental (native) arsenic are found in nature, although rare. Cadet's fuming liquid (impure cacodyl), often claimed as the first synthetic organometallic compound, was synthesized in 1760 by Louis Claude Cadet de Gassicourt by the reaction of potassium acetate with arsenic trioxide.

In the Victorian era, "arsenic" ("white arsenic" or arsenic trioxide) was mixed with vinegar and chalk and eaten by women to improve the complexion of their faces, making their skin paler to show they did not work in the fields. Arsenic was also rubbed into the faces and arms of women to "improve their complexion". The accidental use of arsenic in the adulteration of foodstuffs led to the Bradford sweet poisoning in 1858, which resulted in approximately 20 deaths.



FACTOR	TYPE	SOURCE(S)	PROBLEM
FECAL COLIFORM BACTERIA	BIOLOGICAL	HUMAN SEWAGE; LIVESTOCK WASTE	POSSIBLE PRESENCE OF PATHOGENIC (DISEASE-CAUSING) ORGANISMS
DISSOLVED OXYGEN (DO)	CHEMICAL	AIR; AQUATIC PLANTS	LOW LEVELS CAN KILL AQUATIC ORGANISMS
NITROGEN AND PHOSPHORUS	CHEMICAL	FERTILIZERS AND DETERGENTS FROM LAWNS AND RUNOFF	EXCESSIVE ALGAE GROWTH CAN LEAD TO LOW DO
ZINC, ARSENIC, LEAD, MERCURY, CADMIUM, NICKEL	CHEMICAL	LANDFILLS; INDUSTRIAL DISCHARGES; RUNOFF	GENETIC MUTATIONS OR DEATH IN FISH & WILDLIFE (HUMAN HEALTH THREATS AS WELL)
SALT	CHEMICAL	SALTWATER INTRUSION (IF NEAR OCEAN)	KILLS FRESHWATER SPECIES OF PLANTS AND ANIMALS
MUD, SAND, OTHER SOLID PARTICLES (TURBIDITY)	PHYSICAL	EROSION AND RUNOFF FROM DEVELOPMENT; AGRICULTURE	REDUCES PHOTOSYNTHESIS IN AQUATIC VEGETATION; INTERFERES WITH RESPIRATION IN AQUATIC ANIMALS

WATER QUALITY FACTORS



WATER QUALITY BROKEN DOWN INTO 3 BROAD CATEGORIES

Arsenic Applications

Agricultural

The toxicity of arsenic to insects, bacteria and fungi led to its use as a wood preservative. In the 1950s a process of treating wood with chromated copper arsenate (also known as CCA or Tanalith) was invented, and for decades this treatment was the most extensive industrial use of arsenic. An increased appreciation of the toxicity of arsenic resulted in a ban for the use of CCA in consumer products; the European Union and United States initiated this process in 2004. CCA remains in heavy use in other countries however, e.g. Malaysian rubber plantations.

Arsenic was also used in various agricultural insecticides, termination and poisons. For example, lead hydrogen arsenate was a common insecticide on fruit trees, but contact with the compound sometimes resulted in brain damage among those working the sprayers. In the second half of the 20th century, monosodium methyl arsenate (MSMA) and disodium methyl arsenate (DSMA) – less toxic organic forms of arsenic – have replaced lead arsenate in agriculture.

Arsenic is still added to animal food, in particular in the US as a method of disease prevention and growth stimulation. One example is roxarsone, which is used as a broiler starter by about 70% of the broiler growers since 1995. The Poison-Free Poultry Act of 2009 proposes to ban the use of roxarsone in industrial swine and poultry production. Alpharma, a subsidiary of Pfizer Inc., which produces Roxarsone, has voluntarily suspended sales of the drug in response to studies showing elevated levels of arsenic in treated chickens.

Medical Use

During the 18th, 19th, and 20th centuries, a number of arsenic compounds have been used as medicines, including arsphenamine (by Paul Ehrlich) and arsenic trioxide (by Thomas Fowler). Arsphenamine as well as neosalvarsan was indicated for syphilis and trypanosomiasis, but has been superseded by modern antibiotics. Arsenic trioxide has been used in a variety of ways over the past 500 years, but most commonly in the treatment of cancer. The US Food and Drug Administration in 2000 approved this compound for the treatment of patients with acute promyelocytic leukemia that is resistant to ATRA.

It was also used as Fowler's solution in psoriasis. Recently new research has been done in locating tumors using arsenic-74 (a positron emitter). The advantages of using this isotope instead of the previously used iodine-124 is that the signal in the PET scan is clearer as the body tends to transport iodine to the thyroid gland producing a lot of noise. In subtoxic doses, soluble arsenic compounds act as stimulants, and were once popular in small doses as medicine by people in the mid-18th century.

Alloys

The main use of metallic arsenic is for alloying with lead. Lead components in car batteries are strengthened by the presence of a few percent of arsenic. Dezincification can be strongly reduced by adding arsenic to brass, a copper-zinc alloy. Gallium arsenide is an important semiconductor material, used in integrated circuits. Circuits made from GaAs are much faster (but also much more expensive) than those made in silicon. Unlike silicon it has a direct bandgap, and so can be used in laser diodes and LEDs to directly convert electricity into light.

Military

After World War I, the United States built up a stockpile of 20,000 tons of lewisite ($ClCH=CHAsCl_2$), a chemical weapon that is a vesicant (blister agent) and lung irritant. The stockpile was neutralized with bleach and dumped into the Gulf of Mexico after the 1950s. During the Vietnam War the United States used Agent Blue, a mixture of sodium cacodylate and its acid form, as one of the rainbow herbicides to deprive invading North Vietnamese soldiers of
foliage cover and rice.

Other uses

- Copper acetoarsenite was used as a green pigment known under many names, including 'Paris Green' and 'Emerald Green'. It caused numerous arsenic poisonings. Scheele's Green, a copper arsenate, was used in the 19th century as a coloring agent in sweets.
- Also used in bronzing and pyrotechnics.
- Up to 2% of arsenic is used in lead alloys for lead shots and bullets.
- Arsenic is added in small quantities to alpha-brass to make it dezincification resistant. This grade of brass is used to make plumbing fittings or other items that are in constant contact with water.
- Arsenic is also used for taxonomic sample preservation.
- Until recently arsenic was used in optical glass. Modern glass manufacturers, under pressure from environmentalists, have removed it, along with lead.

Bacteria

Some species of bacteria obtain their energy by oxidizing various fuels while reducing arsenate to arsenite. Under oxidative environmental conditions some bacteria use arsenite, which is oxidized to arsenate as fuel for their metabolism. The enzymes involved are known as arsenate reductases (Arr).

In 2008, bacteria were discovered that employ a version of photosynthesis in the absence of oxygen with arsenites as electron donors, producing arsenates (just as ordinary photosynthesis uses water as electron donor, producing molecular oxygen). Researchers conjecture that, over the course of history, these photosynthesizing organisms produced the arsenates that allowed the arsenate-reducing bacteria to thrive. One strain PHS-1 has been isolated and is related to the Gammaproteobacterium *Ectothiorhodospira shaposhnikovii*.

The mechanism is unknown, but an encoded Arr enzyme may function in reverse to its known homologues. Although the arsenate and phosphate anions are similar structurally, no evidence exists for the replacement of phosphate in ATP or nucleic acids by arsenic.

It is known that even if your water has detectable levels of arsenic that are below the 0.010 mg/L MCL, and you have iron pipes or components in your distribution system, your system's pipes may have arsenic-rich scales attached to them. As long as the scales are not disturbed, they will remain attached to the pipes or other distribution system components. Certain conditions, such as flushing of mains or fire flow conditions, may result in those scales being sloughed off and suspended in the water, releasing the arsenic. Other conditions, such as changes in water chemistry, may result in some of the arsenic dissolving back into the water. Both of these situations could cause high arsenic levels at consumers' taps.

Arsenic Control Measures Can Affect Finished Water Quality

Public water systems installing arsenic treatment should be informed about possible changes to their finished water that may result from the arsenic treatment they install. For example, systems may need to adjust their finished water quality to address new concerns about corrosion. Changes in water chemistry due to using new sources, blending different source waters, or installing arsenic treatment are some of the factors that can affect distribution system water quality. In some cases, this may cause an increase in arsenic levels in the distribution system or create simultaneous compliance issues with other drinking water regulations.

Water systems may also find deposits of arsenic-rich particles in their storage tanks or at locations in their distribution system with low flows. If the flow is increased or a storage tank is drawn down to a low level, these arsenic-rich particles can get stirred up and transported to consumers' taps. This situation occurs primarily when iron media used in treatment are released into the distribution system, or when iron particles are not properly filtered out during iron removal treatment. If these treatment technologies are operated correctly, this should not be a problem for most water systems.

Is Arsenic in your Storage Tank?

Is Your Ground Water System Installing Disinfection for Pathogen Control?

Water systems that disinfect their water should be aware of the possibility of an increase in arsenic concentrations in their distribution system, particularly if the water contains high concentrations of dissolved iron. When chlorinated, the dissolved iron forms particles on which arsenic can accumulate. As a result, high arsenic concentrations may occur in distribution system water even if arsenic concentrations in the raw water are below the MCL.

This happened to a small community water system in the Midwest that began chlorinating water from a series of wells that had raw water arsenic levels between 0.003 and 0.008 mg/L and iron concentrations up to 0.4 mg/L. At the same time, the system installed a polyphosphate feed system for corrosion control. Soon after chlorination began, the system received intermittent colored-water complaints from its customers with increasing frequency across the distribution system.

Samples collected from several representative locations throughout the service area had a reddish-brown color and contained particles. A metals analysis showed high levels of copper and iron oxides in the finished water, along with arsenic concentrations approaching 5 mg/L. Because of the water's colored appearance, it was considered unlikely that customers would consume the water. Doctors and health care professionals were notified of the situation and instructed to watch for signs of arsenic poisoning.

Researchers found that chlorinating the water caused the formation of ferri-hydroxide solids. The minimal arsenic present in the groundwater was being concentrated as it absorbed onto the solids. Copper oxide particulates also formed and were released. To some extent, the polyphosphates served a useful role by keeping iron in solution and counteracting the tendency for the iron oxides to form, but additional steps were needed.

For six months the system alternated their chlorination schedule: on for one day then off two days. The system then returned to full-time chlorination, starting with a low distribution system residual of0.2 mg/L and gradually increasing it to 0.5 mg/L. The system continued to flush water mains on a semi-annual schedule using a unidirectional approach. In the last year, the system received only one colored water complaint.

Heredity

Arsenic has been linked to epigenetic changes, heritable changes in gene expression that occur without changes in DNA sequence. These include DNA methylation, histone modification, and RNA interference. Toxic levels of arsenic cause significant DNA hypermethylation of tumor suppressor genes p16 and p53, thus increasing risk of carcinogenesis.

These epigenetic events have been studied *in vitro* using human kidney cells and *in vivo* using rat liver cells and peripheral blood leukocytes in humans. Inductive coupled plasma mass spectrometry (ICP-MS) is used to detect precise levels of intracellular arsenic and its other bases involved in epigenetic modification of DNA. Studies investigating arsenic as an epigenetic factor will help in developing precise biomarkers of exposure and susceptibility.

The Chinese brake fern (*Pteris vittata*) hyperaccumulates arsenic present in the soil into its leaves and has a proposed use in phytoremediation.

Biomethylation

Inorganic arsenic and its compounds, upon entering the food chain, are progressively metabolized through a process of methylation. For example, the mold Scopulariopsis brevicaulis produce significant amounts of trimethylarsine if inorganic arsenic is present. The organic compound arsenobetaine is found in some marine foods such as fish and algae, and also in mushrooms in larger concentrations. The average person's intake is about 10–50 µg/day. Values about 1000 µg are not unusual following consumption of fish or mushrooms, but there is little danger in eating fish because this arsenic compound is nearly non-toxic.

Arsenic Environmental Issues

Arsenic Control Measures Can Affect Finished Water Quality

Public water systems installing arsenic treatment should be informed about possible changes to their finished water that may result from the arsenic treatment they install. For example, systems may need to adjust their finished water quality to address new concerns about corrosion. Changes in water chemistry due to using new sources, blending different source waters, or installing arsenic treatment are some of the factors that can affect distribution system water quality. In some cases, this may cause an increase in arsenic levels in the distribution system or create simultaneous compliance issues with other drinking water regulations.

Occurrence in drinking water

Widespread arsenic contamination of groundwater has led to a massive epidemic of arsenic poisoning in Bangladesh and neighboring countries. It is estimated that approximately 57 million people in the Bengal basin are drinking groundwater with arsenic concentrations elevated above the World Health Organization's standard of 10 parts per billion (ppb). However, a study of cancer rates in Taiwan suggested that significant increases in cancer mortality appear only at levels above 150 ppb.

The arsenic in the groundwater is of natural origin, and is released from the sediment into the groundwater, owing to the anoxic conditions of the subsurface. This groundwater began to be used after local and western NGOs and the Bangladeshi government undertook a massive shallow tube well drinking-water program in the late twentieth century.

This program was designed to prevent drinking of bacteria-contaminated surface waters, but failed to test for arsenic in the groundwater. Many other countries and districts in Southeast Asia, such as Vietnam and Cambodia have geological environments conducive to generation of high-arsenic groundwaters. Arsenicosis was reported in Nakhon Si Thammarat, Thailand in 1987, and the dissolved arsenic in the Chao Phraya River is suspected of containing high levels of naturally occurring arsenic, but has not been a public health problem owing to the use of bottled water.

In the United States, arsenic is most commonly found in the ground waters of the southwest. Parts of New England, Michigan, Wisconsin, Minnesota and the Dakotas are also known to have significant concentrations of arsenic in ground water. Increased levels of skin cancer have been associated with arsenic exposure in Wisconsin, even at levels below the 10 part per billion drinking water standard, although this link has not been proven. According to a recent film funded by the US Superfund, millions of private wells have unknown arsenic levels, and in some areas of the US, over 20% of wells may contain levels that exceed established limits.

Low-level exposure to arsenic at concentrations found commonly in US drinking water compromises the initial immune response to H1N1 or swine flu infection according to NIEHS-supported scientists. The study, conducted in laboratory mice, suggests that people exposed to arsenic in their drinking water may be at increased risk for more serious illness or death in response to infection from the virus.

Some Canadians are drinking water that contains inorganic arsenic. Private dug well waters are most at risk for containing inorganic arsenic. Preliminary well water analyses typically does not test for arsenic. Researchers at the Geological Survey of Canada have modeled relative variation in natural arsenic hazard potential for the province of New Brunswick. This study has important implications for potable water and health concerns relating to inorganic arsenic.

Epidemiological evidence from Chile shows a dose-dependent connection between chronic arsenic exposure and various forms of cancer, in particular when other risk factors, such as cigarette smoking, are present. These effects have been demonstrated to persist below 50 ppb.

Analyzing multiple epidemiological studies on inorganic arsenic exposure suggests a small but measurable risk increase for bladder cancer at 10 ppb. According to Peter Ravenscroft of the Department of Geography at the University of Cambridge, roughly 80 million people worldwide consume between 10 and 50 ppb arsenic in their drinking water. If they all consumed exactly 10 ppb arsenic in their drinking water, the previously cited multiple epidemiological study analysis would predict an additional 2,000 cases of bladder cancer alone. This represents a clear underestimate of the overall impact, since it does not include lung or skin cancer, and explicitly underestimates the exposure. Those exposed to levels of arsenic above the current WHO standard should weigh the costs and benefits of arsenic remediation.

Early (1973) evaluations of the removal of dissolved arsenic by drinking water treatment processes demonstrated that arsenic is very effectively removed by co-precipitation with either iron or aluminum oxides. The use of iron as a coagulant, in particular, was found to remove arsenic with efficiencies exceeding 90%.

Several adsorptive media systems have been approved for point-of-service use in a study funded by the United States Environmental Protection Agency (US EPA) and the National Science Foundation (NSF). A team of European and Indian scientists and engineers have set up six arsenic treatment plants in West Bengal based on in-situ remediation method (SAR Technology). This technology does not use any chemicals and arsenic is left as an insoluble form (+5 state) in the subterranean zone by recharging aerated water into the aquifer and thus developing an oxidation zone to support arsenic oxidizing micro-organisms. This process does not produce any waste stream or sludge and is relatively cheap.

Another effective and inexpensive method to remove arsenic from contaminated well water is to sink wells 500 feet or deeper to reach purer waters. A recent 2011 study funded by the US National Institute of Environmental Health Sciences' Superfund Research Program shows that deep sediments can remove arsenic and take it out of circulation.

Through this process called adsorption in which arsenic sticks to the surfaces of deep sediment articles, arsenic can be naturally removed from well water.

Magnetic separations of arsenic at very low magnetic field gradients have been demonstrated in point-of-use water purification with high-surface-area and monodisperse magnetite (Fe_3O_4) nanocrystals.

Using the high specific surface area of Fe_3O_4 nanocrystals the mass of waste associated with arsenic removal from water has been dramatically reduced.

Epidemiological studies have suggested a correlation between chronic consumption of drinking water contaminated with arsenic and the incidence of all leading causes of mortality. The literature provides reason to believe arsenic exposure is causative in the pathogenesis of diabetes.

Hungarian engineer László Schremmer has recently discovered that by the use of chaff-based filters it is possible to reduce the arsenic content of water to 3 µg/L. This is especially important in areas where the potable water is provided by filtering the water extracted from the underground aquifer.

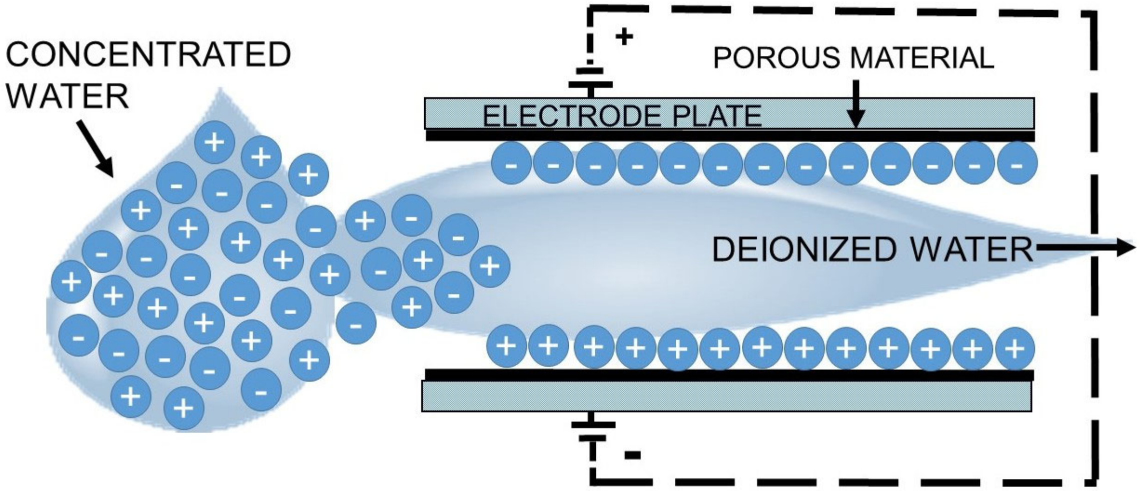
Wood Preservation in the US

As of 2002, US-based industries consumed 19,600 metric tons of arsenic. Ninety percent of this was used for treatment of wood with chromated copper arsenate (CCA). In 2007, 50% of the 5,280 metric tons of consumption was still used for this purpose. In the United States, the use of arsenic in consumer products was discontinued for residential and general consumer construction on December 31, 2003 and alternative chemicals are now used, such as Alkaline Copper Quaternary, borates, copper azole, cyproconazole, and propiconazole.

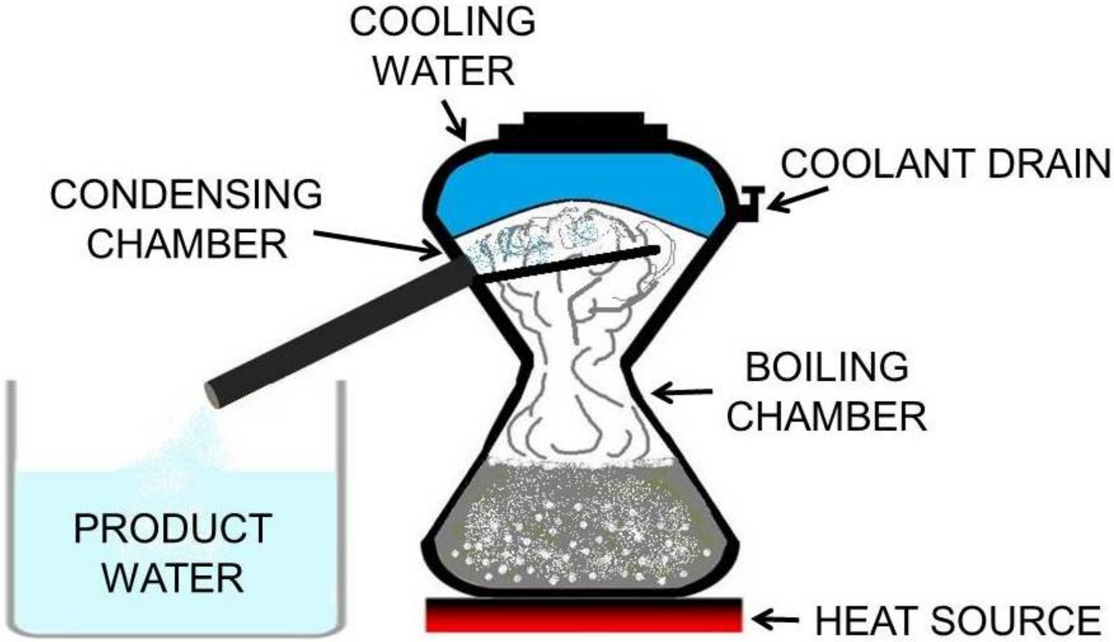
Although discontinued, this application is also one of the most concerns to the general public. The vast majority of older pressure-treated wood was treated with CCA. CCA lumber is still in widespread use in many countries, and was heavily used during the latter half of the 20th century as a structural and outdoor building material.

Although the use of CCA lumber was banned in many areas after studies showed that arsenic could leach out of the wood into the surrounding soil (from playground equipment, for instance), a risk is also presented by the burning of older CCA timber.

The direct or indirect ingestion of wood ash from burnt CCA lumber has caused fatalities in animals and serious poisonings in humans; the lethal human dose is approximately 20 grams of ash. Scrap CCA lumber from construction and demolition sites may be inadvertently used in commercial and domestic fires. Protocols for safe disposal of CCA lumber do not exist evenly throughout the world; there is also concern in some quarters about the widespread landfill disposal of such timber.



CAPACITIVE DEIONIZATION PROCESS DIAGRAM



DESALINATION - DISTILLATION

Water Purification Solutions

Small-scale water treatment

A review of methods to remove arsenic from groundwater in Pakistan summarizes the most technically viable inexpensive methods. A simpler and less expensive form of arsenic removal is known as the Sono arsenic filter, using three pitchers containing cast iron turnings and sand in the first pitcher and wood activated carbon and sand in the second. Plastic buckets can also be used as filter containers. It is claimed that thousands of these systems are in use and can last for years while avoiding the toxic waste disposal problem inherent to conventional arsenic removal plants. Although novel, this filter has not been certified by any sanitary standards such as NSF, ANSI, WQA and does not avoid toxic waste disposal similar to any other iron removal process.

In the United States small "under the sink" units have been used to remove arsenic from drinking water. This option is called "point of use" treatment. The most common types of domestic treatment use the technologies of adsorption (using media such as Bayoxide E33, GFH, or titanium dioxide) or reverse osmosis. Ion exchange and activated alumina have been considered but not commonly used.

Arsenic Large-scale water treatment

In some places, such as the United States, all the water supplied to residences by utilities must meet primary (health-based) drinking water standards. Regulations may necessitate large-scale treatment systems to remove arsenic from the water supply. The effectiveness of any method depends on the chemical makeup of a particular water supply. The aqueous chemistry of arsenic is complex, and may affect the removal rate that can be achieved by a particular process.

Some large utilities with multiple water supply wells could shut down those wells with high arsenic concentrations, and produce only from wells or surface water sources that meet the arsenic standard. Other utilities, however, especially small utilities with only a few wells, may have no available water supply that meets the arsenic standard.

Coagulation/filtration (also known as flocculation) removes arsenic by coprecipitation and adsorption using iron coagulants. Coagulation/filtration using alum is already used by some utilities to remove suspended solids and may be adjusted to remove arsenic. But the problem of this type of filtration system is that it gets clogged very easily, mostly within two to three months. The toxic arsenic sludge are disposed of by concrete stabilization, but there is no guarantee that they won't leach out in future.

Iron oxide adsorption filters the water through a granular medium containing ferric oxide. Ferric oxide has a high affinity for adsorbing dissolved metals such as arsenic. The iron oxide medium eventually becomes saturated, and must be replaced. The sludge disposal is a problem here too.

Activated alumina is an adsorbent that effectively removes arsenic. Activated alumina columns connected to shallow tube wells in India and Bangladesh have successfully removed both As(III) and As(V) from groundwater for decades. Long-term column performance has been possible through the efforts of community-elected water committees that collect a local water tax for funding operations and maintenance. It has also been used to remove undesirably high concentrations of fluoride.

Ion Exchange has long been used as a water-softening process, although usually on a single-home basis. Traditional anion exchange is effective in removing As(V), but not As (III), or arsenic trioxide, which doesn't have a net charge. Effective long-term ion exchange removal of arsenic requires a trained operator to maintain the column.

Both **Reverse osmosis** and **electrodialysis** (also called *electrodialysis reversal*) can remove arsenic with a net ionic charge. (Note that arsenic oxide, As_2O_3, is a common form of arsenic in groundwater that is soluble, but has no net charge.) Some utilities presently use one of these methods to reduce total dissolved solids and therefore improve taste. A problem with both methods is the production of high-salinity waste water, called brine, or concentrate, which then must be disposed of.

Subterranean Arsenic Removal (SAR) Technology

In subterranean arsenic removal (SAR), aerated groundwater is recharged back into the aquifer to create an oxidation zone which can trap iron and arsenic on the soil particles through adsorption process. The oxidation zone created by aerated water boosts the activity of the arsenic-oxidizing microorganisms which can oxidize arsenic from +3 to +5 state SAR Technology.

No chemicals are used and almost no sludge is produced during operational stage since iron and arsenic compounds are rendered inactive in the aquifer itself. Thus toxic waste disposal and the risk of its future mobilization is prevented. Also, it has very long operational life, similar to the long lasting tube wells drawing water from the shallow aquifers.

Six such SAR plants, funded by the World Bank and constructed by Ramakrishna Vivekananda Mission, Barrackpore & Queen's University Belfast, UK are operating in West Bengal. Each plant has been delivering more than 3,000 liters of arsenic and iron-free water daily to the rural community. The first community water treatment plant based on SAR technology was set up at Kashimpore near Kolkata in 2004 by a team of European and Indian engineers led by Dr. Bhaskar Sen Gupta of Queen's University Belfast for TiPOT.

SAR technology had been awarded Dhirubhai Ambani Award, 2010 from IChemE UK for Chemical Innovation. Again, SAR was the winner of the St. Andrews Award for Environment, 2010. The SAR Project was selected by the Blacksmith Institute - New York & Green Cross- Switzerland as one of the "12 Cases of Cleanup & Success" in the World's Worst Polluted Places Report 2009.

The Hungarian Solution

Hungarian engineer László Schremmer has recently discovered that by the use of chaff-based filters it is possible to reduce the arsenic content of water to 3 microgram/liter. This is especially important in areas where the potable water is provided by filtering the water extracted from the underground aquifer.

Arsenic Can Build Up on and Release in Pipes and Storage Tanks

Water systems may also find deposits of arsenic-rich particles in their storage tanks or at locations in their distribution system with low flows. If the flow is increased or a storage tank is drawn down to a low level, these arsenic-rich particles can get stirred up and transported to consumers' taps. This situation occurs primarily when iron media used in treatment are released into the distribution system, or when iron particles are not properly filtered out during iron removal treatment. If these treatment technologies are operated correctly, this should not be a problem for most water systems.

Public water systems with arsenic in their raw water may find that scales on pipes and other components in their distribution systems contain relatively high arsenic concentrations. These arsenic-rich scales can become dislodged and suspended in the water, and may be ultimately delivered to consumers.

Arsenic has been shown to attach to iron in distribution system pipes. Because iron is so effective at binding with arsenic, corrosion deposits can have high concentrations of arsenic solids. In a recent study, arsenic levels found in solids that were collected after pipe sections and hydrants were flushed were as high as 13.65 milligrams of arsenic per gram of solid.

EPA Water Treatment Processes Sub-Section

Treating your water to reduce arsenic will be necessary if more cost-effective alternatives are not available. EPA has identified best available technologies (BATs) and small system compliance technologies (SSCTs) for removing arsenic from drinking water (40 CFR 141.62(c)&(d)).

BATs are technologies that have proven effective for large systems, and SSCTs are technologies that are effective and affordable for small systems. Systems are not required to use any specific technology. Systems can use technologies not listed as BATs or SSCTs if they are effective. Installing a BAT makes a system eligible for a general variance if, due to source water conditions, the system cannot achieve compliance. A general variance, if approved by the State, would allow the system to supply water with an arsenic level above the MCL for a certain period of time.

EPA anticipates that most small systems will use activated alumina (or another type of adsorptive media), reverse osmosis POU devices, or modified lime softening. For more information on these technologies. Most technologies may require pre-treatment (e.g., chlorination) to effectively remove arsenic from drinking water. The need for pre-treatment depends on source water quality.

You may also wish to consider promising technologies such as granular ferric hydroxide and modified activated alumina, which are not yet approved by EPA as BATs or SSCTs. EPA has developed the Arsenic Treatment Technology Design Manual for Small Systems (EPA 816-R-02-011), which examines these new technologies, as well as the BATs and SSCTs. This manual is available from EPA by calling the Safe Drinking Water Hotline at 1-800-426-4791 or by going on line at www.epa.gov/safewater.

Activated Alumina

Activated alumina (AA), an adsorptive medium, uses very small grains, which are packed into a large container. Water is then continuously passed through one or more containers. When AA is exhausted it is simply disposed of and replaced with fresh AA. AA can treat water containing up to 0.160 mg/L of arsenic.

Reverse Osmosis

Reverse osmosis uses high pressure to force water through a membrane with microscopic holes that prevents arsenic and other large contaminants from passing through. Some water is also not able to pass through the membrane and is wasted. Reverse osmosis can treat water containing up to 0.160 mg/L of arsenic.

Modified Lime Softening

The addition of lime to water causes calcium and magnesium to form solid particles, which can then be removed by clarification and filtration. Arsenic can join these particles and be removed along with them. Lime softening is very expensive and water systems are unlikely to install this technology only for arsenic removal. However, for water systems that use lime softening to reduce hardness, the process can be modified to increase arsenic removal. Modified lime softening can treat water containing up to 0.080 mg/L of arsenic.

Point-of-Use Units

Under the Arsenic Rule, systems have another approach available for achieving compliance. This approach involves system-installed and maintained POU devices on a single tap in each customer's household. If you choose this approach, your system will have to arrange for regular inspection and maintenance of the devices. You, not the homeowner, are responsible for maintaining the POU device.

Either system staff or service providers under contract with the system must regularly inspect and service each device. You will need to establish and maintain an especially good working relationship with your customers if you choose POU devices. Your employees or contractors will need to enter customers' homes on a regular basis. Customers may be willing to accept this inconvenience because POU devices may be much less expensive than central treatment.

Currently, EPA considers only activated alumina and reverse osmosis POU devices to be POU SSCTs for arsenic removal. Point-of-use reverse osmosis treatment unit EPA is developing guidance on how to implement a POU compliance strategy. You should consult with your State to determine whether a POU compliance strategy can work for you.

Central Treatment

- ✓ All water treated
- ✓ Less expensive for large communities
- ✓ Capital costs very high, but equipment lasts a long time
- ✓ Little customer involvement
- ✓ Does not require access to individual homes
- ✓ Some technologies require a highly trained operator
- ✓ Waste disposal may be expensive

Point-of-Use Units

- ✓ Treats water at the individual taps where the unit is installed
- ✓ Can be less expensive for small communities
- ✓ Capital costs low, but media and membranes may require frequent replacement
- ✓ Much customer involvement and support necessary
- ✓ Requires access to individual homes
- ✓ Does not require a highly trained operator; maintenance can be contracted out
- ✓ Waste disposal typically not a problem

EPA Arsenic Waste Disposal

What Do I Need to Consider When Deciding on a Waste Disposal Option?
All arsenic treatment technologies, other than zero-treatment options such as alternate source use and blending, produce waste in the form of liquid residuals (e.g., brine, concentrates, filter rinse, and backwash), solid residuals (e.g., spent media, membranes, and dewatered sludge), or both. These residuals contain concentrated arsenic and other contaminants that must be disposed of properly.
Certain raw water characteristics can affect a system's waste disposal options and should be considered when selecting an arsenic treatment technology.

Raw water characteristics that may affect disposal alternatives include:

- ✓ Excessively high or low pH.
- ✓ High concentrations of competing ions (including fluoride, sodium, sulfate, and chloride).
- ✓ High total suspended solids (TSS).
- ✓ High total dissolved solids (TDS).
- ✓ High concentrations of heavy metals (including arsenic, lead, chromium, and aluminum).
- ✓ High concentrations of radionuclides.

The type of waste generated depends on the arsenic treatment technology selected. The following table shows the liquid and solid waste residuals that will be produced by likely small system treatment technologies.

You should work with your State to determine the best waste disposal option for your system based on your treatment processes, the type of

- ✓ waste generated, and the contaminant levels in the waste streams.

Selecting a Technology to Treat Arsenic
When choosing a technology, remember:
1. It is usually easier and cheaper to modify an existing treatment system than to install new treatment.
2. If you choose carefully, you may be able to install one technology to achieve compliance with the Arsenic Rule and other new rules. For more information on EPA's current and proposed regulations see www.epa.gov/safewater/regs.html or call the Safe Drinking Water Hotline at 1-800-426-4791.
3. You may need additional training to learn how to operate and maintain a new treatment process.
4. Most treatment technologies are more effective when the source water is pre-treated.
5. You should consider all options for waste disposal when you are choosing a treatment technology.
6. You should always pilot test a treatment method before installing it. Technologies are highly dependent on system specific considerations.
7. Your State may be able to help you choose an appropriate treatment technology.
For more information about treatment technologies and how they might work for you, ask your State or refer to:

- The *Arsenic Treatment Technology Design Manual for Small Systems* (EPA 816-R-02-011), available from EPA by calling the Safe Drinking Water Hotline at 1-800-426-4791.
- www.epa.gov/ogwdw000/ars/treat.html

Demonstration

EPA is conducting a demonstration program on the treatment of arsenic in drinking water. The Agency intends to identify and evaluate commercially available technologies, engineering options, or other approaches that cost-effectively help small systems (10,000 or fewer customers) meet the revised arsenic MCL. For more information on this program, see www.epa.gov/ORD/NRMRL/arsenic/.

Laboratory Testing

Certain analytical methods previously used by laboratories to measure arsenic concentrations are not sensitive enough to determine if your system is in compliance with the revised arsenic MCL of 0.010 mg/L. The methods that are no longer appropriate for compliance sampling are EPA method 200.7 and SM 3120B. The currently acceptable methods for compliance sampling are:

- ✓ EPA 200.8
- ✓ EPA 200.9
- ✓ SM 3113B
- ✓ SM 3114B
- ✓ ASTM D-2972-93B
- ✓ ASTM D-2972-93C

Contact your State if you are unsure about the method your lab normally uses.

What Does Compliance Monitoring Involve?

Monitoring Instructions

Routine Monitoring

If your monitoring results are at or below the revised MCL, you still must perform routine monitoring for arsenic at each sampling point (40 CFR 141.23(c)(1)):

- ✓ Once every 3 years during each nine year compliance cycle for ground water systems.
- ✓ Annually for surface water and GWUDI systems.

Waivers

Your State may issue you a waiver to reduce your monitoring frequency if your system historically has had arsenic levels below the revised MCL. Waivers allow you to take one sample during each 9-year compliance cycle. To be eligible for a waiver, you must have sampling results from three previous compliance periods (see Routine Monitoring, above) that (40 CFR141.23(c)):

- ✓ Were collected at each sampling point.
- ✓ All were analyzed using analytical methods approved by the Arsenic Rule.
- ✓ All have arsenic levels below 0.010 mg/L.

For example, the system described in the Arsenic Planning Worksheet monitored during the previous three compliance periods (i.e., in 1998, 2001,and 2004). The system also collected samples from each sampling point and analyzed them using approved analytical methods. Since all of the results were below 0.010 mg/L, this system may be eligible for a waiver. Note that, in 1992, the system used analytical method SM 3120B. This method is not approved for compliance with the revised MCL, so the data from 1992 could not be used to satisfy the waiver eligibility requirements. In addition, the system did not sample from each sampling point in 1995. Therefore, these data do not meet the waiver requirements.

Increased Monitoring

Even if you are in compliance with the MCL, your State may require you to monitor more frequently (40 CFR 141.23(g)). Please contact your State for more information.

Compliance Determination

If the arsenic concentration in any of your samples exceeds 0.010 mg/L, your State may direct you to take a confirmation sample within 2 weeks (40 CFR 141.23(f)(1)). If the average of the initial sample and the confirmation sample is over 0.010 mg/L, you must begin quarterly monitoring at that sampling point (40 CFR 141.23(f)(3)&(c)(7)).

Calculate compliance with the MCL based on the running annual average, which is the sum of your results from the previous four quarters divided by the number of samples taken (40 CFR 141.23(i)(2)). You will be in violation when the running annual average exceeds 0.010 mg/L.

- You must divide the sum of the sample results from the previous four quarters by the number of samples taken. For example, if you failed to sample in one quarter, add the results from the other three quarters and divide by 3.
- During your first year of quarterly sampling, you will not yet have four quarters of results. In this case, you can assume the best case scenario when calculating the running annual average. Results for all future quarters (within the first year) can be entered as 0.0 mg/L.

Sampling and Reporting Notes

The four quarters are:
Q1: January - March
Q2: April - June
Q3: July - September
Q4: October - December

When you calculate your running annual average, use 0.0 mg/L for all samples with arsenic levels below what the analytical method can detect. If your State allows you to take more than the required number of samples, all of your samples will be averaged to determine compliance.

Monitoring and Reporting Violations

You have committed a monitoring and reporting (M&R) violation if:

- You fail to take a sample;
- You do not sample from each sampling point; or,
- You do not report your results to the State on time.

Maximum Contaminant Level Violations

If the running annual average of arsenic at a sampling point is greater than 0.010 mg/L, your system is in violation of the MCL (40 CFR 141.23(i)(1)). If you monitor once a year or less and the result from the initial sample (or the average of the results from the initial and confirmation samples) is greater than 0.010 mg/L but not more than 0.040 mg/L, your system has not yet violated the MCL. Having a result greater than 0.010 mg/L will require you to collect quarterly samples. If your system has an MCL violation, you must continue quarterly sampling until your State determines that your system is reliably and consistently below the MCL.

Reporting and Notification Requirements

Keeping the State and your customers informed is part of your responsibility as a public water system. The State needs to know if your system poses any health risks so it can help you protect your customers. Informed customers are more likely to understand the need for a new treatment system, infrastructure changes, and rate increases.

If you have *an M&R violation*, you must (40 CFR 141.31(b) & 141.204):

- ✓ Report this violation to the State within 48 hours of when the violation occurs.
- ✓ Notify your customers within a year. You may be able to incorporate this information into your CCR instead of a separate notification.

If you have an *MCL violation*, you must (40 CFR 141.31(b) & 141.203):

- ✓ Report this violation to the State within 48 hours of receiving the lab results.
- ✓ Notify your customers within 30 days.

In both cases, you must send a copy of any public notice to the State. If you are ***in compliance,*** you must report your results and running annual average, if any, to the State within 10 days after the end of the month in which the sample was taken, or within 10 days of the end of the sampling period, whichever is shorter (40 CFR 141.31(a)).

In your annual ***Consumer Confidence Report,*** you must include a statement about arsenic if monitoring results exceed 0.005 mg/L (40 CFR141.153(d)(6) and 141.154(b)&(f)). See page 12 of this guide for more information.

Monitoring Worksheets

Depending on your source water and your previous arsenic results, you may be required to take samples quarterly, annually, once every 3 years, or once every 9 years.

These monitoring worksheets will help you:

- Collect the correct number of samples for each sampling period.
- Report monitoring results to your State on time.
- Collect appropriate confirmation samples.
- Know when your system is in violation of the arsenic MCL.
- Report MCL violations to your State and your customers on time.

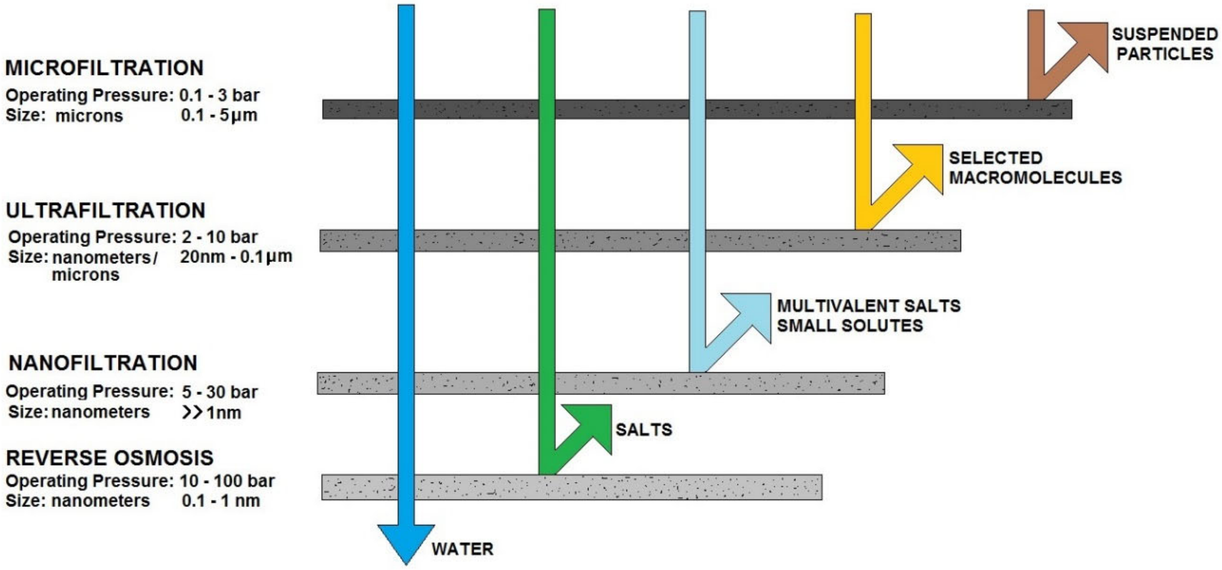
Several copies of each worksheet are provided. The first copy is followed by instructions on how to complete it. The second copy is an example. The third is a blank worksheet that you can photocopy and use.

Please note that your State may have a monitoring form of its own that must be used to submit sample results. If that is the case, the worksheets provided here **do not** replace the State form.

Appendix A: Sources for More Information on Arsenic

- ✓ The final text of the Arsenic Rule: EPA-815-Z-01-001 or Federal Register Vol. 66, No 14., pp. 6976-7066. The document is also available on line at www.epa.gov/safewater/ars/arsenic_finalrule.html.
- ✓ The Arsenic Implementation Guidance, EPA-816-D-01-002: www.epa.gov/safewater/ars/implement.html (available September 2002).
- ✓ EPA's Safe Drinking Water Hotline: 1-800-426-4791
- ✓ EPA's Safewater Web site (www.epa.gov/safewater/arsenic.html) has a number of documents including the text of the Arsenic Rule, the Arsenic Implementation Guidance, many fact sheets, and a quick reference guide to the Rule.
- ✓ American Water Works Association: www.awwa.org
- ✓ Association of State Drinking Water Administrators: www.asdwa.org
- ✓ National Ground Water Association: www.ngwa.org
- ✓ National Rural Water Association: www.nrwa.org
- ✓ Natural Resources Defense Council: www.nrdc.org/water/drinking/qarsenic.asp
- ✓ U.S. Congressional Research Service–*Report for Congress: Arsenic in Drinking Water- Recent Regulatory Developments and Issues:* http://cnie.org/NLE/CRSreports/water/h2o-40.cfm

The World Health Organization: www.who.int/pcs/ehc/summaries/ehc_224.html

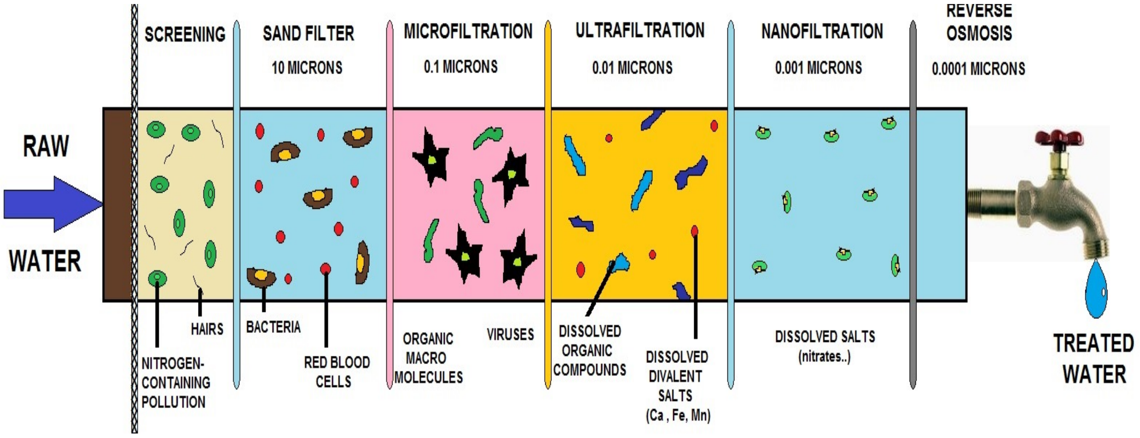


FILTRATION TYPE COMPARISONS

	TASTE AND ODOR	CHLORINE	ORGANICS	INORGANICS	BIOLOGICALS
BOTTLED WATER	●	○	○	○	○
ULTRA VIOLET (UV)	○	○	○	●	○
CARBON FILTERS	●	●	●	○	◒
REVERSE OSMOSIS SYSTEM	◒	◒	●	●	◒

○ NO ● YES ◒ PARTIAL

TYPES OF WATER QUALITY FILTRATION TECHNOLOGIES AND EFFECTIVE USES



FILTRATION METHODS AND REMOVAL SIZES

Astatine- Nonmetal or a Metalloid

Astatine may be a nonmetal or a metalloid. It is ordinarily classified as a nonmetal, but has some 'marked' metallic properties. Immediately following its production in 1940, early investigators considered it to be a metal. In 1949 it was called the most noble (difficult to reduce) nonmetal as well as being a relatively noble (difficult to oxidize) metal. In 1950 astatine was described as a halogen and (therefore) a reactive nonmetal.
In terms of metallic indicators:

- Samsonov observes that, '[L]ike typical metals, it is precipitated by hydrogen sulfide even from strongly acid solutions and is displaced in a free form from sulfate solutions; it is deposited on the cathode on electrolysis'.
- Rossler cites further indications of a tendency for astatine to behave like a (heavy) metal as: '...the formation of pseudohalide compounds...complexes of astatine cations...complex anions of trivalent astatine...as well as complexes with a variety of organic solvents'.
- Rao and Ganguly note that elements with an enthalpy of vaporization (EoV) greater than ~42 kJ/mol are metallic when liquid. Such elements include boron, silicon, germanium, antimony, selenium and tellurium. Vásaros & Berei give estimated values for the EoV of diatomic astatine, the lowest of these being 50 kJ/mol. On this basis astatine may also be metallic in the liquid state. Diatomic iodine, with an EoV of 41.71, falls just short of the threshold figure.
- Siekierski and Burgess contend or presume that astatine would be a metal if it could form a condensed phase.
- Champion et al. argue that astatine demonstrates cationic behavior, by way of stable At^+ and AtO^+ forms, in strongly acidic aqueous solutions.

For Nonmetallic Indicators:

- Batsanov gives a calculated band gap energy for astatine of 0.7 eV. This is consistent with nonmetals (in physics) having separated valence and conduction bands and thereby being either semiconductors or insulators.
- It has the narrow liquid range ordinarily associated with nonmetals (mp 575 K, bp 610).
- Its chemistry in aqueous solution is predominately characterized by the formation of various anionic species.
- Most of its known compounds resemble those of iodine, which is halogen and a nonmetal. Such compounds include astatides (XAt), astatates ($XAtO_3$), and monovalent interhalogen compounds.

Restrepo et al. reported that astatine appeared to share more in common with polonium than it did with the established halogens. They did so on the basis of detailed comparative studies of the known and interpolated properties of 72 elements.

Other Metalloids

Given there is no agreed definition of a metalloid, some other elements are occasionally classified as such. These elements include hydrogen, beryllium, nitrogen, phosphorus, sulfur, zinc, gallium, tin, iodine, lead, bismuth and radon. The term metalloid has also been used to refer to:

- Elements that exhibit metallic luster and electrical conductivity, and that are also amphoteric. Arsenic, antimony, vanadium, chromium, molybdenum, tungsten, tin, lead and aluminum are examples.
- Elements that are otherwise sometimes referred to as poor metals.
- Nonmetallic elements (for example, nitrogen; carbon) that can form alloys with, or modify the properties of, metals.
- Nonmetals in the 'near-metalloid' category include carbon, phosphorus, selenium and iodine. They exhibit metallic luster, semiconducting properties and bonding or valence bands with delocalized character. This applies to their most thermodynamically stable forms under ambient conditions: carbon as graphite; phosphorus as black phosphorus; and selenium as grey selenium. These elements are alternatively described as being 'near metalloidal', showing metalloidal character, or having metalloid-like or some metalloid(al) or metallic properties.

Boron - Metalloid

Boron is a chemical element with chemical symbol **B** and atomic number 5. Because boron is produced entirely by cosmic ray spallation and not by stellar nucleosynthesis, it is a low-abundance element in both the solar system and the Earth's crust. Boron is concentrated on Earth by the water-solubility of its more common naturally occurring compounds, the borate minerals. These are mined industrially as evaporites, such as borax and kernite.

Chemically uncombined boron, which is classed as a metalloid, is not found naturally on Earth. Industrially, very pure boron is produced with difficulty, as boron tends to form refractory materials containing small amounts of carbon or other elements. Several allotropes of boron exist: amorphous boron is a brown powder and crystalline boron is black, extremely hard (about 9.5 on the Mohs scale), and a poor conductor at room temperature. Elemental boron is used as a dopant in the semiconductor industry.

The major industrial-scale uses of boron compounds are in sodium perborate bleaches, and the borax component of fiberglass insulation. Boron polymers and ceramics play specialized roles as high-strength lightweight structural and refractory materials. Boron compounds are used in silica-based glasses and ceramics to give them resistance to thermal shock. Boron-containing reagents are used for as intermediates in the synthesis of organic fine chemicals. A few boron-containing organic pharmaceuticals are used, or are in study. Natural boron is composed of two stable isotopes, one of which (boron-10) has a number of uses as a neutron-capturing agent.

In biology, borates have low toxicity in mammals (similar to table salt), but are more toxic to arthropods and are used as insecticides. Boric acid is mildly antimicrobial, and a natural boron-containing organic antibiotic is known. Boron is essential to life. Small amounts of boron compounds play a strengthening role in the cell walls of all plants, making boron necessary in soils. Experiments indicate a role for boron as an ultratrace element in animals, but the nature of its role in animal physiology is unknown.

Boron compounds were known thousands of years ago. Borax was known from the deserts of western Tibet, where it received the name of *tincal*, derived from the Sanskrit. Borax glazes were used in China from AD300, and some tincal even reached the West, where the Persian alchemist Jābir ibn Hayyān seems to mention it in 700. Marco Polo brought some glazes back to Italy in the 13th century. Agricola, around 1600, reports the use of borax as a flux in metallurgy. In 1777, boric acid was recognized in the hot springs (soffioni) near Florence, Italy, and became known as *sal sedativum*, with mainly medical uses.

The rare mineral is called sassolite, which is found at Sasso, Italy. Sasso was the main source of European borax from 1827 to 1872, at which date American sources replaced it. Boron compounds were relatively rarely used chemicals until the late 1800s when

Francis Marion Smith's Pacific Coast Borax Company first popularized these compounds and made them in volume and hence cheap.

Boron was not recognized as an element until it was isolated by Sir Humphrey Davy and by Joseph Louis Gay-Lussac and Louis Jacques Thénard. In 1808 Davy observed that electric current sent through a solution of borates produced a brown precipitate on one of the electrodes. In his subsequent experiments he used potassium to reduce boric acid instead of electrolysis. He produced enough boron to confirm a new element and named the element *boracium*.

Gay-Lussac and Thénard used iron to reduce boric acid at high temperatures. They showed by oxidizing boron with air that boric acid is an oxidation product of boron. Jöns Jakob Berzelius identified boron as an element in 1824. Pure boron was arguably first produced by the American chemist Ezekiel Weintraub in 1909.

Chemical Compounds

In its most familiar compounds, boron has the formal oxidation state III. These include oxides, sulfides, nitrides, and halides. The trihalides adopt a planar trigonal structure. These compounds are Lewis acids in that they readily form adducts with electron-pair donors, which are called Lewis bases. For example, fluoride (F^-) and boron trifluoride (BF_3) combined to give the tetrafluoroborate anion, BF_4^-. Boron trifluoride is used in the petrochemical industry as a catalyst. The halides react with water to form boric acid.

Boron is found in nature on Earth entirely as various oxides of B (III), often associated with other elements. The more than one hundred borates all feature boron in oxidation state +3. These minerals resemble silicates in some respect, although boron is often found not only in a tetrahedral coordination with oxygen, but also in a trigonal planar configuration. Unlike silicates, the boron minerals never feature boron with coordination number greater than four. A typical motif is exemplified by the tetraborate anions of the common mineral borax. The formal negative charge of the tetrahedral borate centers is balanced by metal cations in the minerals, such as the sodium (Na^+) in borax.

Boron Nitride

The boron nitrides are notable for the variety of structures that they adopt. They adopt structures analogous to various allotropes of carbon, including graphite, diamond, and nanotubes. In the diamond-like structure called cubic boron nitride (tradename Borazon), boron atoms exist in the tetrahedral structure of carbons atoms in diamond, but one in every four B-N bonds can be viewed as a coordinate covalent bond, wherein two electrons are donated by the nitrogen atom which acts as the Lewis base to a bond to the Lewis acidic boron (III) center.

Cubic boron nitride, among other applications, is used as an abrasive, as it has a hardness comparable with diamond (the two substances are able to produce scratches on each other). In the BN compound analogue of graphite, hexagonal boron nitride (h-BN), the positively-charged boron and negatively-charged nitrogen atoms in each plane lie adjacent to the oppositely charged atom in the next plane.

Consequently graphite and h-BN have very different properties, although both are lubricants, as these planes slip past each other easily. However, h-BN is a relatively poor electrical and thermal conductor in the planar directions.

Organoboron Chemistry

A large number of organoboron compounds are known and many are useful in organic synthesis. Organoboron (III) compounds are usually tetrahedral or trigonal planar, for example, tetraphenylborate ($B (C_6H_5)_4^-$) vs triphenylborane ($B(C_6H_5)_3$). Many are produced from hydroboration, which employs diborane (B_2H_6).

Compounds of B(I) and B(II)

Although these are not found on Earth naturally, boron forms a variety of stable compounds with formal oxidation state less than three. As for many covalent compounds, formal oxidation states are often of little meaning in boron hydrides and metal borides. The halides also form derivatives of B(I) and B(II). BF, isoelectronic with N_2, is not isolable in condensed form, but B_2F_4 and B_4Cl_4 are well characterized.

Binary metal-boron compounds, the metal borides, feature boron in oxidation state less than III. Illustrative is magnesium diboride (MgB_2). Each boron atom has a formal −1 charge and magnesium is assigned a formal charge of 2+. In this material, the boron centers are trigonal planar, with an extra double bond for each boron, with the boron atoms forming sheets akin to the carbon in graphite. However, unlike the case with hexagonal boron nitride which by comparison lacks electrons in the plane of the covalent atoms, the delocalized electrons in the plane of magnesium diboride allow it to conduct electricity similar to isoelectronic graphite. In addition, in 2001 this material was found to be a high-temperature superconductor. Certain other metal borides find specialized applications as hard materials for cutting tools.

From the structural perspective, the most distinctive chemical compounds of boron are the hydrides. Included in this series are the cluster compounds dodecaborate ($B_{12}H_{12}^{2-}$), decaborane ($B_{10}H_{14}$), and the carboranes such as $C_2B_{10}H_{12}$. Characteristically such compounds feature boron with coordination numbers greater than four.

Isotopes

Boron has two naturally occurring and stable isotopes, ^{11}B (80.1%) and ^{10}B (19.9%). The mass difference results in a wide range of $\delta^{11}B$ values, which are defined as a fractional difference between the ^{11}B and ^{10}B and traditionally expressed in parts per thousand, in natural waters ranging from −16 to +59. There are 13 known isotopes of boron, the shortest-lived isotope is ^{7}B which decays through proton emission and alpha decay. It has a half-life of 3.5×10^{-22} s. Isotopic fractionation of boron is controlled by the exchange reactions of the boron species $B(OH)_3$ and $[B(OH)_4]^-$. Boron isotopes are also fractionated during mineral crystallization, during H_2O phase changes in hydrothermal systems, and during hydrothermal alteration of rock.

The latter effect results in preferential removal of the $^{10}B(OH)_4$ ion onto clays. It results in solutions enriched in $^{11}B(OH)_3$ and therefore may be responsible for the large ^{11}B enrichment in seawater relative to both oceanic crust and continental crust; this difference may act as an isotopic signature. The exotic ^{17}B exhibits a nuclear halo, i.e. its radius is appreciably larger than that predicted by the liquid drop model.

The ^{10}B isotope is good at capturing thermal neutrons. Natural boron is about 20% ^{10}B and 80% ^{11}B. The nuclear industry enriches natural boron to nearly pure ^{10}B. The less-valuable by-product, depleted boron, is nearly pure ^{11}B.

Commercial Isotope Enrichment

Because of its high neutron cross-section, boron-10 is often used to control fission in nuclear reactors as a neutron-capturing substance. Several industrial-scale enrichment processes have been developed, however only the fractionated vacuum distillation of the dimethyl ether adduct of boron trifluoride (DME-BF_3) and column chromatography of borates are being used.

Enriched Boron (boron-10)

Is used in neutron capture therapy of cancer. In the latter ("boron neutron capture therapy" or BNCT), a compound containing ^{10}B is incorporated into a pharmaceutical which is selectively taken up by a malignant tumor and tissues near it. The patient is then treated with a beam of either thermal neutrons, or else neutrons of low energy, at a relatively low neutron radiation dose. The neutrons, however, trigger energetic and short-range secondary alpha particle and lithium-7 heavy ion radiation that are products of the boron + neutron nuclear reaction, and this ion radiation additionally bombards the tumor, especially from inside the tumor cells.

In nuclear reactors, ^{10}B is used for reactivity control and in emergency shutdown systems. It can serve either function in the form of borosilicate control rods or as boric acid. In pressurized water reactors, boric acid is added to the reactor coolant when the plant is shut down for refueling. It is then slowly filtered out over many months as fissile material is used up and the fuel becomes less reactive.

In future manned interplanetary spacecraft, ^{10}B has a theoretical role as structural material (as boron fibers or BN nanotube material) which would also serve a special role in the radiation shield. One of the difficulties in dealing with cosmic rays, which are mostly high energy protons, is that some secondary radiation from interaction of cosmic rays and spacecraft materials is high energy spallation neutrons. Such neutrons can be moderated by materials high in light elements such as polyethylene, but the moderated neutrons continue to be a radiation hazard unless actively absorbed in the shielding. Among light elements that absorb thermal neutrons, ^{6}Li and ^{10}B appear as potential spacecraft structural materials which serve both for mechanical reinforcement and radiation protection.

Depleted Boron (boron-11)

Cosmic radiation will produce secondary neutrons if it hits spacecraft structures. Those neutrons will be captured in ^{10}B, if it is present in the spacecraft's semiconductors, producing a gamma ray, an alpha particle, and a lithium ion. These resultant decay products may then irradiate nearby semiconductor 'chip' structures, causing data loss (bit flipping, or single event upset). In radiation hardened semiconductor designs, one countermeasure is to use **depleted boron** which is greatly enriched in ^{11}B and contains almost no ^{10}B. ^{11}B is largely immune to radiation damage. Depleted boron is a by-product of the nuclear industry.

^{11}B is also a candidate as a fuel for aneutronic fusion. When struck by a proton with energy of about 500 keV, it produces three alpha particles and 8.7 MeV of energy. Most other fusion reactions involving hydrogen and helium produce penetrating neutron radiation, which weakens reactor structures and induces long term radioactivity thereby endangering operating personnel. Whereas, the alpha particles from ^{11}B fusion can be turned directly into electric power, and all radiation stops as soon as the reactor is turned off.

Applications

Nearly all boron ore extracted from the Earth is destined for refinement into boric acid and sodium tetraborate pentahydrate. In the United States, 70% of the boron is used for the production of glass and ceramics.

Glass and Ceramics

Borosilicate glass, which is typically 12–15% B_2O_3, 80% SiO_2, and 2% Al_2O_3, has a low coefficient of thermal expansion giving it a good resistance to thermal shock. Duran and Pyrex are two major brand names for this glass, used both in laboratory glassware and in consumer cookware and bakeware, chiefly for this resistance.

Boron filaments are high-strength, lightweight materials that are used chiefly for advanced aerospace structures as a component of composite materials, as well as limited production consumer and sporting goods such as golf clubs and fishing rods. The fibers can be produced by chemical vapor deposition of boron on a tungsten filament.

Boron fibers and sub-millimeter sized crystalline boron springs are produced by laser-assisted chemical vapor deposition. Translation of the focused laser beam allows producing even complex helical structures. Such structures show good mechanical properties (elastic modulus 450 GPa, fracture strain 3.7%, fracture stress 17 GPa) and can be applied as reinforcement of ceramics or in micromechanical systems.

Detergent Formulations and Bleaching Agents

Borax is used in various household laundry and cleaning products, including the well-known "20 Mule Team Borax" laundry booster and "Boraxo" powdered hand soap. It is also present in some tooth bleaching formulas.

Sodium perborate serves as a source of active oxygen in many detergents, laundry detergents, cleaning products, and laundry bleaches. However, despite its name, "Borateem" laundry bleach no longer contains any boron compounds, using sodium percarbonate instead as a bleaching agent.

Insecticides

Boric acid is used as an insecticide, notably against ants, fleas, and cockroaches.

Semiconductors

Boron is a useful dopant for such semiconductors as silicon, germanium, and silicon carbide. Having one fewer valence electron than the host atom, it donates a hole resulting in p-type conductivity. Traditional method of introducing boron into semiconductors is via its atomic diffusion at high temperatures. This process uses either solid (B_2O_3), liquid (BBr_3), or gaseous boron sources (B_2H_6 or BF_3). However, after 1970s, it was mostly replaced by ion implantation, which relies mostly on BF_3 as a boron source.

Boron trichloride gas is also an important chemical in semiconductor industry, however not for doping but rather for plasma etching of metals and their oxides. Triethylborane is also injected into vapor deposition reactors as a boron source. Examples are the plasma deposition of boron-containing hard carbon films, silicon nitride-boron nitride films, and for doping of diamond film with boron.

Magnets

Boron is a component of neodymium magnets ($Nd_2Fe_{14}B$), which are the strongest type of permanent magnet. They are found in a variety of domestic and professional electromechanical and electronic devices, such as magnetic resonance imaging (MRI), various motors and actuators, computer HDDs, CD and DVD players, mobile phones, timer switches, speakers, and so on.

High-Hardness and Abrasive Compounds

Several boron compounds are known for their extreme hardness and toughness. Boron carbide and cubic boron nitride powders are widely used as abrasives. Metal borides are used for coating tools through chemical vapor deposition or physical vapor deposition. Implantation of boron ions into metals and alloys, through ion implantation or ion beam deposition, results in a spectacular increase in surface resistance and microhardness. Laser alloying has also been successfully used for the same purpose. These borides are an alternative to diamond coated tools, and their (treated) surfaces have similar properties to those of the bulk boride.

Boron Carbide

Boron carbide is a ceramic material which is obtained by decomposing B_2O_3 with carbon in the electric furnace:

$$2\ B_2O_3 + 7\ C \rightarrow B_4C + 6\ CO$$

Boron carbide's structure is only approximately B_4C, and it shows a clear depletion of carbon from this suggested stoichiometric ratio. This is due to its very complex structure. The substance can be seen with empirical formula $B_{12}C_3$ (i.e., with B_{12} dodecahedra being a motif), but with less carbon as the suggested C_3 units are replaced with B-C chains, and there are smaller (B_6) octahedra present as well. (See the article for structural analysis).

The repeating polymer plus semi-crystalline structure of boron carbide gives it great structural strength per weight. It is used in tank armor, bulletproof vests, and numerous other structural applications.

Boron carbide's ability to absorb neutrons without forming long-lived radionuclides (especially when doped with extra boron-10) makes the material attractive as an absorbent for neutron radiation arising in nuclear power plants. Nuclear applications of boron carbide include shielding, control rods and shut-down pellets. Within control rods, boron carbide is often powdered, to increase its surface area.

Other Super Hard Boron Compounds

- Heterodiamond (also called BCN);
- Boron nitride. This material is isoelectronic to carbon. Similar to carbon, it has both hexagonal (soft graphite-like h-BN) and cubic (hard, diamond-like c-BN) forms. h-BN is used as a high temperature component and lubricant. c-BN, also known under commercial name borazon, is a superior abrasive. Its hardness is only slightly smaller, but chemical stability is superior to that of diamond.
- Rhenium diboride can be produced at ambient pressures, but is rather expensive because of rhenium. The hardness of ReB_2 exhibits considerable anisotropy because of its hexagonal layered structure. Its value is comparable to that of tungsten carbide, silicon carbide, titanium diboride or zirconium diboride.

- $AlMgB_{14}$ + TiB_2 composites possess high hardness and wear resistance and are used in either bulk form or as coatings for components exposed to high temperatures and wear loads.

Shielding in Nuclear Reactors

Boron shielding is used as a control for nuclear reactors, taking advantage of its high cross-section for neutron capture.

Other Nonmedical Uses

- Because of its distinctive green flame, amorphous boron is used in pyrotechnic flares.
- Starch and casein-based adhesives contain sodium tetraborate decahydrate ($Na_2B_4O_7$•10 H_2O)
- Some anti-corrosion systems contain borax.
- Sodium borates are used as a flux for soldering silver and gold and with ammonium chloride for welding ferrous metals. They are also fire retarding additives to plastics and rubber articles.
- Boric acid (also known as orthoboric acid) H_3BO_3 is used in the production of textile fiberglass and flat panel displays and in many PVAc and PVOH based adhesives.
- Triethylborane is a substance which ignites the JP-7 fuel of the Pratt & Whitney J58 turbojet/ramjet engines powering the Lockheed SR-71 Blackbird. It was also used to ignite the F-1 Engines on the Saturn V Rocket utilized by NASA's Apollo and Skylab programs from 1967 until 1973. Triethylborane is suitable for this because of its pyrophoric properties, especially the fact that it burns with a very high temperature. Triethylborane is an industrial initiator in radical reactions, where it is effective even at low temperatures.

Pharmaceutical and Biological Applications

Boric acid has antiseptic, antifungal, and antiviral properties and for these reasons is applied as a water clarifier in swimming pool water treatment. Mild solutions of boric acid have been used as eye antiseptics.

Bortezomib (*Velcade*). Boron appears as an active element in its first-approved organic pharamaceutical in the novel pharmaceutical bortezomib, a new class of drug called the proteasome inhibitors, which are active in myeloma and one form of lymphoma (it is in currently in experimental trials against other types of lymphoma). The boron atom in bortezomib binds the catalytic site of the 26S proteasome with high affinity and specificity.

- A number of potential boronated pharmaceuticals using boron-10, have been prepared for use in boron neutron capture therapy (BNCT).
- Some boron compounds show promise in treating arthritis, though none have as yet been generally approved for the purpose.

Research Areas

Magnesium diboride is an important superconducting material with the transition temperature of 39 K. MgB_2 wires are produced with the powder-in-tube process and applied in superconducting magnets. Amorphous boron is used as a melting point depressant in nickel-chromium braze alloys.

Hexagonal boron nitride forms atomically thin layers, which have been used to enhance the electron mobility in graphene devices. It also forms nanotubular structures (BNNTs), which have with high strength, high chemical stability, and high thermal conductivity, among its list of desirable properties.

Natural Biological Role

There is a boron-containing natural antibiotic, boromycin, isolated from streptomyces. Boron is an essential plant nutrient, required primarily for maintaining the integrity of cell walls. Conversely, high soil concentrations of > 1.0 ppm can cause marginal and tip necrosis in leaves as well as poor overall growth performance. Levels as low as 0.8 ppm can cause these same symptoms to appear in plants particularly sensitive to boron in the soil.

Nearly all plants, even those somewhat tolerant of boron in the soil, will show at least some symptoms of boron toxicity when boron content in the soil is greater than 1.8 ppm. When this content exceeds 2.0 ppm, few plants will perform well and some may not survive. When boron levels in plant tissue exceed 200 ppm symptoms of boron toxicity are likely to appear.

As an ultratrace element, boron is necessary for the optimal health of rats, although it is necessary in such small amounts that ultra purified foods and dust filtration of air is necessary to induce boron deficiency, which manifest as poor coat or hair quality. Presumably, boron is necessary to other mammals. No deficiency syndrome in humans has been described. Small amounts of boron occur widely in the diet, and the amounts needed in the diet would, by analogy with rodent studies, be very small. The exact physiological role of boron in the animal kingdom is poorly understood.

Analytical Quantification

For determination of boron content in food or materials the colorimetric curcumin method is used. Boron has to be transferred to boric acid or borates and on reaction with curcumin in acidic solution, a red colored boron-chelate complex, rosocyanine, is formed.

Health Issues and Toxicity

Elemental boron, boron oxide, boric acid, borates, and many organoboron compounds are non-toxic to humans and animals (approximately similar to table salt). The LD_{50} (dose at which there is 50% mortality) for animals is about 6 g per kg of body weight. Substances with LD_{50} above 2 g are considered non-toxic.

Germanium- Metalloid

Germanium looks like a metal. It has a bright, shiny, silvery color. But it is brittle and breaks apart rather easily, which metals normally do not do. It has a melting point of 937.4°C (1,719°F) and a boiling point of 2,830°C (5,130°F). It conducts an electric current poorly. Substances of this kind are called semiconductors. Semiconductors conduct an electric current, but not nearly as well as metals like silver, copper, and aluminum.

The ability of semiconductors to conduct electricity depends greatly on the presence of small amounts of impurities. The addition of an impurity to a semiconductor is called doping. Doping a semiconductor has significant effects on its ability to conduct an electric current.

Germanium is a chemical element with symbol Ge and atomic number 32. It is a lustrous, hard, grayish-white metalloid in the carbon group, chemically similar to its group neighbor's tin and silicon. Purified germanium is a semiconductor, with an appearance most similar to elemental silicon. Like silicon, germanium naturally reacts and forms complexes with oxygen in nature. Unlike silicon, it is too reactive to be found naturally on Earth in the free (native) state.

Because very few minerals contain it in high concentration, germanium was discovered comparatively late in the history of chemistry. Germanium ranks near fiftieth in relative abundance of the elements in the Earth's crust. In 1869, Dmitri Mendeleev predicted its existence and some of its properties based on its position on his periodic table and called the element ekasilicon. Nearly two decades later, in 1886, Clemens Winkler found the new element along with silver and sulfur, in a rare mineral called argyrodite.

Although the new element somewhat resembled arsenic and antimony in appearance, its combining ratios in the new element's compounds agreed with Mendeleev's predictions for a predicted relative of silicon. Winkler named the element after his country, Germany. Today, germanium is mined primarily from sphalerite (the primary ore of zinc), though germanium is also recovered commercially from silver, lead, and copper ores.

Germanium "metal" (isolated germanium) is used as semiconductor in transistors and various other electronic devices.

Historically the first decade of semiconductor electronics were entirely based on germanium, although its production for such use today is a small fraction (2%) of that of ultra-high purity silicon, which has largely replaced it.

Germanium's major end uses in the present are fiber-optic systems and infrared optics. It is used in solar cell applications. Germanium compounds are used for polymerization catalysts. Germanium is finding a new use in nanowires. Germanium forms a large number of organometallic compounds, such as tetraethylgermane, which are useful in chemistry.

Germanium is not thought to be an essential element for any living organism. Some complexed organic germanium compounds are being investigated as possible pharmaceuticals but none has had success. Similar to silicon and aluminum, natural germanium compounds, which tend to be insoluble in water, have little oral toxicity. However, synthetic soluble germanium salts are nephrotoxic, and synthetic chemically reactive germanium compounds with halogens and hydrogen are irritants and toxins.

In his report on *The Periodic Law of the Chemical Elements*, in 1869, the Russian chemist Dmitri Ivanovich Mendeleev predicted the existence of several unknown chemical elements, including one that would fill a gap in the carbon family in his Periodic Table of the Elements, located between silicon and tin. Because of its position in his Periodic Table, Mendeleev called it *ekasilicon (Es)*, and he estimated its atomic weight as about 72.0.

In mid-1885, at a mine near Freiberg, Saxony, a new mineral was discovered and named *argyrodite*, because of its high silver content. The chemist Clemens Winkler analyzed this new mineral, which proved to be a combination of silver, sulfur, and a new element. Winkler was able to isolate this new element and found it somewhat similar to antimony, in 1886. Before Winkler published his results on the new element, he decided that he would name his element *neptunium*, since the recent discovery of planet Neptune in 1846 had been preceded by mathematical predictions of its existence. However, the name "neptunium" had already been given to another chemical element (though not the element that today bears the name neptunium, which was discovered in 1940), so instead, Winkler named the new element *germanium* (from the Latin word, *Germania*, for Germany) in honor of his homeland. Argyrodite proved empirically to be Ag_8GeS_6.

Because this new element showed some similarities with the elements arsenic and antimony, its proper place in the periodic table was under consideration, but its similarities with Dmitri Mendeleev's predicted element "ekasilicon" confirmed that it belonged in this place on the periodic table. With further material from 500 kg of ore from the mines in Saxony, Winkler confirmed the chemical properties of the new element in 1887. He also determined an atomic weight of 72.32 by analyzing pure germanium tetrachloride ($GeCl_4$), while Lecoq de Boisbaudran deduced 72.3 by a comparison of the lines in the spark spectrum of the element.

Winkler was able to prepare several new compounds of germanium, including its fluorides, chlorides, sulfides, germanium dioxide, and tetraethylgermane ($Ge(C_2H_5)_4$), the first organogermane. The physical data from these compounds — which corresponded well with Mendeleev's predictions — made the discovery an important confirmation of Mendeleev's idea of element periodicity.

Until the late 1930s, germanium was thought to be a poorly conducting metal. Germanium did not become economically significant until after 1945, when its properties as a semiconductor were recognized as being very useful in electronics.

However, during World War II, small amounts of germanium had begun to be used in some special electronic devices, mostly diodes. Its first major use was the point-contact Schottky diodes for radar pulse detection during the War. The first silicon-germanium alloys were obtained in 1955. Before 1945, only a few hundred kilograms of germanium were produced in smelters each year, but by the end of the 1950s, the annual worldwide production had reached 40 metric tons.

The development of the germanium transistor in 1948 opened the door to countless applications of solid state electronics. From 1950 through the early 1970s, this area provided an increasing market for germanium, but then high-purity silicon began replacing germanium in transistors, diodes, and rectifiers. For example, the company that became Fairchild Semiconductor was founded in 1957 with the express purpose of producing silicon transistors. Silicon has superior electrical properties, but it requires far higher purity, and this purity could not be commercially achieved in the early years of semiconductor electronics.

Meanwhile, the demand for germanium for use in fiber optics communication networks, infrared night vision systems, and polymerization catalysts increased dramatically. These end uses represented 85% of worldwide germanium consumption in 2000. The U.S. government even designated germanium as a strategic and critical material, calling for a 146 ton (132 t) supply in the national defense stockpile in 1987. Germanium differs from silicon in that the supply for germanium is limited by the availability of exploitable sources, while the supply of silicon is only limited by production capacity since silicon comes from ordinary sand or quartz.

Characteristics

Under standard conditions germanium is a brittle, silvery-white, semi-metallic element. This form constitutes an allotrope technically known as *α-germanium*, which has a metallic luster and a diamond cubic crystal structure, the same as diamond. At pressures above 120 kbar, a different allotrope known as *β-germanium* forms, which has the same structure as β-tin. Along with silicon, gallium, bismuth, antimony, and water, it is one of the few substances that expands as it solidifies (i.e. freezes) from its molten state.

Germanium is a semiconductor. Zone refining techniques have led to the production of crystalline germanium for semiconductors that has an impurity of only one part in 10^{10}, making it one of the purest materials ever obtained. The first metallic material discovered (in 2005) to become a superconductor in the presence of an extremely strong electromagnetic field was an alloy of germanium with uranium and rhodium.

Pure germanium is known to spontaneously extrude very long screw dislocations. They are one of the primary reasons for the failure of older diodes and transistors made from germanium; depending on what they eventually touch, they may lead to an electrical short.

Chemistry

Germanium is not thought to be essential to the health of plants or animals. Some of its compounds present a hazard to human health, however. For example, germanium chloride and germanium fluoride (GeF_4) are a liquid and gas, respectively that can be very irritating to the eyes, skin, lungs, and throat.

250 °C. Germanium is insoluble in dilute acids and alkalis but dissolves slowly in concentrated sulfuric acid and reacts violently with molten alkalis to produce germanates ($[GeO]^{2-}3$). Germanium occurs mostly in the oxidation state +4 although many compounds are known with the oxidation state of +2. Other oxidation states are rare, such as +3 found in compounds such as Ge_2Cl_6, and +3 and +1 observed on the surface of oxides, or negative oxidation states in germanes, such as −4 in GeH_4.

Germanium cluster anions (Zintl ions) such as Ge_4^{2-}, Ge_9^{4-}, Ge_9^{2-}, $[(Ge_9)_2]^{6-}$ have been prepared by the extraction from alloys containing alkali metals and germanium in liquid ammonia in the presence of ethylenediamine or a cryptand. The oxidation states of the element in these ions are not integers—similar to the ozonides O_3^-.

Two oxides of germanium are known: germanium dioxide (GeO_2, germania) and germanium monoxide, (GeO). The dioxide, GeO_2 can be obtained by roasting germanium disulfide (GeS_2), and is a white powder that is only slightly soluble in water but reacts with alkalis to form germanates. The monoxide, germanous oxide, can be obtained by the high temperature reaction of GeO_2 with Ge metal. The dioxide (and the related oxides and germanates) exhibits the unusual property of having a high refractive index for visible light, but transparency to infrared light. Bismuth germanate, $Bi_4Ge_3O_{12}$, (BGO) is used as a scintillator.

Binary compounds with other chalcogens are also known, such as the disulfide (GeS_2), diselenide ($GeSe_2$), and the monosulfide (GeS), selenide ($GeSe$), and telluride ($GeTe$). GeS_2 forms as a white precipitate when hydrogen sulfide is passed through strongly acid solutions containing Ge(IV) The disulfide is appreciably soluble in water and in solutions of caustic alkalis or alkaline sulfides.

Nevertheless, it is not soluble in acidic water, which allowed Winkler to discover the element. By heating the disulfide in a current of hydrogen, the monosulfide (GeS) is formed, which sublimes in thin plates of a dark color and metallic luster, and is soluble in solutions of the caustic alkalis. Upon melting with alkaline carbonates and sulfur, germanium compounds form salts known as thiogermanates.

Four tetrahalides are known. Under normal conditions GeI_4 is a solid, GeF_4 a gas and the others volatile liquids. For example, germanium tetrachloride, $GeCl_4$, is obtained as a colorless fuming liquid boiling at 83.1 °C by heating the metal with chlorine.

All the tetrahalides are readily hydrolyzed to hydrated germanium dioxide. $GeCl_4$ is used in the production of organogermanium compounds. All four dihalides are known and in contrast to the tetrahalides are polymeric solids. Additionally Ge_2Cl_6 and some higher compounds of formula Ge_nCl_{2n+2} are known. The unusual compound Ge_6Cl_{16} has been prepared that contains the Ge_5Cl_{12} unit with a neopentane structure.

Germane (GeH_4) is a compound similar in structure to methane. Polygermanes—compounds that are similar to alkanes—with formula Ge_nH_{2n+2} containing up to five germanium atoms are known. The germanes are less volatile and less reactive than their corresponding silicon analogues. GeH_4 reacts with alkali metals in liquid ammonia to form white crystalline $MGeH_3$ which contain the GeH_3^- anion. The germanium hydrohalides with one, two and three halogen atoms are colorless reactive liquids.

The first organogermanium compound was synthesized by Winkler in 1887; the reaction of germanium tetrachloride with diethylzinc yielded tetraethylgermane ($Ge(C_2H_5)_4$). Organogermanes of the type R_4Ge (where R is an alkyl) such as tetramethylgermane ($Ge(CH_3)_4$) and tetraethylgermane are accessed through the cheapest available germanium precursor germanium tetrachloride and alkyl nucleophiles.

Organic germanium hydrides such as isobutylgermane ($(CH_3)_2CHCH_2GeH_3$) were found to be less hazardous and may be used as a liquid substitute for toxic germane gas in semiconductor applications. Many germanium reactive intermediates are known: germyl free radicals, germylenes (similar to carbenes), and germynes (similar to carbynes). The organogermanium compound 2-carboxyethylgermasesquioxane was first reported in the 1970s, and for a while was used as a dietary supplement and thought to possibly have anti-tumor qualities.

Applications

The major end uses for germanium in 2007, worldwide, were estimated to be: 35% for fiber-optic systems, 30% infrared optics, 15% for polymerization catalysts, and 15% for electronics and solar electric applications. The remaining 5% went into other uses such as phosphors, metallurgy, and chemotherapy.

Optics

The most notable physical characteristics of germania (GeO_2) are its high index of refraction and its low optical dispersion. These make it especially useful for wide-angle camera lenses, microscopy, and for the core part of optical fibers. It also replaced titania as the silica dopant for silica fiber, eliminating the need for subsequent heat treatment, which made the fibers brittle. At the end of 2002 the fiber optics industry accounted for 60% of the annual germanium use in the United States, but this use accounts for less than 10% of worldwide consumption. GeSbTe is a phase change material used for its optic properties, such as in rewritable DVDs.

Because germanium is transparent in the infrared it is a very important infrared optical material, that can be readily cut and polished into lenses and windows. It is especially used as the front optic in thermal imaging cameras working in the 8 to 14-micron wavelength range for passive thermal imaging and for hot-spot detection in military, night vision system in cars, and firefighting applications.

It is therefore used in infrared spectroscopes and other optical equipment which require extremely sensitive infrared detectors. The material has a very high refractive index (4.0) and so needs to be anti-reflection coated. Particularly, a very hard special antireflection coating of diamond-like carbon (DLC), refractive index 2.0, is a good match and produces a diamond-hard surface that can withstand much environmental rough treatment.

Electronics

Silicon-germanium alloys are rapidly becoming an important semiconductor material, for use in high-speed integrated circuits. Circuits utilizing the properties of Si-SiGe junctions can be much faster than those using silicon alone. Silicon-germanium is beginning to replace gallium arsenide (GaAs) in wireless communications devices. The SiGe chips, with high-speed properties, can be made with low-cost, well-established production techniques of the silicon chip industry.

The recent rise in energy cost has improved the economics of solar panels, a potential major new use of germanium. Germanium is the substrate of the wafers for high-efficiency multijunction photovoltaic cells for space applications.

Because germanium and gallium arsenide have very similar lattice constants, germanium substrates can be used to make gallium arsenide solar cells. The Mars Exploration Rovers and several satellites use triple junction gallium arsenide on germanium cells.

Germanium-on-insulator substrates are seen as a potential replacement for silicon on miniaturized chips. Other uses in electronics include phosphors in fluorescent lamps, and germanium-base solid-state light-emitting diodes (LEDs). Germanium transistors are still used in some effects pedals by musicians who wish to reproduce the distinctive tonal character of the "fuzz"-tone from the early rock and roll era.

Other Uses

Germanium dioxide is also used in catalysts for polymerization in the production of polyethylene terephthalate (PET). The high brilliance of the produced polyester is especially used for PET bottles marketed in Japan. However, in the United States, no germanium is used for polymerization catalysts. Due to the similarity between silica (SiO_2) and germanium dioxide (GeO_2), the silica stationary phase in some gas chromatography columns can be replaced by GeO_2.

In recent years germanium has seen increasing use in precious metal alloys. In sterling silver alloys, for instance, it has been found to reduce firescale, increase tarnish resistance, and increase the alloy's response to precipitation hardening. A tarnish-proof sterling silver alloy, trademarked Argentium, requires 1.2% germanium.

High purity germanium single crystal detectors can precisely identify radiation sources—for example in airport security. Germanium is useful for monochromators for beamlines used in single crystal neutron scattering and synchrotron X-ray diffraction. The reflectivity has advantages over silicon in neutron and high energy X-ray applications. Crystals of high purity germanium are used in detectors for gamma spectroscopy and the search for dark matter.

Dietary Supplements, Pharmaceutical Development, and Health Hazard

Germanium is not thought to be essential to the health of plants or animals. Germanium in the environment has little or no health impact. This is primarily because it usually occurs only as a trace element in ores and carbonaceous materials, and is used in very small quantities that are not likely to be ingested, in its various industrial and electronic applications. For similar reasons, germanium in end-uses has little impact on the environment as a biohazard. Some reactive intermediate compounds of germanium are poisonous (see precautions, below).

Polonium- Metalloid

Polonium is a chemical element with the symbol **Po** and atomic number 84, discovered in 1898 by Marie and Pierre Curie. A rare and highly radioactive element with no stable isotopes, polonium is chemically similar to bismuth and tellurium, and it occurs in uranium ores. Applications of polonium are few, and include heaters in space probes, antistatic devices, and sources of neutrons and alpha particles. Because of its position in the periodic table, polonium is sometimes referred to as a metalloid, however others note that on the basis of its properties and behavior it is "unambiguously a metal".

Polonium is 'distinctly metallic' in some ways, or shows metallic character by way of:

- The metallic conductivity of both of its allotropic forms.
- The presence of the rose-colored Po^{2+} cation in aqueous solution.
- The many salts it forms.
- The predominating basicity of polonium dioxide.
- The highly reducing conditions required for the formation of the Po^{2-} anion in aqueous solution.

However, polonium shows nonmetallic character in that:

- Its halides have properties generally characteristic of nonmetal halides (being volatile, easily hydrolyzed, and soluble in organic solvents).
- Many metal polonides, obtained by heating the elements together at 500–1,000 °C, and containing the Po^{2-} anion, are also known.

Toxicity Overview

Polonium is highly dangerous and has no biological role. By mass, polonium-210 is around 250,000 times more toxic than hydrogen cyanide (the actual LD_{50} for ^{210}Po is less than 1 microgram for an average adult (see below) compared with about 250 milligrams for hydrogen cyanide). The main hazard is its intense radioactivity (as an alpha emitter), which makes it very difficult to handle safely. Even in microgram amounts, handling ^{210}Po is extremely dangerous, requiring specialized equipment (a negative pressure alpha glove box equipped with high performance filters), adequate monitoring, and strict handling procedures to avoid any contamination.

Alpha particles emitted by polonium will damage organic tissue easily if polonium is ingested, inhaled, or absorbed, although they do not penetrate the epidermis and hence are not hazardous as long as the alpha particles remain outside of the body. Meanwhile, wearing chemically resistant and "intact" gloves is a mandatory precaution to avoid transcutaneous diffusion of polonium directly through the skin. Polonium delivered in concentrated nitric acid can easily diffuse through inadequate gloves (e.g., latex gloves) or the acid may damage the gloves.

Acute Effects

The median lethal dose (LD_{50}) for acute radiation exposure is generally about 4.5 Sv. The committed effective dose equivalent ^{210}Po is 0.51 μSv/Bq if ingested, and 2.5 μSv/Bq if inhaled. Since ^{210}Po has an activity of 166 TBq per gram (4,500 Ci/g) (1 gram produces 166×10^{12} decays per second), a fatal 4.5 Sv (J/kg) dose can be caused by ingesting 8.8 MBq (238 microcuries, μCi), about 50 nanograms (ng), or inhaling 1.8 MBq (48 μCi), about 10 ng. One gram of ^{210}Po could thus in theory poison 20 million people of whom 10 million would die.

The actual toxicity of ^{210}Po is lower than these estimates, because radiation exposure that is spread out over several weeks (the biological half-life of polonium in humans is 30 to 50 days) is somewhat less damaging than an instantaneous dose. It has been estimated that a median lethal dose of ^{210}Po is 0.015 GBq (0.4 mCi), or 0.089 micrograms, still an extremely small amount.

Long Term (Chronic) Effects

In addition to the acute effects, radiation exposure (both internal and external) carries a long-term risk of death from cancer of 5–10% per Sv. The general population is exposed to small amounts of polonium as a radon daughter in indoor air; the isotopes ^{214}Po and ^{218}Po are thought to cause the majority of the estimated 15,000–22,000 lung cancer deaths in the US every year that have been attributed to indoor radon. Tobacco smoking causes additional exposure to polonium.

Regulatory Exposure Limits and Handling

The maximum allowable body burden for ingested ^{210}Po is only 1.1 kBq (30 nCi), which is equivalent to a particle massing only 6.8 picograms. The maximum permissible workplace concentration of airborne ^{210}Po is about 10 Bq/m^3 (3×10^{-10} $\mu Ci/cm^3$). The target organs for polonium in humans are the spleen and liver. As the spleen (150 g) and the liver (1.3 to 3 kg) are much smaller than the rest of the body, if the polonium is concentrated in these vital organs, it is a greater threat to life than the dose which would be suffered (on average) by the whole body if it were spread evenly throughout the body, in the same way as caesium or tritium (as T_2O).

^{210}Po is widely used in industry, and readily available with little regulation or restriction. In the US, a tracking system run by the Nuclear Regulatory Commission will be implemented in 2007 to register purchases of more than 16 curies (590 GBq) of polonium-210 (enough to make up 5,000 lethal doses). The IAEA "is said to be considering tighter regulations... There is talk that it might tighten the polonium reporting requirement by a factor of 10, to 1.6 curies (59 GBq)."

Polonium and its compounds must be handled in a glove box, which is further enclosed in another box, maintained at a slightly lower pressure than the glove box to prevent the radioactive materials from leaking out. Gloves made of natural rubber do not provide sufficient protection against the radiation from polonium; surgical gloves are necessary. Neoprene gloves shield radiation from polonium better than natural rubber.

Treatment

It has been suggested that chelation agents such as British Anti-Lewisite (dimercaprol) can be used to decontaminate humans. In one experiment, rats were given a fatal dose of 1.45 MBq/kg (8.7 ng/kg) of ^{210}Po; all untreated rats were dead after 44 days, but 90% of the rats treated with the chelation agent HOEtTTC remained alive after 5 months.

Commercial Products Containing Polonium

Some anti-static brushes contain up to 500 microcuries (20 MBq) of ^{210}Po as a source of charged particles for neutralizing static electricity. In USA, the devices with no more than 500 µCi of (sealed) ^{210}Po per unit can be bought in any amount under a "general license", which means that a buyer need not be registered by any authorities.

Tiny amounts of such radioisotopes are sometimes used in the laboratory and for teaching purposes—typically of the order of 4–40 kBq (0.1–1.0 µCi), in the form of sealed sources, with the polonium deposited on a substrate or in a resin or polymer matrix—are often exempt from licensing by the NRC and similar authorities as they are not considered hazardous.

Small amounts of ^{210}Po are manufactured for sale to the public in the United States as 'needle sources' for laboratory experimentation, and are retailed by scientific supply companies. The actual polonium is a layer of plating which in turn is plated with a material such as gold. This allows the alpha radiation (used in experiments such as cloud chambers) while preventing the polonium from being released and presenting a toxic hazard. According to United Nuclear, they typically sell between four and eight sources per year.

Occurrence in Humans and the Biosphere

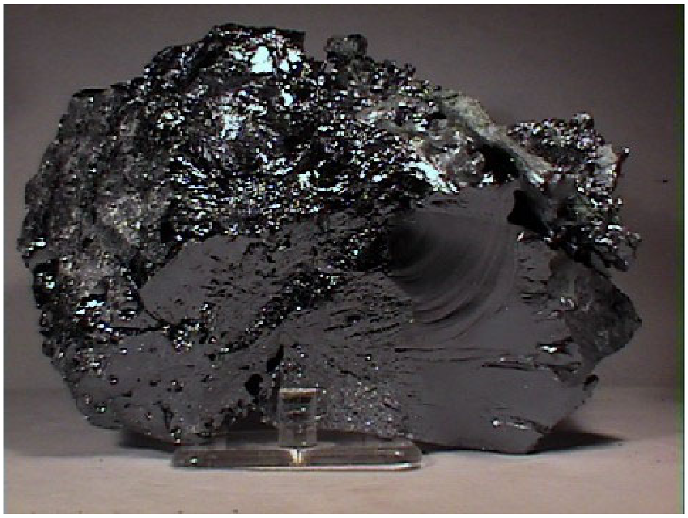
Polonium-210 is widespread in the biosphere, including in human tissues, because of its position in the uranium-238 decay chain. Natural uranium-238 in the Earth's crust decays to through a series of solid radioactive intermediates including radium-226 to the radioactive gas radon-222, some of which, during its 3.6-day half-life, diffuses into the atmosphere. There it decays through several more steps to Polonium-210, much of which, during its 138-day half-life, is washed back down to the Earth's surface, thus entering the biosphere, before finally decaying to stable lead-206.

As early as the 1920s Lacassagne, using polonium provided by his colleague Marie Curie, showed that the element has a very specific pattern of uptake in rabbit tissues, with high concentrations particularly in liver, kidney and testes.

More recent evidence suggests that this behavior results from polonium substituting for sulfur in S-containing amino-acids or related molecules and that similar patterns of distribution occur in human tissues. Polonium is indeed an element naturally present in all humans, contributing appreciably to natural background dose, with wide geographical and cultural variations, and particularly high levels in arctic residents, for example.

Silicon- Metalloid

Silicon is a tetravalent metalloid, is a chemical element with the symbol **Si** and atomic number 14. It is less reactive than its chemical analog carbon, the nonmetal directly above it in the periodic table, but more reactive than germanium, the metalloid directly below it in the table. Controversy about silicon's character dates to its discovery: silicon was first prepared and characterized in pure form in 1824, and given the name silicium (from Latin: *silicis*, flints), with an ***-ium*** word-ending to suggest a metal, a name which the element retains in several non-English languages. However, its final English name, suggested in 1831, reflects the more physically similar elements carbon and boron.



Silicon is the eighth most common element in the universe by mass, but very rarely occurs as the pure free element in nature. It is most widely distributed in dusts, sands, planetoids, and planets as various forms of silicon dioxide (silica) or silicates. Over 90% of the Earth's crust is composed of silicate minerals, making silicon the second most abundant element in the Earth's crust (about 28% by mass) after oxygen.

Most silicon is used commercially without being separated, and indeed often with little processing of compounds from nature. These include direct industrial building-use of clays, silica sand and stone. Silica is used in ceramic brick. Silicate goes into Portland cement for mortar and stucco, and when combined with silica sand and gravel, to make concrete. Silicates are also in whiteware ceramics such as porcelain, and in traditional quartz-based soda-lime glass. More modern silicon compounds such as silicon carbide form abrasives and high-strength ceramics. Silicon is the basis of the ubiquitous synthetic silicon-based polymers called silicones.

Elemental silicon also has a large impact on the modern world economy. Although most free silicon is used in the steel refining, aluminum-casting, and fine chemical industries (often to make fumed silica), the relatively small portion of very highly purified silicon that is used in semiconductor electronics (< 10%) is perhaps even more critical. Because of wide use of silicon in integrated circuits, the basis of most computers, a great deal of modern technology depends on it.

Silicon is an essential element in biology, although only tiny traces of it appear to be required by animals, however various sea sponges as well as microorganisms like diatoms need silicon in order to have structure. It is much more important to the metabolism of plants, particularly many grasses, and silicic acid (a type of silica) forms the basis of the striking array of protective shells of the microscopic diatoms.

Silicon is a solid at room temperature, with relatively high melting and boiling points of approximately 1,400 and 2,800 degrees Celsius respectively. Interestingly, silicon has a greater density in a liquid state than a solid state.

Therefore, it does not contract when it freezes like most substances, but expands, similar to how ice is less dense than water and has less mass per unit of volume than liquid water. With a relatively high thermal conductivity of 149 $W \cdot m^{-1} \cdot K^{-1}$, silicon conducts heat well and as a result is not often used to insulate hot objects.

In its crystalline form, pure silicon has a gray color and a metallic luster. Like germanium, silicon is rather strong, very brittle, and prone to chipping. Silicon, like carbon and germanium, crystallizes in a diamond cubic crystal structure, with a lattice spacing of approximately 0.5430710 nm (5.430710 Å).

The outer electron orbital of silicon, like that of carbon, has four valence electrons. The 1s, 2s, 2p and 3s subshells are completely filled while the 3p subshell contains two electrons out of a possible six.

Silicon is a semiconductor. It has a negative temperature coefficient of resistance, since the number of free charge carriers increases with temperature. The electrical resistance of single crystal silicon significantly changes under the application of mechanical stress due to the piezoresistive effect.

Isotopes of Silicon

Naturally occurring silicon is composed of three stable isotopes, silicon-28, silicon-29, and silicon-30, with silicon-28 being the most abundant (92% natural abundance). Out of these, only silicon-29 is of use in NMR and EPR spectroscopy. Twenty radioisotopes have been characterized, with the most stable being silicon-32 with a half-life of 170 years, and silicon-31 with a half-life of 157.3 minutes.

All of the remaining radioactive isotopes have half-lives that are less than seven seconds, and the majority of these have half-lives that are less than one tenth of a second. Silicon does not have any known nuclear isomers.

The isotopes of silicon range in mass number from 22 to 44. The most common decay mode of six isotopes with mass numbers lower than the most abundant stable isotope, silicon-28, is Beta Positive $\beta+$, primarily forming aluminum isotopes (13 protons) as decay products. The most common decay mode(s) for 16 isotopes with mass numbers higher than silicon-28 is beta negative $\beta-$, primarily forming phosphorus isotopes (15 protons) as decay products.

Occurrence

Measured by mass, silicon makes up 27.7% of the Earth's crust and is the second most abundant element in the crust, with only oxygen having a greater abundance. Silicon is usually found in the form of complex silicate minerals, and less often as silicon dioxide (**silica**, a major component of common sand). Pure silicon crystals are very rarely found in nature.

The silicate minerals—various minerals containing silicon, oxygen and reactive metals—account for 90% of the mass of the Earth's crust. This is due to the fact that at the high temperatures characteristic of the formation of the inner solar system, silicon and oxygen have a great affinity for each other, forming networks of silicon and oxygen in chemical compounds of very low volatility.

Since oxygen and silicon were the most common non-gaseous and non-metallic elements in the debris from supernova dust which formed the protoplanetary disk in the formation and evolution of the Solar System, they formed many complex silicates which accreted into larger rocky planetesimals that formed the terrestrial planets.

Here, the reduced silicate mineral matrix entrapped the metals reactive enough to be oxidized (aluminum, calcium, sodium, potassium and magnesium). After loss of volatile gases, as well as carbon and sulfur via reaction with hydrogen, this silicate mixture of elements formed most of the Earth's crust. These silicates were of relatively low density with respect to iron, nickel, and other metals non-reactive to oxygen and thus a residuum of uncombined iron and nickel sank to the planet's core, leaving a thick mantle consisting mostly of magnesium and iron silicates above.

Examples of silicate minerals in the crust include those in the pyroxene, amphibole, mica, and feldspar groups. These minerals occur in clay and various types of rock such as granite and sandstone.

Silica occurs in minerals consisting of very pure silicon dioxide in different crystalline forms, quartz, agate amethyst, rock crystal, chalcedony, flint, jasper, and opal. The crystals have the empirical formula of silicon dioxide, but do not consist of separate silicon dioxide molecules in the manner of solid carbon dioxide. Rather, silica is structurally a network-solid consisting of silicon and oxygen in three-dimensional crystals, like diamond. Less pure silica forms the natural glass obsidian. Biogenic silica occurs in the structure of diatoms, radiolaria and siliceous sponges.

Silicon is also a principal component of many meteorites, and is a component of tektites, a silicate mineral of possibly lunar origin, or (if Earth-derived) which has been subjected to unusual temperatures and pressures, possibly from meteorite strike.

Production

Alloys

Ferrosilicon, an iron-silicon alloy that contains varying ratios of elemental silicon and iron, accounts for about 80% of the world's production of elemental silicon, with China, the leading supplier of elemental silicon, providing 4.6 million tons (or 2/3 of the world output) of silicon, most of which is in the form of ferrosilicon. It is followed by Russia (610,000 t), Norway (330,000 t), Brazil (240,000 t) and the United States (170,000 t). Ferrosilicon is primarily used by the steel industry (see below).

Aluminum-silicon alloys are heavily used in the aluminum alloy casting industry, where silicon is the single most important additive to aluminum to improve its casting properties. Since cast aluminum is widely used in the automobile industry, this use of silicon is thus the single largest industrial use of "metallurgical grade" pure silicon (as this purified silicon is added to pure aluminum, whereas ferrosilicon is never purified before being added to steel).

Metallurgical Grade

Elemental silicon not alloyed with significant quantities of other elements, and usually > 95%, is often referred to loosely as silicon metal. It makes up about 20% of the world total elemental silicon production, with less than 1 to 2% of total elemental silicon (5–10% of metallurgical grade silicon) ever purified to higher grades for use in electronics.

Metallurgical grade silicon is commercially prepared by the reaction of high-purity silica with wood, charcoal, and coal in an electric arc furnace using carbon electrodes. At temperatures over 1,900 °C (3,450 °F), the carbon in the aforementioned materials and the silicon undergo the chemical reaction $SiO_2 + 2\ C \rightarrow Si + 2\ CO$. Liquid silicon collects in the bottom of the furnace, which is then drained and cooled.

The silicon produced this manner is called *metallurgical grade silicon* and is at least 98% pure. Using this method, silicon carbide (SiC) may also form from an excess of carbon in one or both of the following ways: $SiO_2 + C \rightarrow SiO + CO$ or $SiO + 2\ C \rightarrow SiC + CO$. However, provided the concentration of SiO_2 is kept high, the silicon carbide can be eliminated by the chemical reaction

$2\ SiC + SiO_2 \rightarrow 3\ Si + 2\ CO$.

As noted above, metallurgical grade silicon "metal" has its primary use in the aluminum casting industry to make aluminum-silicon alloy parts. The remainder (about 45%) is used by the chemical industry, where it is primarily employed to make fumed silica.

Electronic Grade

The use of silicon in semiconductor devices demands a much greater purity than afforded by metallurgical grade silicon. Very pure silicon (>99.9%) can be extracted directly from solid silica or other silicon compounds by molten salt electrolysis. This method, known as early as 1854 (see also FFC Cambridge process), has the potential to directly produce solar-grade silicon without any carbon dioxide emission at much lower energy consumption.

Solar grade silicon cannot be used for semiconductors, where purity must be extreme to properly control the process. Bulk silicon wafers used at the beginning of the integrated circuit making process must first be refined to "nine nines" purity (99.9999999%), a process which requires repeated applications of refining technology.

The majority of silicon crystals grown for device production are produced by the Czochralski process, (CZ-Si) since it is the cheapest method available and it is capable of producing large size crystals. However, single crystals grown by the Czochralski process contain impurities because the crucible containing the melt often dissolves. Historically, a number of methods have been used to produce ultra-high-purity silicon.

Early silicon purification techniques were based on the fact that if silicon is melted and re-solidified, the last parts of the mass to solidify contain most of the impurities. The earliest method of silicon purification, first described in 1919 and used on a limited basis to make radar components during World War II, involved crushing metallurgical grade silicon and then partially dissolving the silicon powder in an acid. When crushed, the silicon cracked so that the weaker impurity-rich regions were on the outside of the resulting grains of silicon. As a result, the impurity-rich silicon was the first to be dissolved when treated with acid, leaving behind a more pure product.

In zone melting, also called zone refining, the first silicon purification method to be widely used industrially, rods of metallurgical grade silicon are heated to melt at one end. Then, the heater is slowly moved down the length of the rod, keeping a small length of the rod molten as the silicon cools and re-solidifies behind it.

Since most impurities tend to remain in the molten region rather than re-solidify, when the process is complete, most of the impurities in the rod will have been moved into the end that was the last to be melted. This end is then cut off and discarded, and the process repeated if a still higher purity is desired.

At one time, DuPont produced ultra-pure silicon by reacting silicon tetrachloride with high-purity zinc vapors at 950 °C, producing silicon by $SiCl_4 + 2\ Zn \rightarrow Si + 2\ ZnCl_2$. However, this technique was plagued with practical problems (such as the zinc chloride byproduct solidifying and clogging lines) and was eventually abandoned in favor of the Siemens process. In the *Siemens process*, high-purity silicon rods are exposed to trichlorosilane at 1150 °C. The trichlorosilane gas decomposes and deposits additional silicon onto the rods, enlarging them because $2\ HSiCl_3 \rightarrow Si + 2\ HCl + SiCl_4$. Silicon produced from this and similar processes is called *polycrystalline silicon*. Polycrystalline silicon typically has impurity levels of less than one part per billion.

In 2006 REC announced construction of a plant based on *fluidized bed* (FB) technology using silane: $3\ SiCl_4 + Si + 2\ H_2 \rightarrow 4\ HSiCl_3$, $4\ HSiCl_3 \rightarrow 3\ SiCl_4 + SiH_4$, $SiH_4 \rightarrow Si + 2\ H_2$. The advantage of fluid bed technology is that processes can be run continuously, yielding higher yields than Siemens Process, which is a batch process.

Today, silicon is purified by converting it to a silicon compound that can be more easily purified by distillation than in its original state, and then converting that silicon compound back into pure silicon. Trichlorosilane is the silicon compound most commonly used as the intermediate, although silicon tetrachloride and silane are also used. When these gases are blown over silicon at high temperature, they decompose to high-purity silicon.

In addition, there is the *Schumacher process*, which utilizes tribromosilane in place of trichlorosilane and fluid bed technology. It requires lower deposition temperatures, lower capital costs to build facilities and operate, no hazardous polymers nor explosive material, and produces no amorphous silicon dust waste, all of which are drawbacks of the Siemens process. However, there are yet to be any major factories built using this process.

Compounds

- Silicon forms binary compounds called silicides with many metallic elements whose properties range from reactive compounds, e.g. magnesium silicide, Mg_2Si through high melting refractory compounds such as molybdenum disilicide, $MoSi_2$.
- Silicon carbide, SiC (carborundum) is a hard, high melting solid and a well-known abrasive. It may also be sintered into a type of high-strength ceramic used in armor.
- Silane, SiH_4, is a pyrophoric gas with a similar tetrahedral structure to methane, CH_4. When pure, it does not react with pure water or dilute acids; however, even small amounts of alkali impurities from the laboratory glass can result in a rapid hydrolysis. There is a range of catenated silicon hydrides that form a homologous series of compounds, Si_nH_{2n+2} where $n = 2–8$ (analogous to the alkanes). These are all readily hydrolyzed and are thermally unstable, particularly the heavier members.
- Disilenes contain a silicon-silicon double bond (analogous to the alkenes) and are generally highly reactive requiring large substituent groups to stabilize them A disilyne with a silicon-silicon triple bond was first isolated in 2004; although as the compound is non-linear, the bonding is dissimilar to that in alkynes.
- Tetrahalides, SiX_4, are formed with all the halogens. Silicon tetrachloride, for example, reacts with water, unlike its carbon analogue, carbon tetrachloride.

Silicon dihalides are formed by the high temperature reaction of tetrahalides and silicon; with a structure analogous to a carbene they are reactive compounds. Silicon difluoride condenses to form a polymeric compound, $(SiF_2)_n$.

- Silicon dioxide is a high melting solid with a number of crystal forms; the most familiar of which is the mineral quartz. In quartz each silicon atom is surrounded by four oxygen atoms that bridge to other silicon atoms to form a three dimensional lattice. Silica is soluble in water at high temperatures forming a range of compounds called *monosilicic acid*, $Si(OH)_4$.
- Under the right conditions monosilicic acid readily polymerizes to form more complex silicic acids, ranging from the simplest condensate, disilicic acid ($H_6Si_2O_7$) to linear, ribbon, layer and lattice structures which form the basis of the many silicate minerals and are called *polysilicic acids* $\{Si_x(OH)_{4-2x}\}_n$.
- With oxides of other elements the high temperature reaction of silicon dioxide can give a wide range of glasses with various properties. Examples include soda lime glass, borosilicate glass and lead crystal glass.
- Silicon sulfide, SiS_2 is a polymeric solid (unlike its carbon analogue the liquid CS_2).
- Silicon forms a nitride, Si_3N_4 which is a ceramic. Silatranes, a group of tricyclic compounds containing five-coordinate silicon, may have physiological properties.
- Many transition metal complexes containing a metal-silicon bond are now known, which include complexes containing SiH_nX_{3-n} ligands, SiX_3 ligands, and $Si(OR)_3$ ligands.
- Silicones are large group of polymeric compounds with an (Si-O-Si) backbone. An example is the silicone oil PDMS (polydimethylsiloxane). These polymers can be crosslinked to produce resins and elastomers.
- Many organosilicon compounds are known which contain a silicon-carbon single bond. Many of these are based on a central tetrahedral silicon atom, and some are optically active when central chirality exists. Long chain polymers containing a silicon backbone are known, such as polydimethysilylene $(SiMe_2)_n$. Polycarbosilane, $[(SiMe_2)_2CH_2]_n$ with a backbone containing a repeating -Si-Si-C unit, is a precursor in the production of silicon carbide fibers.

History

Attention was first drawn to quartz as the possible oxide of a fundamental chemical element by Antoine Lavoisier, in 1787. In 1811, Gay-Lussac and Thénard are thought to have prepared impure amorphous silicon, through the heating of recently isolated potassium metal with silicon tetrafluoride, but they did not purify and characterize the product, nor identify it as a new element. In 1824, Berzelius prepared amorphous silicon using approximately the same method as Gay-Lussac (potassium metal and potassium fluorosilicate), but purifying the product to a brown powder by repeatedly washing it. He named the product *silicium* from the Latin *silex*, *silicis* for flint, flints, and adding the "-ium" ending because he believed it was a metal. As a result he is usually given credit for the element's discovery. Silicon was given its present name in 1831 by Scottish chemist Thomas Thomson. He retained part of Berzelius's name but added "-on" because he believed silicon a nonmetal more similar to boron and carbon.

Tellurium- Metalloid

Tellurium is a chemical element with symbol Te and atomic number 52. A brittle, mildly toxic, rare, silver-white metalloid which looks similar to tin, tellurium is chemically related to selenium and sulfur. It is occasionally found in native form, as elemental crystals. Tellurium is far more common in the universe as a whole than it is on Earth. Its extreme rarity in the Earth's crust, comparable to that of platinum, is partly due to its high atomic number, but also due to its formation of a volatile hydride which caused the element to be lost to space as a gas during the hot nebular formation of the planet.

Tellurium was discovered in Transylvania (today part of Romania) in 1782 by Franz-Joseph Müller von Reichenstein in a mineral containing tellurium and gold. Martin Heinrich Klaproth named the new element in 1798 after the Latin word for "earth", *tellus*. Gold telluride minerals are the most notable natural gold compounds. However, they are not a commercially significant source of tellurium itself, which is normally extracted as a by-product of copper and lead production.

Commercially, the primary use of tellurium is in alloys, foremost in steel and copper to improve machinability. Applications in solar panels and as a semiconductor material also consume a considerable fraction of tellurium production.

Tellurium has no biological function, although fungi can incorporate it in place of sulfur and selenium into amino acids such as tellurocysteine and telluromethionine. In humans, tellurium is partly metabolized into dimethyl telluride, $(CH_3)_2Te$, a gas with a garlic-like odor which is exhaled in the breath of victims of tellurium toxicity or exposure.

Characteristics

Physical Properties

When crystalline, tellurium is silvery-white and when it is in pure state it has a metallic luster. It is a brittle and easily pulverized metalloid. Amorphous tellurium is found by precipitating it from a solution of tellurous or telluric acid ($Te(OH)_6$). Tellurium is a semiconductor that shows a greater electrical conductivity in certain directions which depends on atomic alignment; the conductivity increases slightly when exposed to light (photoconductivity). When in its molten state, tellurium is corrosive to copper, iron and stainless steel.

Chemical Properties

Tellurium adopts a polymeric structure, consisting of zig-zag chains of Te atoms. This gray material resists oxidation by air and is nonvolatile.

Isotopes

Naturally occurring tellurium has eight isotopes. Five of those isotopes, ^{122}Te, ^{123}Te, ^{124}Te, ^{125}Te and ^{126}Te, are stable. The other three, ^{120}Te, ^{128}Te and ^{130}Te, have been observed to be radioactive. The stable isotopes make up only 33.2% of the naturally occurring tellurium; this is possible due to the long half-lives of the unstable isotopes.

They are in the range from 10^{13} to 2.2×10^{24} years (for ^{128}Te). This makes ^{128}Te the isotope with the longest half-life among all radionuclides, which is approximately 160 trillion (10^{12}) times the age of known universe.

There are 38 known nuclear isomers of tellurium with atomic masses that range from 105 to 142. Tellurium is among the lightest elements known to undergo alpha decay, with isotopes ^{106}Te to ^{110}Te being able to undergo this mode of decay.[6] The atomic mass of tellurium (127.60 $g \cdot mol^{-1}$) exceeds that of the following element iodine (126.90 $g \cdot mol^{-1}$).

Occurrence

With an abundance in the Earth's crust comparable to that of platinum, tellurium is one of the rarest stable solid elements in the Earth's crust. Its abundance is about 1 μg/kg. In comparison, even the rarest of the lanthanides have crustal abundances of 500 μg/kg (see Abundance of the chemical elements).

The extreme rarity of tellurium in the Earth's crust is not a reflection of its cosmic abundance, which is in fact greater than that of rubidium, even though rubidium is ten thousand times more abundant in the Earth's crust. The extraordinarily low abundance of tellurium on Earth is rather thought to be due to conditions in the Earth's formation, when the stable form of certain elements, in the absence of oxygen and water, was controlled by the reductive power of free hydrogen. Under this scenario, certain elements such as tellurium which form volatile hydrides were severely depleted during the formation of the Earth's crust, through evaporation of these hydrides. Tellurium and selenium are the heavy elements most depleted in the Earth's crust by this process.

Tellurium is sometimes found in its native (i.e., elemental) form, but is more often found as the tellurides of gold such as calaverite and krennerite (two different polymorphs of $AuTe_2$), petzite, Ag_3AuTe_2, and sylvanite, $AgAuTe_4$. The city of Telluride, Colorado was named in hope of a strike of gold telluride (which never materialized, though gold metal ore was found). Gold itself is usually found uncombined, but when found naturally as a chemical compound, it is most often combined with tellurium (a few rare non-telluride gold compounds such as the antimonide aurostibite, $AuSb_2$, and bismuthide maldonite, Au_2Bi, are also known).

Although tellurium is found with gold more often than in uncombined form, it is found even more often combined with elements other than gold, as tellurides more common metals (e.g. melonite, $NiTe_2$). Natural tellurite and tellurate minerals also occur, formed by oxidation of tellurides near the Earth's surface. In contrast to selenium, tellurium is not in general able to replace sulfur in its minerals, due to the large difference in ion radius of sulfur and tellurium. In consequence, many common sulfide minerals contain considerable amounts of selenium, but only traces of tellurium.

In the gold rush of 1893, diggers in Kalgoorlie discarded a pyritic material which got in their way as they searched for pure gold. The Kalgoorlie waste was thus used to fill in potholes or as part of sidewalks. Three years passed before it was realized that this waste was calaverite, a telluride of gold that had not been recognized. This led to a second gold rush in 1896 which included mining the streets.

Production

The principal source of tellurium is from anode sludges produced during the electrolytic refining of blister copper. It is a component of dusts from blast furnace refining of lead. Treatment of 500 tons of copper ore typically yields one pound (0.45 kg) of tellurium. Tellurium is produced mainly in the United States, Peru, Japan and Canada.

For the year 2009 the British Geological Survey gives the following numbers: United States 50 t, Peru 7 t, Japan 40 t and Canada 16 t. The anode sludges contain the selenides and tellurides of the noble metals in compounds with the formula M_2Se or M_2Te (M = Cu, Ag, Au). At temperatures of 500 °C the anode sludges are roasted with sodium carbonate under air.

The metal ions are reduced to the metals, while the telluride is converted to sodium tellurite.

$$M_2Te + O_2 + Na_2CO_3 \rightarrow Na_2TeO_3 + 2\ M + CO_2$$

Tellurites can be leached from the mixture with water and are normally present as hydrotellurites $HTeO_3^-$ in solution. Selenites are also formed during this process, but they can be separated by adding sulfuric acid. The hydrotellurites are converted into the insoluble tellurium dioxide while the selenites stay in solution.

$$HTeO-3 + OH^- + H_2SO_4 \rightarrow TeO_2 + SO2-4 + 2\ H_2O$$

The reduction to the metal is done either by electrolysis or by reacting the tellurium dioxide with sulfur dioxide in sulfuric acid.

$$TeO_2 + 2\ SO_2 + 2H_2O \rightarrow Te + SO2-4 + 4\ H^+$$

Commercial-grade tellurium is usually marketed as 200-mesh powder but is also available as slabs, ingots, sticks, or lumps. The year-end price for tellurium in 2000 was US$14 per pound. In recent years, the tellurium price was driven up by increased demand and limited supply, reaching as high as US$100 per pound in 2006. Despite an expected doubling in production due to improved extraction methods, the United States Department of Energy (DoE) anticipates a supply shortfall of tellurium by 2025.

Compounds

Tellurium belongs to the same chemical family as oxygen, sulfur, selenium and polonium: the chalcogen family. Tellurium and selenium compounds are similar. It exhibits the oxidation states −2, +2, +4 and +6, with the +4 state being most common.

Tellurides

Reduction of Te metal produces the tellurides and polytellurides, Te_n^{2-}. The −2 oxidation state is exhibited in binary compounds with many metals, such as zinc telluride, ZnTe, formed by heating tellurium with zinc. Decomposition of ZnTe with hydrochloric acid yields hydrogen telluride (H_2Te), a highly unstable analogue of the other chalcogen hydrides, H_2O, H_2S and H_2Se:

$$ZnTe + 2\ HCl \rightarrow ZnCl_2 + H_2Te$$

H_2Te is unstable, whereas salts of its conjugate base $[TeH]^-$ are stable.

Halides

The +2 oxidation state is exhibited by the dihalides, $TeCl_2$, $TeBr_2$ and TeI_2. The dihalides have not been obtained in pure form, although they are known decomposition products of the tetrahalides in organic solvents, and their derived tetrahalotellurates are well-characterized:

$Te + X_2 + 2\ X^- \rightarrow$ TeX2− 4

where X is Cl, Br, or I. These anions are square planar in geometry. Polynuclear anionic species also exist, such as the dark brown Te 2I2− 6, and the black Te 4I2−14.

Fluorine forms two halides with tellurium: the mixed-valence Te_2F_4 and TeF_6. In the +6 oxidation state, the $–OTeF_5$ structural group occurs in a number of compounds such as $HOTeF_5$, $B(OTeF_5)_3$, $Xe(OTeF_5)_2$, $Te(OTeF_5)_4$ and $Te(OTeF_5)_6$. The square antiprismatic anion TeF2−8 is also attested. The other halogens do not form halides with tellurium in the +6 oxidation state, but only tetrahalides ($TeCl_4$, $TeBr_4$ and TeI_4) in the +4 state, and other lower halides (Te_3Cl_2, Te_2Cl_2, Te_2Br_2, Te_2I and two forms of TeI). In the +4 oxidation state, halotellurate anions are known, such as TeCl2−6 and Te_2Cl2− 10.

Halotellurium cations are also attested, including TeI+3, found in TeI_3AsF_6.

Oxocompounds

Tellurium monoxide was first reported in 1883 as a black amorphous solid formed by the heat decomposition of $TeSO_3$ in vacuum, disproportionating into tellurium dioxide, TeO_2 and elemental tellurium upon heating.

Since then, however, some doubt has been cast on its existence in the solid phase, although it is known as a vapor phase fragment; the black solid may be merely an equimolar mixture of elemental tellurium and tellurium dioxide.

Tellurium dioxide is formed by heating tellurium in air, causing it to burn with a blue flame. Tellurium trioxide, β-TeO_3, is obtained by thermal decomposition of $Te(OH)_6$. The other two forms of trioxide reported in the literature, the α- and γ- forms, were found not to be true oxides of tellurium in the +6 oxidation state, but a mixture of Te^{4+}, OH^- and O−2. Tellurium also exhibits mixed-valence oxides, Te_2O_5 and Te_4O_9.

The tellurium oxides and hydrated oxides form a series of acids, including tellurous acid (H_2TeO_3), orthotelluric acid ($Te(OH)_6$) and metatelluric acid ($(H_2TeO_4)_n$). The two forms of telluric acid form *tellurate* salts containing the TeO2–4 and TeO6−6 anions, respectively. Tellurous acid forms *tellurite* salts containing the anion TeO2−3. Other tellurium cations include TeF2+8, which consists of two fused tellurium rings and the polymeric TeF2+7.

Zintl cations

When tellurium is treated with concentrated sulfuric acid, it forms red solutions containing the Zintl ion, Te2+4. The oxidation of tellurium by AsF_5 in liquid SO_2 also produces this square planar cation, as well as with the trigonal prismatic, yellow-orange Te4+6:

4 Te + 3 AsF_5 → Te2+
4(AsF−
6)$_2$ + AsF_3
6 Te + 6 AsF_5 → Te4+
6(AsF−
6)$_4$ + 2 AsF_3

Other tellurium Zintl cations include the polymeric Te2+7 and the blue-black Te2+
8, which consists of two fused 5-membered tellurium rings. The latter cation is formed by the reaction of tellurium with tungsten hexachloride:

8 Te + 2 WCl_6 → Te2+
8(WCl−6)$_2$

Interchalcogen cations also exist, such as Te_2Se2+6 (distorted cubic geometry) and Te_2Se2+ 8. These are formed by oxidizing mixtures of tellurium and selenium with AsF_5 or SbF_5.

Organotellurium compounds

Tellurium does not readily form analogues of alcohols and thiols, with the functional group –TeH and are called tellurols. The –TeH functional group is also attributed to using the prefix *tellanyl-*. Like H_2Te, these species are unstable with respect to loss of hydrogen. Telluraethers (R-Te-R) are more stable as are telluroxides.

History

from the mines in Zlatna, near what is now Sibiu, Transylvania. This ore was known as "Faczebajer weißes blättriges Golderz" (white leafy gold ore from Faczebaja) or *antimonalischer Goldkies* (antimonic gold pyrite), and, according to Anton von Rupprecht, was *Spießglaskönig* (*argent molybdique*), containing native antimony. In 1782 Franz-Joseph Müller von Reichenstein, who was then serving as the Austrian chief inspector of mines in Transylvania, concluded that the ore did not contain antimony, but that it was bismuth sulfide.

The following year, he reported that this was erroneous and that the ore contained mostly gold and an unknown metal very similar to antimony. After a thorough investigation which lasted for three years and consisted of more than fifty tests, Müller determined the specific gravity of the mineral and noted the radish-like odor of the white smoke which passed off when the new metal was heated, the red color which the metal imparts to sulfuric acid, and the black precipitate which this solution gives when diluted with water.

Nevertheless, he was not able to identify this metal and gave it the names *aurum paradoxium* and *metallum problematicum*, as it did not show the properties predicted for the expected antimony.

In 1789, another Hungarian scientist, Pál Kitaibel, also discovered the element independently in an ore from Deutsch-Pilsen which had been regarded as argentiferous molybdenite, but later he gave the credit to Müller. In 1798, it was named by Martin Heinrich Klaproth who earlier isolated it from the mineral calaverite. The 1960s brought growth in thermoelectric applications for tellurium (as bismuth telluride), as well as its use in free-machining steel, which became the dominant use.

Applications

Metallurgy

The largest consumer of tellurium is metallurgy, where it is used in iron, copper and lead alloys. When added to stainless steel and copper it makes these metals more machinable. It is alloyed into cast iron for promoting chill for spectroscopic purposes, as the presence of electrically conductive free graphite tends to deleteriously affect spark emission testing results. In lead it improves strength and durability and decreases the corrosive action of sulfuric acid.

Semiconductor and electronics industry uses

Tellurium is used in cadmium telluride (CdTe) solar panels. National Renewable Energy Laboratory lab tests using this material achieved some of the highest efficiencies for solar cell electric power generation. Massive commercial production of CdTe solar panels by First Solar in recent years has significantly increased tellurium demand. If some of the cadmium in CdTe is replaced by zinc then (Cd,Zn)Te is formed which is used in solid-state X-ray detectors.

Alloyed with both cadmium and mercury, to form mercury cadmium telluride, an infrared sensitive semiconductor material is formed. Organotellurium compounds such as dimethyl telluride, diethyl telluride, diisopropyl telluride, diallyl telluride and methyl allyl telluride are used as precursors for metalorganic vapor phase epitaxy growth of II-VI compound semiconductors. Diisopropyl telluride (DIPTe) is employed as the preferred precursor for achieving the low-temperature growth of CdHgTe by MOVPE. For these processes highest purity metalorganics of both selenium and tellurium are used. The compounds for semiconductor industry and are prepared by adduct purification.

Tellurium as a tellurium suboxide is used in the media layer of several types of rewritable optical discs, including ReWritable Compact Discs (CD-RW), ReWritable Digital Video Discs (DVD-RW) and ReWritable Blu-ray Discs. Tellurium is used in the new phase change memory chips developed by Intel. Bismuth telluride (Bi_2Te_3) and lead telluride are working elements of thermoelectric devices. Lead telluride is used in far-infrared detectors.

Other Uses

- Used to color ceramics.
- The strong increase in optical refraction upon the addition of selenides and tellurides into glass is used in the production of glass fibers for telecommunications. These chalcogenide glasses are widely used.
- Mixtures of selenium and tellurium are used with barium peroxide as oxidizer in the delay powder of electric blasting caps.
- Organic tellurides have been employed as initiators for living radical polymerization and electron-rich mono- and di-tellurides possess antioxidant activity.

Allotropes Sub-Section

Allotropy or allotropism is the property of some chemical elements to exist in two or more different forms, known as allotropes of these elements. Allotropes are different structural modifications of an element; the atoms of the element are bonded together in a different manner.

For example, the allotropes of carbon include diamond (where the carbon atoms are bonded together in a tetrahedral lattice arrangement), graphite (where the carbon atoms are bonded together in sheets of a hexagonal lattice), graphene (single sheets of graphite), and fullerenes (where the carbon atoms are bonded together in spherical, tubular, or ellipsoidal formations).

The term allotropy is used for elements only, not for compounds. The more general term, used for any crystalline material, is polymorphism. Allotropy refers only to different forms of an element within the same phase (i.e. different solid, liquid or gas forms); the changes of state between solid, liquid and gas in themselves are not considered allotropy.

For some elements, allotropes have different molecular formulae which can persist in different phases – for example, two allotropes of oxygen (dioxygen, O_2 and ozone, O_3), can both exist in the solid, liquid and gaseous states. Conversely, some elements do not maintain distinct allotropes in different phases – for example phosphorus has numerous solid allotropes, which all revert to the same P_4 form when melted to the liquid state.

The concept of allotropy was originally proposed in 1841 by the Swedish scientist Baron Jöns Jakob Berzelius (1779–1848). The term is derived from the Greek άλλοτροπἱα (*allotropia*; variability, changeableness). After the acceptance of Avogadro's hypothesis in 1860 it was understood that elements could exist as polyatomic molecules, and the two allotropes of oxygen were recognized as O_2 and O_3. In the early 20th century it was recognized that other cases such as carbon were due to differences in crystal structure.

By 1912, Ostwald noted that the allotropy of elements is just a special case of the phenomenon of polymorphism known for compounds, and proposed that the terms allotrope and allotropy be abandoned and replaced by polymorph and polymorphism. Although many other chemists have repeated this advice, IUPAC and most chemistry texts still favor the usage of allotrope and allotropy for elements only.

List of Allotropes

Typically, elements capable of variable coordination number and/or oxidation states tend to exhibit greater numbers of allotropic forms. Another contributing factor is the ability of an element to catenate. Allotropes are typically more noticeable in non-metals (excluding the halogens and the noble gases) and metalloids. Nevertheless, metals tend to have many allotropes.

Cerium, left, Dysprosium, right.

Examples of allotropes include:

Non-metals

Element	**Allotropes**
Carbon	• Diamond - an extremely hard, transparent crystal, with the carbon atoms arranged in a tetrahedral lattice. A poor electrical conductor. An excellent thermal conductor. • Lonsdaleite - also called hexagonal diamond. • Graphite - a soft, black, flaky solid, a moderate electrical conductor. The C atoms are bonded in flat hexagonal lattices (graphene), which are then layered in sheets. • Linear acetylenic carbon (Carbyne) • Amorphous carbon • Fullerenes, including Buckminsterfullerene, aka "buckyballs", such as C_{60}. • Carbon nanotubes - allotropes of carbon with a cylindrical nanostructure.
Phosphorus:	• White phosphorus - crystalline solid P_4 • Red phosphorus - polymeric solid • Scarlet phosphorus • Violet phosphorus • Black phosphorus - semiconductor, analogous to graphite • Diphosphorus
Oxygen:	• dioxygen, O_2 - colorless (faint blue) • Ozone, O_3 - blue • Tetraoxygen, O_4 - metastable • Octaoxygen, O_8 - red
Sulfur:	• Sulfur has a large number of allotropes, second only to carbon
Selenium:	• "Red selenium," cyclo-Se_8 • Gray selenium, polymeric Se

Metalloids Element	Allotropes
Boron:	• Amorphous boron - brown powder - B_{12} regular icosahedra • α-rhombohedral boron • β-rhombohedral boron • γ-orthorhombic boron • α-tetragonal boron • β-tetragonal boron • High-pressure superconducting phase
Silicon:	• Amorphous silicon • crystalline silicon, Diamond cubic structure
Arsenic:	• Yellow arsenic - molecular non-metallic As_4, with the same structure of white phosphorus • Gray arsenic, polymeric As (metalloid) • Black arsenic - molecular and non-metallic, with the same structure of red phosphorus
Germanium:	• α-germanium – semi-metallic, with the same structure of diamond • β-germanium - metallic, with the same structure of beta-tin
Antimony:	• blue-white antimony - the stable form (metalloid) • yellow antimony (non-metallic) • black antimony (non-metallic) • explosive antimony
Polonium:	• α-polonium - simple cubic (metallic) • β-polonium - rhombohedral (metallic)

Element	Allotropes
Tin:	• grey tin (alpha tin) • white tin (beta tin) • rhombic tin (gamma tin) • sigma tin
Iron:	• ferrite (alpha iron) - forms below 770°C (the Curie point, T_C); the iron becomes magnetic in its alpha form; BCC • beta - forms below 912°C ; BCC crystal structure • gamma - forms below 1,394°C; FCC crystal structure • delta - forms from cooling down molten iron below 1,538°C; BCC crystal structure • epsilon - forms at high pressures

Lanthanides and Actinides

- Cerium, samarium, terbium, dysprosium and ytterbium have three allotropes.
- Praseodymium, neodymium, gadolinium and terbium have two allotropes.
- Plutonium has six distinct solid allotropes under "normal" pressures. Their densities vary within a ratio of some 4:3, which vastly complicates all kinds of work with the metal (particularly casting, machining, and storage). A seventh plutonium allotrope exists at very high pressures. The transuranium metals Np, Am, and Cm are also allotropic.
- Promethium, americium, berkelium and californium have 3 allotropes each

Metals

Among the metallic elements that occur in nature in significant quantities (up to U, without Tc and Pm), 27 are allotropic at ambient pressure: Li, Be, Na, Ca, Ti, Mn, Fe, Co, Sr, Y, Zr, Sn, La, Ce, Pr, Nd, Sm, Gd, Tb, Dy, Yb, Hf, Tl, Th, Pa and U. Some phase transitions between allotropic forms of technologically-relevant metals are those of Ti at 882˚C, Fe at 912˚C and 1394˚C, Co at 422˚C, Zr at 863˚C, Sn at 13˚C and U at 668˚C and 776˚C.

hydrogen 1 **H** 1.0079																	helium 2 **He** 4.0026
lithium 3 **Li** 6.941	beryllium 4 **Be** 9.0122											boron 5 **B** 10.811	carbon 6 **C** 12.011	nitrogen 7 **N** 14.007	oxygen 8 **O** 15.999	fluorine 9 **F** 18.998	neon 10 **Ne** 20.180
sodium 11 **Na** 22.990	magnesium 12 **Mg** 24.305											aluminium 13 **Al** 26.982	silicon 14 **Si** 28.086	phosphorus 15 **P** 30.974	sulfur 16 **S** 32.065	chlorine 17 **Cl** 35.453	argon 18 **Ar** 39.948
potassium 19 **K** 39.098	calcium 20 **Ca** 40.078		scandium 21 **Sc** 44.956	titanium 22 **Ti** 47.867	vanadium 23 **V** 50.942	chromium 24 **Cr** 51.996	manganese 25 **Mn** 54.938	iron 26 **Fe** 55.845	cobalt 27 **Co** 58.933	nickel 28 **Ni** 58.693	copper 29 **Cu** 63.546	zinc 30 **Zn** 65.39	gallium 31 **Ga** 69.723	germanium 32 **Ge** 72.61	arsenic 33 **As** 74.922	selenium 34 **Se** 78.96	bromine 35 **Br** 79.904	krypton 36 **Kr** 83.80
rubidium 37 **Rb** 85.468	strontium 38 **Sr** 87.62		yttrium 39 **Y** 88.906	zirconium 40 **Zr** 91.224	niobium 41 **Nb** 92.906	molybdenum 42 **Mo** 95.94	technetium 43 **Tc** [98]	ruthenium 44 **Ru** 101.07	rhodium 45 **Rh** 102.91	palladium 46 **Pd** 106.42	silver 47 **Ag** 107.87	cadmium 48 **Cd** 112.41	indium 49 **In** 114.82	tin 50 **Sn** 118.71	antimony 51 **Sb** 121.76	tellurium 52 **Te** 127.60	iodine 53 **I** 126.90	xenon 54 **Xe** 131.29
caesium 55 **Cs** 132.91	barium 56 **Ba** 137.33	57-70 *	lutetium 71 **Lu** 174.97	hafnium 72 **Hf** 178.49	tantalum 73 **Ta** 180.95	tungsten 74 **W** 183.84	rhenium 75 **Re** 186.21	osmium 76 **Os** 190.23	iridium 77 **Ir** 192.22	platinum 78 **Pt** 195.08	gold 79 **Au** 196.97	mercury 80 **Hg** 200.59	thallium 81 **Tl** 204.38	lead 82 **Pb** 207.2	bismuth 83 **Bi** 208.98	polonium 84 **Po** [209]	astatine 85 **At** [210]	radon 86 **Rn** [222]
francium 87 **Fr** [223]	radium 88 **Ra** [226]	89-102 **	lawrencium 103 **Lr** [262]	rutherfordium 104 **Rf** [261]	dubnium 105 **Db** [262]	seaborgium 106 **Sg** [266]	bohrium 107 **Bh** [264]	hassium 108 **Hs** [269]	meitnerium 109 **Mt** [268]	ununnilium 110 **Uun** [271]	unununium 111 **Uuu** [272]	ununbium 112 **Uub** [277]		ununquadium 114 **Uuq** [289]				

*Lanthanide series	lanthanum 57 **La** 138.91	cerium 58 **Ce** 140.12	praseodymium 59 **Pr** 140.91	neodymium 60 **Nd** 144.24	promethium 61 **Pm** [145]	samarium 62 **Sm** 150.36	europium 63 **Eu** 151.96	gadolinium 64 **Gd** 157.25	terbium 65 **Tb** 158.93	dysprosium 66 **Dy** 162.50	holmium 67 **Ho** 164.93	erbium 68 **Er** 167.26	thulium 69 **Tm** 168.93	ytterbium 70 **Yb** 173.04
**Actinide series	actinium 89 **Ac** [227]	thorium 90 **Th** 232.04	protactinium 91 **Pa** 231.04	uranium 92 **U** 238.03	neptunium 93 **Np** [237]	plutonium 94 **Pu** [244]	americium 95 **Am** [243]	curium 96 **Cm** [247]	berkelium 97 **Bk** [247]	californium 98 **Cf** [251]	einsteinium 99 **Es** [252]	fermium 100 **Fm** [257]	mendelevium 101 **Md** [258]	nobelium 102 **No** [259]

Drinking Water Analysis Chart

ANALYSIS	METHOD	HOLDING TIME
Inorganic Compounds (IOC) Antimony, Arsenic, Barium, Beryllium, Cadmium, Chromium, Copper, Iron, Lead, Manganese, Mercury, Nickel, Selenium, Silver, Sodium, Thallium, Zinc, Hardness, Conductivity, Turbidity, Color, Chloride, Cyanide, Fluoride, Nitrate, Nitrite, Sulfate, and Total Dissolved Solids.	**(various)**	**48 hours**
Primary Pollutants (Short IOC) Antimony, Arsenic, Barium, Beryllium, Cadmium, Chromium, Lead, Mercury, Selenium, Silver, Sodium, Thallium, Turbidity, Fluoride, Cyanide, Nitrate, and Nitrite.	**(various)**	**48 hours**
Municipal Testing		
Lead and Copper	**EPA 200.9 for Pb** **EPA 200.7 for Cu**	**14 days**
Public or Individual Water Source Testing		
Nitrate	**SM-4500 NO3 D**	**48 hours**
Total Coliform & E. Coli	**SM-9223 B**	**30 Hours**
Metals Analysis on Drinking Water (per element)		
GFAA **(As, Pb, Sb, Se, Tl)**	**EPA 200.9**	**6 months**
ICP (Ag, Al, B, Ba, Be, Cd, Cr, Cu, Fe, Mn, Mo, Na, Ni, Zn)	**EPA 200.7**	**6 months**
CVAA (Hg)	**EPA 245.1**	**6 months**
Primary Pollutant Metals	**GFAA/ICP/CVAA**	**6 months**
Drinking Water Analysis		
PH	**EPA 150.1**	
Acidity	**SM-2310 B (4b)**	**14 days**
Alkalinity (Bicarbonate & Carbonate)	**SM-2320 B (4a)**	**14 days**
BOD	**SM-5210 B**	**48 hours**
Calcium	**EPA 200.7**	**6 months**
Chloride	**SM-4500 Cl**	**8 days**
Chlorine, total	**SM-4500 Cl**	**5 hours**
Color	**SM-2120 B**	**8 hours**
COD	**EPA 410.4 (7.3)**	**28 days**
Cyanide	**EPA 335.2 (8.7)**	**28 days**
Dissolved Oxygen	**SM-4500 O C**	**8 hours**
Fluoride	**SM-4500 F C**	**28 days**

Hardness	**SM-2340 B**	**6 months**
Magnesium	**EPA 200.7**	**6 months**
Nitrogen, ammonia	**SM-4500 NH3 E** **SM-4500 NH3 H**	**28 days**
Nitrogen, nitrate	**SM-4500 NO3 D**	**48 hours**
Nitrogen, nitrite	**SM-4500 NO2**	**48 hours**
Nitrate + Nitrite	**SM-4500 NO3 E**	**48 hours**
Nitrogen, TKN	**EPA 351.4**	**28 days**
Odor	**SM-2150**	**6 days**
Phosphorous, ortho	**EPA 200.7**	**48 hours**
Phosphorous, total	**SM-4500 P**	**28 days**
Solids, settle able	**SM-2540**	**7 days**
Solids, suspended	**SM-2540 D**	**7 days**
<u>Drinking Water Analysis</u>		
Solids, total	**SM-2540 B**	**7 days**
Solids, volatile	**SM-2540 E**	**7 days**
Specific Conductance	**SM-2510 B**	**28 days**
Sulfate	**SM-4500 SO-4 E**	**28 days**
Sulfide	**SM-4500 S-2 D**	**28 days**
Sulfite	**EPA 377.1**	**28 days**
Silica	**SM-4500 SI E**	**28 days**
Total Organic Carbon	**EPA 415.1**	**28 days**
Turbidity	**SM- 2130 B**	**48 hours**

ORGANICS		
Semi-volatile Organics in Water (SOC)*	**(various)**	**7 days**
Volatile Organics in Water*	**(various)**	**7 days**
Trihalomethanes*	**EPA 501.1**	**7 days**
Gross Alpha & Bata (Radionuclides)*	**(various)**	**7 days**
BOD	**SM-5210 B**	**48 hours**
COD	**EPA 410.4(7.3)**	**28 days**
Oil and Grease	**EPA 413.1(1.2)**	**28 days**
Hardness W/digestion	**SM-2340 B**	**6 months**
Nitrogen, TKN	**EPA 351.4**	**28 days**
Nitrogen, ammonia	**SM-4500 NH3 F**	**28 days**
Nitrogen, Total Organic	**SM-4500 NorgNH3**	**28 days**
Nitrogen, nitrate	**SM-4500 NO3 D**	**48 hours**
Nitrogen, nitrite	**SM-4500 NO2 B**	**48 hours**
Phosphorous, ortho	**SM-4500 P E**	**48 hours**
Sulfate	**SM-4500 SO4 E**	**28 days**
Solids, dissolved	**SM-2540**	**7 days**
Solids, settle able	**SM-2540 F**	**7 days**
Solids, suspended	**SM-2540 D**	**7 days**
Solids, total	**SM-2540 B**	**7 days**
Solids, volatile	**SM-2540 E**	**7 days**
Total Organic Carbon	**EPA 415.1**	**28 days**
PH	**EPA 150.1**	
Metals (per element)		

ICP **(Ag, Al, Ca, Cd, Co, Cr, Cu, Fe, K, Mg, Mn, Mo, Na, Ni, Sb,**	**EPA 200.7**	**6 months**
GFAA **(As, Pb, Ba, Se, Tl)**	**EPA 200.9**	**6 months**
CVAA (Hg)	**EPA 245.1**	**6 months**

Definitions:

Action level - the concentration of a contaminant which, if exceeded, triggers treatment or other requirements which a water system must follow.

Maximum Contaminant Level - the “Maximum Allowed” (MCL) is the highest level of a contaminant that is allowed in drinking water. MCLs are set as close to the MCLGs as feasible using the best available treatment technology.

Maximum Contaminant Level Goal - the “Goal” (MCLG) is the level of a contaminant in drinking water below which there is no known or expected risk to health. MCLGs allow for a margin of safety.

Non-Detects (ND) - laboratory analysis indicates that the constituent is not present.

Parts per million (ppm) or Milligrams per liter (mg/L) - one part per million corresponds to one minute in two years or a single penny in $10,000.

Parts per billion (ppb) or Micrograms per liter (ug/L) - one part per billion corresponds to one minute in 2,000 years, or a single penny in $10,000,000.

Picocuries per liter (pCi/L) - picocuries per liter is a measure of the radioactivity in water.

SAMPLE CONTAINERS and PRESERVATION

Methods used by the laboratory usually specify what type of container and how much sample is required to run an analysis. The following table provides a summary of the sample handling and preservation requirements for some of the most common tests.

Parameter	Bottle Type	Minimum Sample Size	Maximum Holding Time	Storage & Preservation
Acidity	P or G^B	100ml	24 hrs/14 days	refrigerate
Alkalinity	P or G	200ml	24 hrs/14 days	refrigerate
BOD (5 day)	P or G	1L	6 hrs/48 hrs	refrigerate
Boron	P	100ml	28 days/6 months	
Chloride	P or G	250ml	28 days	
Chlorine, residual	P or G	500ml	0.5 hr/stat	analyze on site ASAP
COD	P or G	500ml	28 days/28 days	analyze on site ASAP
Color	P or G	500ml	48 hrs/48 hrs	refrigerate
Coliform, Total	P or G	125ml	30 hrs	refrigerate
Conductivity	P or G	500ml	48 hrs/48 hrs	refrigerate
Cyanide, Total	P or G	500ml	28 days/28 days	add NaOH to pH>12
				refrigerate in dark
Fluoride	P	300ml	28days/ 28 days	
Hardness	P or G	100ml	6 months/6 months	add HNO_3 to pH<2
Metals, general	P^A or G^A	250ml	6 months/6 months	add HNO_3 to pH<2
Furnace	P^A or G^A	250ml	6 months/6 months	
Flame	P^A or G^A	250ml	6 months/6 months	
Mercury	P^A or G^A	500ml	28 days/28 days	add HNO_3 to pH<2
Nitrogen *Ammonia*	P or G	500ml	7 days/ 28 days	ASAP or add H_2SO_4 to pH<2 & refrigerate

Nitrate	P or G	100ml	48 hrs/48 hrs	ASAP & refrigerate
Nitrate + Nitrite	P or G	200ml	48 hrs/28 days	ASAP & refrigerate
Nitrite	P or G	100ml	none/48 hrs	ASAP & refrigerate
TKN	P or G	500ml	7 days/28 days	add H_2SO_4 to pH<2
Oxygen, dissolved	G (BOD)	300ml		
Electrode			0.5 hrs/stat	ASAP on site
Winkler			8hrs/8 hrs	ASAP on site
pH	P or G	50ml	2 hrs/stat	ASAP on site
Phosphate,	G^A			
Ortho		100ml	48hrs	filter ASAP refrigerate
Total		100ml	28 days/28 days	refrigerate
Solids,	P or G			
Dissolved		250ml	7 days	refrigerate
Settleable		1L	48 hrs	refrigerate
Suspended		250ml	7 days	refrigerate
Total		250ml	7 days	refrigerate
Volatile		250ml	7 days	refrigerate
Silica	P	200ml	28 days/28 days	refrigerate
Sulfate	P or G	100ml	28 days/28 days	refrigerate
Turbidity	P or G	100ml	24 hrs/48 hrs	ASAP/refrigerate, store in dark up to 24 hrs

Refrigerate = storage at 4 degrees C, in the dark. P = plastic (polyethylene or equivalent); G = glass, G^A or P^A = rinsed with 1:1 HNO_3; G^B = glass, borosilicate, G^S = glass rinsed with organic solvents; NS = not stated in cited reference; stat = no storage allowed; analyze immediately.

Chain of Custody Procedures

Because a sample is physical evidence, chain of custody procedures are used to maintain and document sample possession from the time the sample is collected until it is introduced as evidence. Chain of custody requirements will vary from agency to agency.

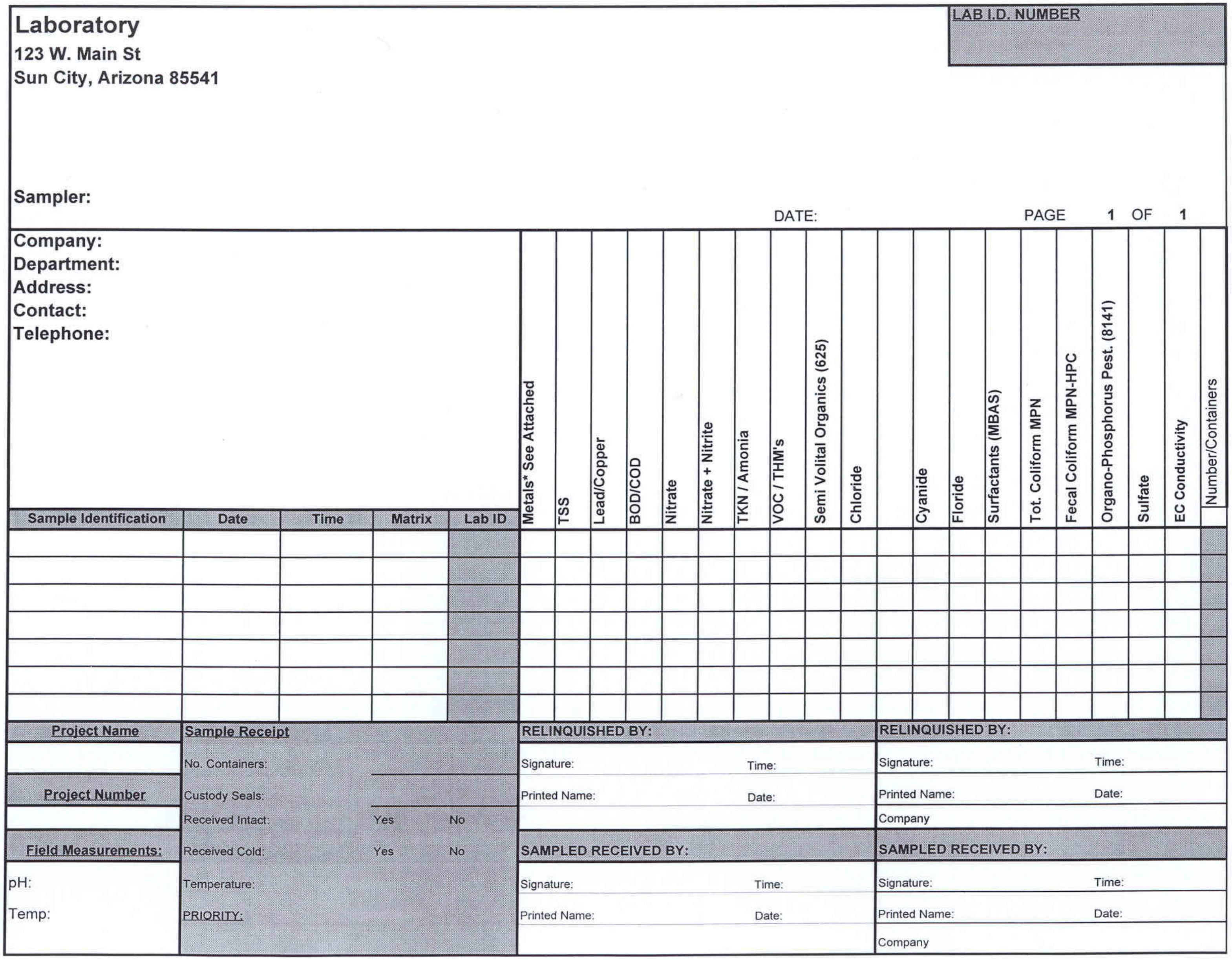
However, these procedures are similar and the chain of custody outlined in this manual is only a guideline. Consult your project manager for specific requirements.

If you have physical possession of a sample, have it in view, or have physically secured it to prevent tampering then it is defined as being in ***“custody*."** A chain of custody record, therefore, begins when the sample containers are obtained from the laboratory. From this point on, a chain of custody record will accompany the sample containers.

Handle the samples as little as possible in the field. Each custody sample requires a chain of custody record and may require a seal. If you do not seal individual samples, then seal the containers in which the samples are shipped.

When the samples transfer possession, both parties involved in the transfer must sign, date and note the time on the chain of custody record. If a shipper refuses to sign the chain-of-custody you must seal the samples and chain of custody documents inside a box or cooler with bottle seals or evidence tape. The recipient will then attach the shipping invoices showing the transfer dates and times to the custody sheets. If the samples are split and sent to more than one laboratory, prepare a separate chain of custody record for each sample. If the samples are delivered to after-hours night drop-off boxes, the custody record should note such a transfer and be locked with the sealed samples inside sealed boxes.

Using alcohol to disinfect a special sample tap before obtaining a sample.



Laboratory
123 W. Main St
Sun City, Arizona 85541

LAB I.D. NUMBER

Sampler:

DATE:

PAGE 1 OF 1

Company:
Department:
Address:
Contact:
Telephone:

Sample Identification	Date	Time	Matrix	Lab ID	Metals* See Attached	TSS	Lead/Copper	BOD/COD	Nitrate	Nitrate + Nitrite	TKN / Amonia	VOC / THM's	Semi Volital Organics (625)	Chloride		Cyanide	Floride	Surfactants (MBAS)	Tot. Coliform MPN	Fecal Coliform MPN-HPC	Organo-Phosphorus Pest. (8141)	Sulfate	EC Conductivity	Number/Containers

Project Name

Project Number

Field Measurements:
pH:
Temp:

Sample Receipt
No. Containers:
Custody Seals:
Received Intact: Yes No
Received Cold: Yes No
Temperature:
PRIORITY:

RELINQUISHED BY:
Signature: Time:
Printed Name: Date:

SAMPLED RECEIVED BY:
Signature: Time:
Printed Name: Date:

RELINQUISHED BY:
Signature: Time:
Printed Name: Date:
Company

SAMPLED RECEIVED BY:
Signature: Time:
Printed Name: Date:
Company

Chain of Custody Example.

SOC Sub-Section

Common water sampling bottles.

SOC/VOC bottles are the smaller, thin bottles with the septum tops. Be careful not to get any air bubbles in the SOC/VOC bottles and this may take a few weeks to learn to collect a proper sample.

SOC Introduction

Synthetic Organic Chemicals (SOCs) are organic (carbon based) chemicals that are less volatile than Volatile Organic Compounds (VOCs). SOCs are used as pesticides, defoliants, fuel additives and as ingredients for other organic compounds. They are all man made and do not naturally occur in the environment. Some of the more well-known SOCs are Atrazine, 2,4-D, Dioxin and Polychlorinated Biphenyls (PCBs).

SOCs most often enter the natural environment through application of pesticide (including runoff from areas where they are applied), as part of a legally discharged waste stream, improper or illegal waste disposal, accidental releases or as a byproduct of incineration. Some SOCs are very persistent in the environment, whether in soil or water.

SOCs are generally toxic and can have substantial health impacts from both acute (short-term) and chronic (long-term) exposure. Many are known carcinogens (cancer causing). EPA has set Maximum Contaminant Levels (MCL) for 30 SOCs under the Safe Drinking Water Act.

The Safe Drinking Water Act requires that all water sources of all public water systems be periodically monitored for regulated SOCs. The monitoring frequency can be adjusted through a waiver if SOCs are not detected.

EPA established Maximum Contaminant Levels (MCL), Maximum Contaminant Level Goals (MCLG), monitoring requirements and best available technologies for removal for 65 chemical contaminants over a five year period as EPA gathered and analyzed occurrence and health effects data. This series of rules are known as the Chemical Phase Rules and they define regulations for three contaminant groups:

- Inorganic Chemicals (IOC),
- Synthetic Organic Chemicals (SOC), and
- Volatile Organic Chemicals (VOC).

The Chemical Phase rules provide public health protection through the reduction of chronic risks from:

- cancer;
- organ damage; and
- circulatory,
- nervous, and
- reproductive system disorders.

They also help to reduce the occurrence of Methemoglobinemia or "blue baby syndrome" from ingestion of elevated levels of nitrate or nitrite.All public water systems must monitor for Nitrate and Nitrite. Community water systems and Non-transient non-community water systems must also monitor for IOCs, SOCs, and VOCs.

This is a list of the organic chemicals—which include pesticides, industrial chemicals, and disinfection by-products—that are tested for in public water systems (those that provide water to the public), along with the maximum standard for the contaminant, and a brief description of the potential health effects associated with long-term consumption of elevated levels of the contaminants.

The federal standard for most contaminants is listed as a Maximum Contaminant Level (MCL), the lowest concentration at which that particular contaminant is believed to represent a potential health concern. Unless otherwise noted, the MCL is expressed as parts per billion (ppb). Also, because of technological limitations or other factors, it is not possible to test for some contaminants in a reliable fashion. Instead, public water systems are required to use specific Treatment Techniques (TT) that are designed to remove these particular contaminants from the water.

In addition to the chemicals listed, monitoring is done for approximately 60 organic chemicals for which MCLs have not been established. If unacceptable levels are found of these “unregulated” contaminants—based on established state health standards and an assessment of the risks they pose—the response is the same as if an MCL has been exceeded: the public water system must notify those served by the system.

Synthetic Organic Chemicals	**MCL (ppb)**	**Potential Health Effects**
Acrylamide	TT	Cancer, nervous system effects
Alachlor	2	Cancer
Aldicarb	3	Nervous system effects
Aldicarb sulfoxide	4	Nervous system effects
Aldicarb sulfone	2	Nervous system effects
Atrazine	3	Liver, kidney, lung, cardiovascular effects; possible carcinogen
Benzo(a)pyrene (PAHs)	0.2	Liver, kidney effects, possible carcinogen
Carbofuran	40	Nervous system, reproductive system effects
Chlordane	2	Cancer
2,4-D	70	Liver, kidney effects
Di(2-ethylhexyl) adipate	400	Reproductive effects
Di(2-ethylhexyl) phthalate	6	Cancer
Dibromochloro-propane (DBCP)	0.2	Cancer
Dinoseb	7	Thyroid, reproductive effects
Diquat	20	Ocular, liver, kidney effects
Endothall	100	Liver, kidney, gastrointestinal effects
Endrin	2	Liver, kidney effects
Epichlorohydrin	TT	Cancer
Ethylene dibromide (EDB)	0.05	Cancer
Glyphosate	700	Liver, kidney effects
Heptachlor	0.4	Cancer
Heptachlor epoxide	0.2	Cancer

Hexachlorobenzene	1	Cancer
Hexachlorocyclopentadiene (HEX)	50	Kidney, stomach effects
Lindane	0.2	Liver, kidney, nervous system, immune system, circulatory system effects
Methoxychlor	40	Developmental, liver, kidney, nervous system effects
Oxamyl (Vydate)	200	Kidney effects
Pentachlorophenol	1	Cancer
Picloram	500	Kidney, liver effects
Polychlorinated biphenyls (PCBs)	0.5	Cancer
Simazine	4	Body weight and blood effects, possible carcinogen
2,3,7,8-TCDD (Dioxin)	0.00003	Cancer
Toxaphene	3	Cancer
2,4,5-TP (Silvex)	50	Liver, kidney effects

Volatile Organic Compounds (VOCs) Sub-Section

Definitions

Volatile Organic Compounds (VOCs) – "VOCs are ground-water contaminants of concern because of very large environmental releases, human toxicity, and a tendency for some compounds to persist in and migrate with ground-water to drinking-water supply well … In general, VOCs have high vapor pressures, low-to-medium water solubilities, and low molecular weights. Some VOCs may occur naturally in the environment, other compounds occur only as a result of manmade activities, and some compounds have both origins." - Zogorski and others, 2006

Volatile Organic Compounds (VOCs) – "Volatile organic compounds released into the atmosphere by anthropogenic and natural emissions which are important because of their involvement in photochemical pollution." - Lincoln and others, 1998

Volatile Organic Compounds (VOCs) – "Hydrocarbon compounds that have low boiling points, usually less than 100ºC, and therefore evaporate readily. Some are gases at room temperature. Propane, benzene, and other components of gasoline are all volatile organic compounds." - Art, 1993

Volatile Organic Compounds (VOCs) – "VOCs are organic compounds that can be isolated from the water phase of a sample by purging the water sample with inert gas, such as helium, and, subsequently, analyzed by gas chromatography. Many VOCs are human-made chemicals that are used and produced in the manufacture of paints, adhesives, petroleum products, pharmaceuticals, and refrigerants.

They often are compounds of fuels, solvents, hydraulic fluids, paint thinners, and dry-cleaning agents commonly used in urban settings. VOC contamination of drinking water supplies is a human-health concern because many are toxic and are known or suspected human carcinogens." - U.S. Geological Survey, 2005

VOCs Explained

Volatile organic compounds (VOCs) are organic chemicals that have a high vapor pressure at ordinary, room-temperature conditions. Their high vapor pressure results from a low boiling point, which causes large numbers of molecules to evaporate or sublimate from the liquid or solid form of the compound and enter the surrounding air. An example is formaldehyde, with a boiling point of –19 °C (–2 °F), slowly exiting paint and getting into the air.

VOCs are numerous, varied, and ubiquitous. They include both human-made and naturally occurring chemical compounds. Most scents or odors are of VOCs. VOCs play an important role in communication between plants. Some VOCs are dangerous to human health or cause harm to the environment. Anthropogenic VOCs are regulated by law, especially indoors, where concentrations are the highest.

Harmful VOCs are typically not acutely toxic, but instead have compounding long-term health effects. Because the concentrations are usually low and the symptoms slow to develop, research into VOCs and their effects is difficult.

Specific Components

Paints and Coatings

A major source of man-made VOCs are coatings, especially paints and protective coatings. Solvents are required to spread a protective or decorative film. Approximately 12 billion liters of paints are produced annually. Typical solvents are aliphatic hydrocarbons, ethyl acetate, glycol ethers, and acetone. Motivated by cost, environmental concerns, and regulation, the paint and coating industries are increasingly shifting toward aqueous solvents.

Chlorofluorocarbons and Chlorocarbons

Chlorofluorocarbons, which are banned or highly regulated, were widely used cleaning products and refrigerants. Tetrachloroethene is used widely in dry cleaning and by industry. Industrial use of fossil fuels produces VOCs either directly as products (e.g., gasoline) or indirectly as byproducts (e.g., automobile exhaust).

Benzene

One VOC that is a known human carcinogen is benzene, which is a chemical found in environmental tobacco smoke, stored fuels, and exhaust from cars in an attached garage. Benzene also has natural sources such as volcanoes and forest fires. It is frequently used to make other chemicals in the production of plastics, resins, and synthetic fibers. Benzene evaporates into the air quickly and the vapor of benzene is heavier than air allowing the compound to sink into low-lying areas. Benzene has also been known to contaminate food and water and if digested can lead to vomiting, dizziness, sleepiness, rapid heartbeat, and at high levels, even death may occur.

Methylene Chloride

Methylene chloride is another VOC that is highly dangerous to human health. It can be found in adhesive removers and aerosol spray paints and the chemical has been proven to cause cancer in animals. In the human body, methylene chloride is converted to carbon monoxide and a person will suffer the same symptoms as exposure to carbon monoxide. If a product that contains methylene chloride needs to be used the best way to protect human health is to use the product outdoors. If it must be used indoors, proper ventilation is essential to keeping exposure levels down.

Perchloroethylene

Perchloroethylene is a volatile organic compound that has been linked to causing cancer in animals. It is also suspected to cause many of the breathing related symptoms of exposure to VOC’s. Perchloroethylene is used mostly in dry cleaning. Studies show that people breathe in low levels of this VOC in homes where dry-cleaned clothes are stored and while wearing dry-cleaned clothing. While dry cleaners attempt to recapture perchlorothylene in the dry cleaning process to reuse it in an effort to save money, they can’t recapture it all. To avoid exposure to perchlorothylene, if a strong chemical odor is coming from clothing when picked up from the dry cleaner, do not accept them and request that less of the chemical be used as well as a complete drying of the garments

MTBE

MTBE was banned in the US around 2004 in order to limit further contamination of drinking water aquifers primarily from leaking underground gasoline storage tanks where MTBE was used as an octane booster and oxygenated-additive.

Formaldehyde
Many building materials such as paints, adhesives, wall boards, and ceiling tiles slowly emit formaldehyde, which irritates the mucous membranes and can make a person irritated and uncomfortable. Formaldehyde emissions from wood are in the range of 0.02 – 0.04 ppm. Relative humidity within an indoor environment can also affect the emissions of formaldehyde. High relative humidity and high temperatures allow more vaporization of formaldehyde from wood-materials.

Health Risks
Respiratory, allergic, or immune effects in infants or children are associated with man-made VOCs and other indoor or outdoor air pollutants. Some VOCs, such as styrene and limonene, can react with nitrogen oxides or with ozone to produce new oxidation products and secondary aerosols, which can cause sensory irritation symptoms. Unspecified VOCs are important in the creation of smog.

Health effects include:

> Eye, nose, and throat irritation; headaches, loss of coordination, nausea; damage to liver, kidney, and central nervous system. Some organics can cause cancer in animals; some are suspected or known to cause cancer in humans. Key signs or symptoms associated with exposure to VOCs include conjunctival irritation, nose and throat discomfort, headache, allergic skin reaction, dyspnea, declines in serum cholinesterase levels, nausea, emesis, epistaxis, fatigue, dizziness.

The ability of organic chemicals to cause health effects varies greatly from those that are highly toxic, to those with no known health effects. As with other pollutants, the extent and nature of the health effect will depend on many factors including level of exposure and length of time exposed. Eye and respiratory tract irritation, headaches, dizziness, visual disorders, and memory impairment are among the immediate symptoms that some people have experienced soon after exposure to some organics. At present, not much is known about what health effects occur from the levels of organics usually found in homes. Many organic compounds are known to cause cancer in animals; some are suspected of causing, or are known to cause, cancer in humans.

Reducing Exposure
To reduce exposure to these toxins, one should buy products that contain Low-VOC's or No VOC's. Only the quantity which will soon be needed should be purchased, eliminating stockpiling of these chemicals.

Use products with VOC's in well ventilated areas. When designing homes and buildings, design teams can implement the best possible ventilation plans, call for the best mechanical systems available, and design assemblies to reduce the amount of infiltration into the building.

These methods will help improve indoor air quality, but by themselves they cannot keep a building from becoming an unhealthy place to breathe. While proper building ventilation is a key component to improving indoor air quality, it cannot do the job on its own. As stated earlier, awareness is the key component to improving air quality, when choosing building materials, furnishings, and decorations. When architects and engineers implement best practices in ventilation and mechanical systems, the owner must maintain good air quality levels thereafter.

Limit Values for VOC Emissions

Limit values for VOC emissions into indoor air are published by e.g. AgBB, AFSSET, California Department of Public Health, and others.

Chemical Fingerprinting

The exhaled human breath contains a few hundred volatile organic compounds and is used in breath analysis to serve as a VOC biomarker to test for diseases such as lung cancer. One study has shown that "volatile organic compounds ... are mainly blood borne and therefore enable monitoring of different processes in the body." And it appears that VOC compounds in the body "may be either produced by metabolic processes or inhaled/absorbed from exogenous sources" such as environmental tobacco smoke. Research is still in the process to determine whether VOCs in the body are contributed by cellular processes or by the cancerous tumors in the lung or other organs.

Volatile Organic Chemicals	MCL (ppb)	Potential Health Effects
Benzene	5	Cancer
Carbon tetrachloride	5	Liver effects, cancer
Chlorobenzene	100	Liver, kidney, nervous system effects
o-Dichlorobenzene	600	Liver, kidney, blood cell effects
para-Dichlorobenzene	175	Kidney effects, possible carcinogen
1,2-Dichloroethane	5	Cancer
1,1-Dichloroethylene	7	Liver, kidney effects, possible carcinogen
cis-1,2-Dichloroethylene	70	Liver, kidney, nervous system, circulatory system effects
trans-1,2-Dichloroethylene	100	Liver, kidney, nervous system, circulatory system effects
1,2-Dichloropropane	5	Cancer
Ethylbenzene	700	Liver, kidney, nervous system effects
Methylene chloride	5	Cancer
Styrene	100	Liver, nervous systems effects, possible carcinogen
Tetrachloroethylene (PCE)	5	Cancer
Toluene	1,000	Liver, kidney, nervous system, circulatory system effects
Total trihalomethanes Chloroform Bromoform Bromodichloromethane Chlorodibromomethane	100	Cancer
1,2,4-Trichlorobenzene	70	Liver, kidney effects
1,1,1-Trichloroethane	200	Liver, nervous system effects
1,1,2-Trichloroethane	5	Kidney, liver effects, possible carcinogen
Trichloroethylene (TCE)	5	Cancer

Vinyl chloride	2	Nervous system, liver effects, cancer
Xylenes (total)	10,000	Liver, kidney, nervous system effects

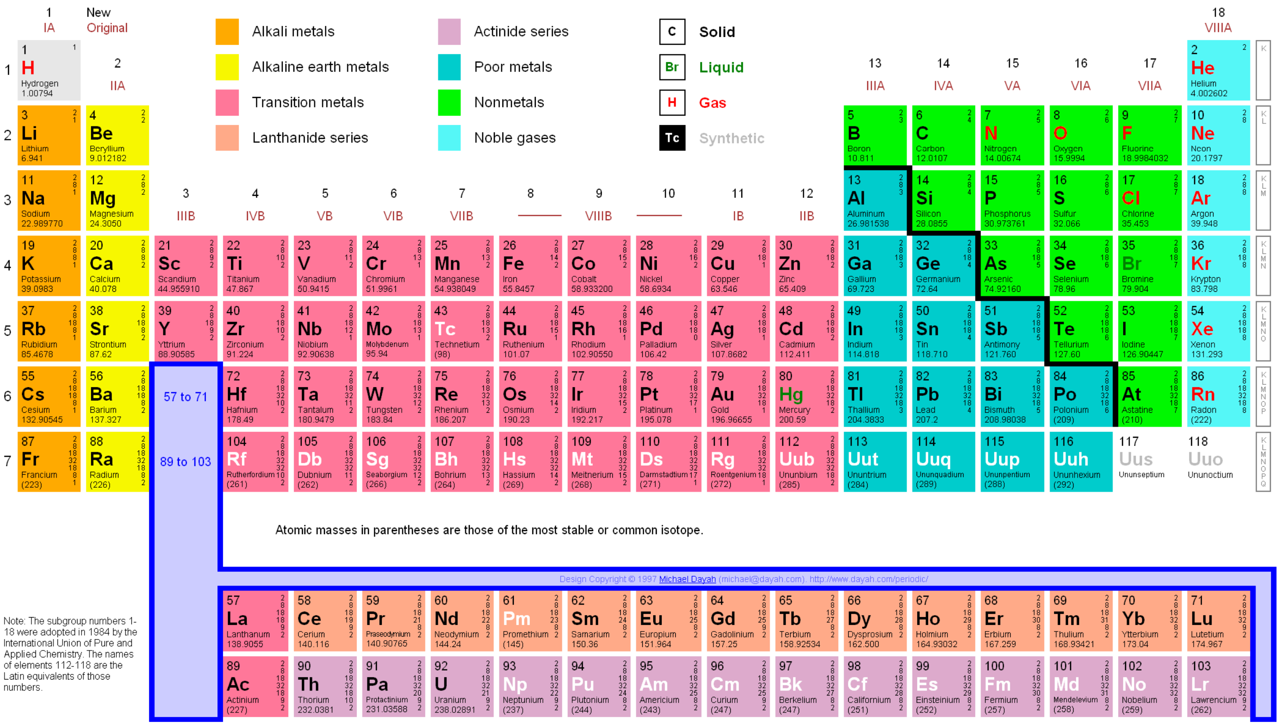
Disinfection By-products	**MCL (ppb)**	**Potential Health Effects**
Bromate	10	Cancer
Chlorate	1,000	Anemia, nervous system effects
Haloacetic Acids (HAA5)*	60	Cancer
Total trihalomethanes (TTHMs)**	100	Cancer

*Haloacetic acids consist of monochloroacetic acid, dichloroacetic acid, trichloroacetic acid, monobromoacetic acid, and dibromoacetic acid.

**Total trihalomethanes consist of chloroform, bromoform, bromodichloromethane, and chlorodibromomethane.

IOC Sub-Section

Periodic Table of the Elements



	1 IA	2 IIA	3 IIIB	4 IVB	5 VB	6 VIB	7 VIIB	8 ——	9 VIIIB	10 ——	11 IB	12 IIB	13 IIIA	14 IVA	15 VA	16 VIA	17 VIIA	18 VIIIA
1	1 H Hydrogen 1.00794																	2 He Helium 4.002602
2	3 Li Lithium 6.941	4 Be Beryllium 9.012182											5 B Boron 10.811	6 C Carbon 12.0107	7 N Nitrogen 14.00674	8 O Oxygen 15.9994	9 F Fluorine 18.9984032	10 Ne Neon 20.1797
3	11 Na Sodium 22.989770	12 Mg Magnesium 24.3050											13 Al Aluminum 26.981538	14 Si Silicon 28.0855	15 P Phosphorus 30.973761	16 S Sulfur 32.066	17 Cl Chlorine 35.453	18 Ar Argon 39.948
4	19 K Potassium 39.0983	20 Ca Calcium 40.078	21 Sc Scandium 44.955910	22 Ti Titanium 47.867	23 V Vanadium 50.9415	24 Cr Chromium 51.9961	25 Mn Manganese 54.938049	26 Fe Iron 55.8457	27 Co Cobalt 58.933200	28 Ni Nickel 58.6934	29 Cu Copper 63.546	30 Zn Zinc 65.409	31 Ga Gallium 69.723	32 Ge Germanium 72.64	33 As Arsenic 74.92160	34 Se Selenium 78.96	35 Br Bromine 79.904	36 Kr Krypton 83.798
5	37 Rb Rubidium 85.4678	38 Sr Strontium 87.62	39 Y Yttrium 88.90585	40 Zr Zirconium 91.224	41 Nb Niobium 92.90638	42 Mo Molybdenum 95.94	43 Tc Technetium (98)	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.90550	46 Pd Palladium 106.42	47 Ag Silver 107.8682	48 Cd Cadmium 112.411	49 In Indium 114.818	50 Sn Tin 118.710	51 Sb Antimony 121.760	52 Te Tellurium 127.60	53 I Iodine 126.90447	54 Xe Xenon 131.293
6	55 Cs Cesium 132.90545	56 Ba Barium 137.327	57 to 71	72 Hf Hafnium 178.49	73 Ta Tantalum 180.9479	74 W Tungsten 183.84	75 Re Rhenium 186.207	76 Os Osmium 190.23	77 Ir Iridium 192.217	78 Pt Platinum 195.078	79 Au Gold 196.96655	80 Hg Mercury 200.59	81 Tl Thallium 204.3833	82 Pb Lead 207.2	83 Bi Bismuth 208.98038	84 Po Polonium (209)	85 At Astatine (210)	86 Rn Radon (222)
7	87 Fr Francium (223)	88 Ra Radium (226)	89 to 103	104 Rf Rutherfordium (261)	105 Db Dubnium (262)	106 Sg Seaborgium (266)	107 Bh Bohrium (264)	108 Hs Hassium (269)	109 Mt Meitnerium (268)	110 Ds Darmstadtium (271)	111 Rg Roentgenium (272)	112 Uub Ununbium (285)	113 Uut Ununtrium (284)	114 Uuq Ununquadium (289)	115 Uup Ununpentium (288)	116 Uuh Ununhexium (292)	117 Uus Ununseptium	118 Uuo Ununoctium

57 La Lanthanum 138.9055	58 Ce Cerium 140.116	59 Pr Praseodymium 140.90765	60 Nd Neodymium 144.24	61 Pm Promethium (145)	62 Sm Samarium 150.36	63 Eu Europium 151.964	64 Gd Gadolinium 157.25	65 Tb Terbium 158.92534	66 Dy Dysprosium 162.500	67 Ho Holmium 164.93032	68 Er Erbium 167.259	69 Tm Thulium 168.93421	70 Yb Ytterbium 173.04	71 Lu Lutetium 174.967
89 Ac Actinium (227)	90 Th Thorium 232.0381	91 Pa Protactinium 231.03588	92 U Uranium 238.02891	93 Np Neptunium (237)	94 Pu Plutonium (244)	95 Am Americium (243)	96 Cm Curium (247)	97 Bk Berkelium (247)	98 Cf Californium (251)	99 Es Einsteinium (252)	100 Fm Fermium (257)	101 Md Mendelevium (258)	102 No Nobelium (259)	103 Lr Lawrencium (262)

Atomic masses in parentheses are those of the most stable or common isotope.

Note: The subgroup numbers 1-18 were adopted in 1984 by the International Union of Pure and Applied Chemistry. The names of elements 112-118 are the Latin equivalents of those numbers.

Left, Tellurium, right Astatine with Fluorine

Common water sample bottles for distribution systems.

Radiochems, VOCs, (Volatile Organic Compounds), TTHMs, Total Trihalomethanes), Nitrate, Nitrite.

Most of these sample bottles will come with the preservative already inside the bottle.

Some bottles will come with a separate preservative (acid) for the field preservation.

Slowly add the acid or other preservative to the water sample; not water to the acid or preservative.

Inorganic Chemicals

Contaminant	MCLG[1] (mg/L)[2]	MCL or TT[1] (mg/L)[2]	Potential Health Effects from Long-Term Exposure Above the MCL (unless specified as short-term)	Sources of Contaminant in Drinking Water
Antimony	0.006	0.006	Increase in blood cholesterol; decrease in blood sugar	Discharge from petroleum refineries; fire retardants; ceramics; electronics; solder
Arsenic	0[7]	0.010 as of 01/23/06	Skin damage or problems with circulatory systems, and may have increased risk of getting cancer	Erosion of natural deposits; runoff from orchards, runoff from glass & electronics production wastes
Asbestos (fiber >10 micrometers)	7 million fibers per liter	7 MFL	Increased risk of developing benign intestinal polyps	Decay of asbestos cement in water mains; erosion of natural deposits
Barium	2	2	Increase in blood pressure	Discharge of drilling wastes; discharge from metal refineries; erosion of natural deposits
Beryllium	0.004	0.004	Intestinal lesions	Discharge from metal refineries and coal-burning factories; discharge from electrical, aerospace, and defense industries
Cadmium	0.005	0.005	Kidney damage	Corrosion of galvanized pipes; erosion of natural deposits; discharge from metal refineries; runoff from waste batteries and paints
Chromium (total)	0.1	0.1	Allergic dermatitis	Discharge from steel and pulp mills; erosion of natural deposits
Copper	1.3	TT[7]; Action Level=1.3	Short term exposure: Gastrointestinal distress	Corrosion of household plumbing systems; erosion of natural deposits

Inorganic Chemicals

Contaminant	MCLG[1] (mg/L)[2]	MCL or TT[1] (mg/L)[2]	Potential Health Effects from Long-Term Exposure Above the MCL (unless specified as short-term)	Sources of Contaminant in Drinking Water
			Long term exposure: Liver or kidney damage People with Wilson's Disease should consult their personal doctor if the amount of copper in their water exceeds the action level	
Cyanide (as free cyanide)	0.2	0.2	Nerve damage or thyroid problems	Discharge from steel/metal factories; discharge from plastic and fertilizer factories
Fluoride	4.0	4.0	Bone disease (pain and tenderness of the bones); Children may get mottled teeth	Water additive which promotes strong teeth; erosion of natural deposits; discharge from fertilizer and aluminum factories
Lead	zero	TT[7]; Action Level=0.015	Infants and children: Delays in physical or mental development; children could show slight deficits in attention span and learning abilities Adults: Kidney problems; high blood pressure	Corrosion of household plumbing systems; erosion of natural deposits
Mercury (inorganic)	0.002	0.002	Kidney damage	Erosion of natural deposits; discharge from refineries and factories; runoff from landfills and croplands
Nitrate (measured as Nitrogen)	10	10	Infants below the age of six months who drink water containing nitrate in excess of the MCL could become seriously ill and, if untreated, may die. Symptoms include shortness of breath and blue-baby syndrome.	Runoff from fertilizer use; leaking from septic tanks, sewage; erosion of natural deposits

Inorganic Chemicals

Contaminant	MCLG[1] (mg/L)[2]	MCL or TT[1] (mg/L)[2]	Potential Health Effects from Long-Term Exposure Above the MCL (unless specified as short-term)	Sources of Contaminant in Drinking Water
Nitrite (measured as Nitrogen)	1	1	Infants below the age of six months who drink water containing nitrite in excess of the MCL could become seriously ill and, if untreated, may die. Symptoms include shortness of breath and blue-baby syndrome.	Runoff from fertilizer use; leaking from septic tanks, sewage; erosion of natural deposits
Selenium	0.05	0.05	Hair or fingernail loss; numbness in fingers or toes; circulatory problems	Discharge from petroleum refineries; erosion of natural deposits; discharge from mines
Thallium	0.0005	0.002	Hair loss; changes in blood; kidney, intestine, or liver problems	Leaching from ore-processing sites; discharge from electronics, glass, and drug factories

What are Inorganic Compounds?

Inorganic compounds are of inanimate, not biological origin. Inorganic compounds lack carbon and hydrogen atoms and are synthesized by the agency of geological systems. In contrast, the synthesis of organic compounds in biological systems incorporates carbohydrates into the molecular structure. Organic chemists traditionally refer to any molecule containing carbon as an organic compound and by default this means that inorganic chemistry deals with molecules lacking carbon. However, biologists may distinguish organic from inorganic compounds in a different way that does not hinge on the presence of a carbon atom.

Pools of organic matter, for example, that have been metabolically incorporated into living tissues persist in decomposing tissues, but as molecules become oxidized into the open environment, such as atmospheric CO_2, this creates a separate pool of inorganic compounds. The distinction between inorganic and organic compounds is not always clear when dealing with open and closed systems, because everything is ultimately connected to everything else on the planet. Some scientists, for example, view the open environment (i.e., the ecosphere) as an extension of life and from this perspective may consider atmospheric CO_2 as an organic compound. IUPAC, an agency widely recognized for defining chemical terms, does not offer definitions of inorganic or organic.

Inorganic compounds are rather simple chemicals present in ground water. These chemicals are generally described as mineral in nature and usually exist as ions (chemical substances with a positive or negative charge) when dissolved in water. Typical examples include sodium, iron, calcium, magnesium, manganese, nitrate, chloride, sulfate, and zinc. Many of these chemicals are naturally occurring minerals that are dissolved from the rock/soil which make up the aquifer or water-bearing rock formations below the soil surface.

However, some of these compounds may be introduced into ground water by human activities. Nitrate (an agricultural fertilizer) and sodium chloride (road salt) are two examples. Water purveyors need to test for 30 different inorganic compounds including all arsenic, barium, cadmium, lead, mercury, selenium, and thallium

- ✓ **Organic compounds** - these are once living, or are living and can bring life to cells. These contain carbon, and their electrons spin clockwise, just like those of the human body. Additionally, these cells can form an ionic bond with the body and can easily break down into materials to help with bodily function, such as tissue repair.
- ✓ **Inorganic compounds**- these were never living, without carbon and cannot bring life to cells. The body treats these metals like toxins and are tightly held together; they cannot be easily broken down. And, their electrons spin counterclockwise, out of sync with the rest of the body.

Drinking Water Standards

The US Environmental Protection Agency is responsible for establishing maximum contaminant levels for drinking water. These standards are expressed as MCL (Maximum Contaminant Level). In most cases, this measurement is expressed as milligrams per liter of water (mg/l) or as parts per million (ppm).

In general terms, inorganic compounds are those materials that do not contain carbon. These compounds are often able to be dissolved in water. For example, dissolved gases such as nitrogen, oxygen, radon, and methane can be classified as inorganic compounds.

In addition to dissolved gases, some metals may be present in water as well. Some of these metals can be hazardous to human health, and may be introduced into water either naturally or through man-made activities.

Some of the more common metals include arsenic and aluminum which the EPA has established a MCL of no more than.05. Lead with a MCL of.015. Mercury MCL of.002. In addition, zinc, calcium, sodium, magnesium, potassium, and copper, all with a 1.3 MCL.

Lead, mercury, and arsenic can be dangerous to human health even at low concentrations, and as mentioned above can be introduced to our water from a variety of sources, including old pipes and lead solder. Conversely, some of the other inorganic compounds such as sodium, potassium, calcium, and magnesium are important to our overall health and well-being.

Another class of inorganic compounds are known as negative ions. These include substances such as fluoride: MCL 4.0 PPM (parts per million). Chloride and nitrate: MCL 10.0 ppm. Nitrite MCL 1.0. Sulfate, phosphate, carbonate, and cyanide: MCL 0.2

Inorganic Chemistry

Inorganic chemistry is the study of the synthesis and behavior of inorganic and organometallic compounds. This field covers all chemical compounds except the myriad organic compounds (carbon based compounds, usually containing C-H bonds), which are the subjects of organic chemistry. The distinction between the two disciplines is far from absolute, and there is much overlap, most importantly in the sub-discipline of organometallic chemistry. It has applications in every aspect of the chemical industry–including catalysis, materials science, pigments, surfactants, coatings, medicine, fuel, and agriculture.

Key Concepts

Many inorganic compounds are ionic compounds, consisting of cations and anions joined by ionic bonding. Examples of salts (which are ionic compounds) are magnesium chloride $MgCl_2$, which consists of magnesium cations Mg^{2+} and chloride anions Cl^-; or sodium oxide Na_2O, which consists of sodium cations Na^+ and oxide anions O^{2-}.

In any salt, the proportions of the ions are such that the electric charges cancel out, so that the bulk compound is electrically neutral. The ions are described by their oxidation state and their ease of formation can be inferred from the ionization potential (for cations) or from the electron affinity (anions) of the parent elements.

Important classes of inorganic salts are the oxides, the carbonates, the sulfates and the halides. Many inorganic compounds are characterized by high melting points. Inorganic salts typically are poor conductors in the solid state. Another important feature is their solubility in water, e.g., and ease of crystallization. Where some salts (e.g., NaCl) are very soluble in water, others (e.g., SiO_2) are not.

The simplest inorganic reaction is double displacement when in mixing of two salts the ions are swapped without a change in oxidation state. In redox reactions one reactant, the *oxidant*, lowers its oxidation state and another reactant, the *reductant*, has its oxidation state increased. The net result is an exchange of electrons. Electron exchange can occur indirectly as well, e.g., in batteries, a key concept in electrochemistry.

When one reactant contains hydrogen atoms, a reaction can take place by exchanging protons in acid-base chemistry. In a more general definition, an acid can be any chemical species capable of binding to electron pairs is called a Lewis acid; conversely any molecule that tends to donate an electron pair is referred to as a Lewis base. As a refinement of acid-base interactions, the HSAB theory takes into account polarizability and size of ions.

Inorganic compounds are found in nature as minerals. Soil may contain iron sulfide as pyrite or calcium sulfate as gypsum. Inorganic compounds are also found multitasking as biomolecules: as electrolytes (sodium chloride), in energy storage (ATP) or in construction (the polyphosphate backbone in DNA).

The first important man-made inorganic compound was ammonium nitrate for soil fertilization through the Haber process. Inorganic compounds are synthesized for use as catalysts such as vanadium(V) oxide and titanium(III) chloride, or as reagents in organic chemistry such as lithium aluminum hydride.

Subdivisions of inorganic chemistry are organometallic chemistry, cluster chemistry and bioinorganic chemistry. These fields are active areas of research in inorganic chemistry, aimed toward new catalysts, superconductors, and therapies.

Industrial Inorganic Chemistry

Inorganic chemistry is a highly practical area of science. Traditionally, the scale of a nation's economy could be evaluated by their productivity of sulfuric acid. The top 20 inorganic chemicals manufactured in Canada, China, Europe, India, Japan, and the US (2005 data): aluminum sulfate, ammonia, ammonium nitrate, ammonium sulfate, carbon black, chlorine, hydrochloric acid, hydrogen, hydrogen peroxide, nitric acid, nitrogen, oxygen, phosphoric acid, sodium carbonate, sodium chlorate, sodium hydroxide, sodium silicate, sodium sulfate, sulfuric acid, and titanium dioxide. The manufacturing of fertilizers is another practical application of industrial inorganic chemistry.

Descriptive Inorganic Chemistry

Descriptive inorganic chemistry focuses on the classification of compounds based on their properties. Partly the classification focuses on the position in the periodic table of the heaviest element (the element with the highest atomic weight) in the compound, partly by grouping compounds by their structural similarities.

When studying inorganic compounds, one often encounters parts of the different classes of inorganic chemistry (an organometallic compound is characterized by its coordination chemistry, and may show interesting solid state properties).

Different Classifications are:

Coordination Compounds

Classical coordination compounds feature metals bound to "lone pairs" of electrons residing on the main group atoms of ligands such as H_2O, NH_3, Cl^-, and CN^-. In modern coordination compounds almost all organic and inorganic compounds can be used as ligands. The "metal" usually is a metal from the groups 3-13, as well as the *trans*-lanthanides and *trans*-actinides, but from a certain perspective, all chemical compounds can be described as coordination complexes.

The stereochemistry of coordination complexes can be quite rich, as hinted at by Werner's separation of two enantiomers of $[Co((OH)_2Co(NH_3)_4)_3]^{6+}$, an early demonstration that chirality is not inherent to organic compounds. A topical theme within this specialization is supramolecular coordination chemistry.

- **Examples:** $[Co(EDTA)]^-$, $[Co(NH_3)_6]^{3+}$, $TiCl_4(THF)_2$.

Main Group Compounds

These species feature elements from groups 1, 2 and 13-18 (excluding hydrogen) of the periodic table. Due to their often similar reactivity, the elements in group 3 (Sc, Y, and La) and group 12 (Zn, Cd, and Hg) are also generally included.

Main group compounds have been known since the beginnings of chemistry, e.g., elemental sulfur and the distillable white phosphorus. Experiments on oxygen, O_2, by Lavoisier and Priestley not only identified an important diatomic gas, but opened the way for describing compounds and reactions according to stoichiometric ratios. The discovery of a practical synthesis of ammonia using iron catalysts by Carl Bosch and Fritz Haber in the early 1900s deeply impacted mankind, demonstrating the significance of inorganic chemical synthesis.

Typical main group compounds are SiO_2, $SnCl_4$, and N_2O. Many main group compounds can also be classed as “organometallic”, as they contain organic groups, e.g., $B(CH_3)_3$). Main group compounds also occur in nature, e.g., phosphate in DNA, and therefore may be classed as bioinorganic. Conversely, organic compounds lacking (many) hydrogen ligands can be classed as “inorganic”, such as the fullerenes, buckytubes and binary carbon oxides.

- **Examples:** tetrasulfur tetranitride S_4N_4, diborane B_2H_6, silicones, buckminsterfullerene C_{60}.

Transition Metal Compounds

Compounds containing metals from group 4 to 11 are considered transition metal compounds. Compounds with a metal from group 3 or 12 are sometimes also incorporated into this group, but also often classified as main group compounds.

Transition metal compounds show a rich coordination chemistry, varying from tetrahedral for titanium (e.g., $TiCl_4$) to square planar for some nickel complexes to octahedral for coordination complexes of cobalt. A range of transition metals can be found in biologically important compounds, such as iron in hemoglobin.

- **Examples:** iron pentacarbonyl, titanium tetrachloride, cisplatin

Organometallic Compounds

Usually, organometallic compounds are considered to contain the M-C-H group. The metal (M) in these species can either be a main group element or a transition metal. Operationally, the definition of an organometallic compound is more relaxed to include also highly lipophilic complexes such as metal carbonyls and even metal alkoxides.

Organometallic compounds are mainly considered a special category because organic ligands are often sensitive to hydrolysis or oxidation, necessitating that organometallic chemistry employs more specialized preparative methods than was traditional in Werner-type complexes.

Synthetic methodology, especially the ability to manipulate complexes in solvents of low coordinating power, enabled the exploration of very weakly coordinating ligands such as hydrocarbons, H_2, and N_2. Because the ligands are petrochemicals in some sense, the area of organometallic chemistry has greatly benefited from its relevance to industry.

- **Examples:** Cyclopentadienyliron dicarbonyl dimer $(C_5H_5)Fe(CO)_2CH_3$, Ferrocene $Fe(C_5H_5)_2$, Molybdenum hexacarbonyl $Mo(CO)_6$, Diborane B_2H_6, Tetrakis(triphenylphosphine)palladium(0) $Pd[P(C_6H_5)_3]_4$

Cluster Compounds

Clusters can be found in all classes of chemical compounds. According to the commonly accepted definition, a cluster consists minimally of a triangular set of atoms that are directly bonded to each other. But metal-metal bonded dimetallic complexes are highly relevant to the area. Clusters occur in "pure" inorganic systems, organometallic chemistry, main group chemistry, and bioinorganic chemistry. The distinction between very large clusters and bulk solids is increasingly blurred. This interface is the chemical basis of nanoscience or nanotechnology and specifically arise from the study of quantum size effects in cadmium selenide clusters. Thus, large clusters can be described as an array of bound atoms intermediate in character between a molecule and a solid.

- **Examples:** $Fe_3(CO)_{12}$, $B_{10}H_{14}$, $[Mo_6Cl_{14}]^{2-}$, 4Fe-4S

Bioinorganic Compounds

By definition, these compounds occur in nature, but the subfield includes anthropogenic species, such as pollutants (e.g., methylmercury) and drugs (e.g., Cisplatin). The field, which incorporates many aspects of biochemistry, includes many kinds of compounds, e.g., the phosphates in DNA, and also metal complexes containing ligands that range from biological macromolecules, commonly peptides, to ill-defined species such as humic acid, and to water (e.g., coordinated to gadolinium complexes employed for MRI). Traditionally bioinorganic chemistry focuses on electron- and energy-transfer in proteins relevant to respiration. Medicinal inorganic chemistry includes the study of both non-essential and essential elements with applications to diagnosis and therapies.

- **Examples**: hemoglobin, methylmercury, carboxypeptidase

Solid State Compounds

This important area focuses on structure, bonding, and the physical properties of materials. In practice, solid state inorganic chemistry uses techniques such as crystallography to gain an understanding of the properties that result from collective interactions between the subunits of the solid. Included in solid state chemistry are metals and their alloys or intermetallic derivatives. Related fields are condensed matter physics, mineralogy, and materials science.

- **Examples:** silicon chips, zeolites, $YBa_2Cu_3O_7$

Theoretical Inorganic Chemistry

An alternative perspective on the area of inorganic chemistry begins with the Bohr model of the atom and, using the tools and models of theoretical chemistry and computational chemistry, expands into bonding in simple and then more complex molecules. Precise quantum mechanical descriptions for multielectron species, the province of inorganic chemistry, is difficult. This challenge has spawned many semi-quantitative or semi-empirical approaches including molecular orbital theory and ligand field theory, In parallel with these theoretical descriptions, approximate methodologies are employed, including density functional theory.

Exceptions to theories, qualitative and quantitative, are extremely important in the development of the field. For example, $Cu^{II}_2(OAc)_4(H_2O)_2$ is almost diamagnetic below room temperature whereas Crystal Field Theory predicts that the molecule would have two unpaired electrons. The disagreement between qualitative theory (paramagnetic) and observation (diamagnetic) led to the development of models for "magnetic coupling." These improved models led to the development of new magnetic materials and new technologies.

Qualitative Theories

Inorganic chemistry has greatly benefited from qualitative theories. Such theories are easier to learn as they require little background in quantum theory. Within main group compounds, VSEPR theory powerfully predicts, or at least rationalizes, the structures of main group compounds, such as an explanation for why NH_3 is pyramidal whereas ClF_3 is T-shaped. For the transition metals, crystal field theory allows one to understand the magnetism of many simple complexes, such as why $[Fe^{III}(CN)_6]^{3-}$ has only one unpaired electron, whereas $[Fe^{III}(H_2O)_6]^{3+}$ has five. A particularly powerful qualitative approach to assessing the structure and reactivity begins with classifying molecules according to electron counting, focusing on the numbers of valence electrons, usually at the central atom in a molecule.

Molecular Symmetry Group Theory

A central construct in inorganic chemistry is the theory of molecular symmetry. Mathematical group theory provides the language to describe the shapes of molecules according to their point group symmetry. Group theory also enables factoring and simplification of theoretical calculations.

Spectroscopic features are analyzed and described with respect to the symmetry properties of the, *inter alia*, vibrational or electronic states. Knowledge of the symmetry properties of the ground and excited states allows one to predict the numbers and intensities of absorptions in vibrational and electronic spectra. A classic application of group theory is the prediction of the number of C-O vibrations in substituted metal carbonyl complexes. The most common applications of symmetry to spectroscopy involve vibrational and electronic spectra. As an instructional tool, group theory highlights commonalities and differences in the bonding of otherwise disparate species, such as WF_6 and $Mo(CO)_6$ or CO_2 and NO_2.

Thermodynamics and Inorganic Chemistry

An alternative quantitative approach to inorganic chemistry focuses on energies of reactions. This approach is highly traditional and empirical, but it is also useful. Broad concepts that are couched in thermodynamic terms include redox potential, acidity, phase changes.

A classic concept in inorganic thermodynamics is the Born-Haber cycle, which is used for assessing the energies of elementary processes such as electron affinity, some of which cannot be observed directly.

Mechanistic Inorganic Chemistry

An important and increasingly popular aspect of inorganic chemistry focuses on reaction pathways. The mechanisms of reactions are discussed differently for different classes of compounds.

Main Group Elements and Lanthanides

The mechanisms of main group compounds of groups 13-18 are usually discussed in the context of organic chemistry (organic compounds are main group compounds, after all). Elements heavier than C, N, O, and F often form compounds with more electrons than predicted by the octet rule, as explained in the article on hypervalent molecules. The mechanisms of their reactions differ from organic compounds for this reason. Elements lighter than carbon (B, Be, Li) as well as Al and Mg often form electron-deficient structures that are electronically akin to carbocations. Such electron-deficient species tend to react via associative pathways. The chemistry of the lanthanides mirrors many aspects of chemistry seen for aluminum.

Transition Metal Complexes

Mechanisms for the reactions of transition metals are discussed differently from main group compounds. The important role of d-orbitals in bonding strongly influences the pathways and rates of ligand substitution and dissociation. These themes are covered in articles on coordination chemistry and ligand. Both associative and dissociative pathways are observed.

An overarching aspect of mechanistic transition metal chemistry is the kinetic lability of the complex illustrated by the exchange of free and bound water in the prototypical complexes $[M(H_2O)_6]^{n+}$:

$$[M(H_2O)_6]^{n+} + 6\ H_2O^* \rightarrow [M(H_2O^*)_6]^{n+} + 6\ H_2O$$

where H_2O^* denotes isotopically enriched water, e.g., $H_2{}^{17}O$

The rates of water exchange varies by 20 orders of magnitude across the periodic table, with lanthanide complexes at one extreme and Ir(III) species being the slowest.

Redox Reactions

Redox reactions are prevalent for the transition elements. Two classes of redox reaction are considered: atom-transfer reactions, such as oxidative addition/reductive elimination, and electron-transfer. A fundamental redox reaction is "self-exchange", which involves the degenerate reaction between an oxidant and a reductant. For example, permanganate and its one-electron reduced relative manganate exchange one electron:

$$[MnO_4]^- + [Mn^*O_4]^{2-} \rightarrow [MnO_4]^{2-} + [Mn^*O_4]^-$$

Reactions at Ligands

Coordinated ligands display reactivity distinct from the free ligands. For example, the acidity of the ammonia ligands in $[Co(NH_3)_6]^{3+}$ is elevated relative to NH_3 itself.

Alkenes bound to metal cations are reactive toward nucleophiles whereas alkenes normally are not. The large and industrially important area of catalysis hinges on the ability of metals to modify the reactivity of organic ligands. Homogeneous catalysis occurs in solution and heterogeneous catalysis occurs when gaseous or dissolved substrates interact with surfaces of solids.

Traditionally homogeneous catalysis is considered part of organometallic chemistry and heterogeneous catalysis is discussed in the context of surface science, a subfield of solid state chemistry. But the basic inorganic chemical principles are the same. Transition metals, almost uniquely, react with small molecules such as CO, H_2, O_2, and C_2H_4. The industrial significance of these feedstocks drives the active area of catalysis. Ligands can also undergo ligand transfer reactions such as transmetalation.

Characterization of Inorganic Compounds

Because of the diverse range of elements and the correspondingly diverse properties of the resulting derivatives, inorganic chemistry is closely associated with many methods of analysis. Older methods tended to examine bulk properties such as the electrical conductivity of solutions, melting points, solubility, and acidity. With the advent of quantum theory and the corresponding expansion of electronic apparatus, new tools have been introduced to probe the electronic properties of inorganic molecules and solids. Often these measurements provide insights relevant to theoretical models.

For example, measurements on the photoelectron spectrum of methane demonstrated that describing the bonding by the two-center, two-electron bonds predicted between the carbon and hydrogen using Valence Bond Theory is not appropriate for describing ionization processes in a simple way. Such insights led to the popularization of molecular orbital theory as fully delocalized orbitals are a more appropriate simple description of electron removal and electron excitation.

Commonly encountered techniques are:

- X-ray crystallography: This technique allows for the 3D determination of molecular structures.
- Dual polarization interferometer: This technique measures the conformation and conformational change of molecules.
- Various forms of spectroscopy
    - Ultraviolet-visible spectroscopy: Historically, this has been an important tool, since many inorganic compounds are strongly colored
    - NMR spectroscopy: Besides ^{1}H and ^{13}C many other "good" NMR nuclei (e.g., ^{11}B, ^{19}F, ^{31}P, and ^{195}Pt) give important information on compound properties and structure. Also the NMR of paramagnetic species can result in important structural information. Proton NMR is also important because the light hydrogen nucleus is not easily detected by X-ray crystallography.
    - Infrared spectroscopy: Mostly for absorptions from carbonyl ligands
    - Electron nuclear double resonance (ENDOR) spectroscopy

  - Mössbauer spectroscopy
  - Electron-spin resonance: ESR (or EPR) allows for the measurement of the environment of paramagnetic metal centers.
- Electrochemistry: Cyclic voltammetry and related techniques probe the redox characteristics of compounds.

Synthetic Inorganic Chemistry
Although some inorganic species can be obtained in pure form from nature, most are synthesized in chemical plants and in the laboratory.

Inorganic synthetic methods can be classified roughly according the volatility or solubility of the component reactants. Soluble inorganic compounds are prepared using methods of organic synthesis. For metal-containing compounds that are reactive toward air, Schlenk line and glove box techniques are followed. Volatile compounds and gases are manipulated in “vacuum manifolds” consisting of glass piping interconnected through valves, the entirety of which can be evacuated to 0.001 mm Hg or less. Compounds are condensed using liquid nitrogen (b.p. 78K) or other cryogens. Solids are typically prepared using tube furnaces, the reactants and products being sealed in containers, often made of fused silica (amorphous SiO_2) but sometimes more specialized materials such as welded Ta tubes or Pt “boats”. Products and reactants are transported between temperature zones to drive reactions.

Glossary

ABSENCE OF OXYGEN: The complete absence of oxygen in water described as Anaerobic.
ABSOLUTE ZERO: A theoretical condition concerning a system at zero Kelvin where a system does not emit or absorb energy (all atoms are at rest).
ACCURACY : How close a value is to the actual or true value; also see precision. How closely an instrument measures the true or actual value.
ACID AND BASE ARE MIXED: When an acid and a base are mixed, an explosive reaction occurs and decomposition products are created under certain conditions.
ACID ANHYDRIDE: A compound with two acyl groups bound to a single oxygen atom.
ACID DISSOCIATION CONSTANT : An equilibrium constant for the dissociation of a weak acid.
ACID RAIN: A result of airborne pollutants.
ACID: Slowly add the acid to water while stirring. An operator should not mix acid and water or acid to a strong base.
ACTINIDES: The fifteen chemical elements that are between actinium (89) and lawrencium (103).
ACTIVATED CARBON FILTRATION: Can remove organic chemicals that produce off-taste and odor. These compounds are not dangerous to health but can make the water unpleasant to drink. Carbon filtration comes in several forms, from small filters that attach to sink faucets to large tanks that contain removable cartridges. Activated carbon filters require regular maintenance or they can become a health hazard.
ACTIVATED CHARCOAL (GAC or PAC): Granular Activated Charcoal or Powered Activated Charcoal. Used for taste and odor removal. A treatment technique that is not included in the grading of a water facility.
ACTIVATED COMPLEX : A structure that forms because of a collision between molecules while new bonds are formed.
ACTIVATION ENERGY: The minimum energy that must be input to a chemical system.
ADDITION REACTION : Within organic chemistry, when two or more molecules combine to make a larger one.
ADSORPTION CLARIFIERS: The concept of the adsorption clarifier package plant was developed in the early 1980s. This technology uses an up-flow clarifier with low-density plastic bead media, usually held in place by a screen. This adsorption media is designed to enhance the sedimentation/clarification process by combining flocculation and sedimentation into one step. In this step, turbidity is reduced by adsorption of the coagulated and flocculated solids onto the adsorption media and onto the solids already adsorbed onto the media. Air scouring cleans adsorption clarifiers followed by water flushing. Cleaning of this type of clarifier is initiated more often than filter backwashing because the clarifier removes more solids. As with the tube-settler type of package plant, the sedimentation/ clarification process is followed by mixed-media filtration and disinfection to complete the water treatment.
ADSORPTION: Not to be confused with absorption. Adsorption is a process that occurs when a gas or liquid solute accumulates on the surface of a solid or a liquid (adsorbent), forming a film of molecules or atoms (the adsorbate). It is different from absorption, in which a substance diffuses into a liquid or solid to form a solution. The term sorption encompasses both processes, while desorption is the reverse process. Adsorption is present in many natural physical, biological, and chemical systems, and is widely used in industrial applications such as activated charcoal, synthetic resins, and water purification.

AERATION: The mixing of air into a liquid or solid.
AGGLOMERATION: A jumbled cluster or mass of varied parts. The act or process of agglomerating.
AIR ENTRAINMENT: The dissolution or inclusion of air bubbles into water.
AIR GAP SEPARATION: A physical separation space that is present between the discharge vessel and the receiving vessel; for an example, a kitchen faucet.
Air Hammer: A pneumatic cylindrical hammering device containing a piston used on air rotary rigs. The air hammer's heavy piston moves up and down by the introduction of compressed air creating a hammering action on the bit.
AIR HOOD: The most suitable protection when working with a chemical that produces dangerous fumes.
ALGAE: Microscopic plants that are free-living and usually live in water. They occur as single cells floating in water, or as multicellular plants like seaweed or strands of algae that attach to rocks.
ALKALI METALS : The metals of Group 1 on the periodic table.
ALKALINITY: Alkalinity or AT is a measure of the ability of a solution to neutralize acids to the equivalence point of carbonate or bicarbonate. Alkalinity is closely related to the acid neutralizing capacity (ANC) of a solution and ANC is often incorrectly used to refer to alkalinity. However, the acid neutralizing capacity refers to the combination of the solution and solids present (e.g., suspended matter, or aquifer solids), and the contribution of solids can dominate the ANC (see carbonate minerals below).
ALKANLINE EARTH METALS : The metals of Group 2 on the periodic table.
ALLOMER : A substance that has different composition than another, but has the same crystalline structure.
ALLOTROPY: Elements that can have different structures (and therefore different forms), such as Carbon (diamonds, graphite, and fullerene).
ALPHA AND BETA RADIOACTIVITY: Represent two common forms of radioactive decay. Radioactive elements have atomic nuclei so heavy that the nucleus will break apart, or disintegrate spontaneously. When decay occurs, high-energy particles are released. These high-energy particles are called radioactivity. Although radioactivity from refined radioactive elements can be dangerous, it is rare to find dangerous levels of radioactivity in natural waters. An alpha particle is a doubly-charged helium nucleus comprised of two protons, two neutrons, and no electrons. A beta particle is a high-speed electron. Alpha particles do not penetrate matter easily, and are stopped by a piece of paper. Beta particles are much more penetrating and can pass through a millimeter of lead.
ALTERNATIVE DISINFECTANTS: Disinfectants - other than chlorination (halogens) - used to treat water, e.g. ozone, ultraviolet radiation, chlorine dioxide, and chloramine. There is limited experience and scientific knowledge about the by-products and risks associated with the use of alternatives.
ALUMINUM SULFATE: The chemical name for Alum. The molecular formula of Alum is $Al2(SO4)3{\sim}14H2O$. It is a cationic polymer.
AMMONIA: A chemical made with Nitrogen and Hydrogen and used with chlorine to disinfect water.
AMMONIA: NH3 A chemical made with Nitrogen and Hydrogen and used with chlorine to disinfect water. Most ammonia in water is present as the ammonium ion rather than as ammonia.
AMMONIATOR: AA control device which meters gaseous ammonia directly into water under positive pressure.
ANAEROBIC CONDITIONS: When anaerobic conditions exist in either the metalimnion or hypolimnion of a stratified lake or reservoir, water quality problems may make the

water unappealing for domestic use without costly water treatment procedures. Most of these problems are associated with Reduction in the stratified waters.
ANAEROBIC: An abnormal condition in which color and odor problems are most likely to occur.
ANEROID: Using no fluid, as in aneroid barometer.
ANION: Negatively charge ions.
ANODE : The positive side of a dry cell battery or a cell.
AQUIFER PARAMETERS: Referring to such attributes as specific capacity, aquifer storage, transmissivity, hydraulic conductivity, gradient, and water levels. Refers to all of the components of Darcy's Law and related parameters.
AROMATICITY : Chemical property of conjugated rings that results in unusual stability. See also benzene.
AS NITROGEN: An expression that tells how the concentration of a chemical is expressed mathematically. The chemical formula for the nitrate ion is NO3 , with a mass of 62. The concentration of nitrate can be expressed either in terms of the nitrate ion or in terms of the principal element, nitrogen. The mass of the nitrogen atom is 14. The ratio of the nitrate ion mass to the nitrogen atom mass is 4.43. Thus a concentration of 10 mg/L nitrate expressed as nitrogen would be equivalent to a concentration of 44.3 mg/L nitrate expressed as nitrate ion. When dealing with nitrate numbers it is very important to know how numeric values are expressed.
As: The chemical symbol of Arsenic.
ASEPTIC: Free from the living germs of disease, fermentation, or putrefaction.
ASYNCHRONOUS: Not occurring at the same time.
ATOM: The general definition of an ion is an atom with a positive or negative charge. Electron is the name of a negatively charged atomic particle.
ATOMIC NUMBER : The number representing an element which corresponds with the number of protons within the nucleus.
ATOMIC ORBITAL : The region where the electron of the atom may be found.
AVOGADRO'S NUMBER : Is the number of particles in a mole of a substance (6.02x10^23).

B

BARITE: Processed barium sulfate, often used to increase drilling fluid densities in mud rotary.
BAROMETER: A device used to measure the pressure in the atmosphere.
BASE : A substance that accepts a proton and has a high pH; a common example is sodium hydroxide (NaOH).
Bentonite: High quality clay composed primarily of montmorillonite. Used to thicken drilling mud in mud rotary drilling and used to form seals in well construction or abandonment.
BEST AVAILABLE TECHNOLOGY ECONOMICALLY ACHIEVABLE (BAT): A level of technology based on the best existing control and treatment measures that are economically achievable within the given industrial category or subcategory.
BEST MANAGEMENT PRACTICES (BMPs): Schedules of activities, prohibitions of practices, maintenance procedures, and other management practices to prevent or reduce the pollution of waters of the U.S. BMPs also include treatment requirements, operating procedures and practices to control plant site runoff, spillage or leaks, sludge or waste disposal, or drainage from raw material storage.
BEST PRACTICABLE CONTROL TECHNOLOGY CURRENTLY AVAILABLE (BPT): A level of technology represented by the average of the best existing wastewater treatment performance levels within an industrial category or subcategory.

BEST PROFESSIONAL JUDGMENT (BPJ): The method used by a permit writer to develop technology-based limitations on a case-by-case basis using all reasonably available and relevant data.

BIOCHEMISTRY : The chemistry of organisms.

BOILING POINT : The temperature in which the substance starts to boil.

BOILING POINT ELEVATION: The process where the boiling point is elevated by adding a substance.

BOILING: The phase transition of liquid vaporizing.

BOND : The attraction and repulsion between atoms and molecules that is a cornerstone of chemistry.

BREAK POINT CHLORINATION: The process of chlorinating the water with significant quantities of chlorine to oxidize all contaminants and organic wastes and leave all remaining chlorine as free chlorine.

BROMINE: Chemical disinfectant (HALOGEN) that kills bacteria and algae. This chemical disinfectant has been used only on a very limited scale for water treatment because of its handling difficulties. This chemical causes skin burns on contact, and a residual is difficult to obtain.

BRONSTED-LOWREY ACID: A chemical species that donates a proton.

BRONSTED-LOWREY BASE : A chemical species that accepts a proton.

BUFFER: Chemical that resists pH change, e.g. sodium bicarbonate

BUFFERED SOLTION : An aqueous solution consisting of a weak acid and its conjugate base or a weak base and its conjugate acid that resists changes in pH when strong acids or bases are added.

BURETTE (also BURET) : Glassware used to dispense specific amounts of liquid when precision is necessary (e.g. titration and resource dependent reactions).

C

Ca: The chemical symbol for calcium.

CADMIUM: A contaminant that is usually not found naturally in water or in very small amounts.

CALCIUM HARDNESS: A measure of the calcium salts dissolved in water.

CALCIUM HARDNESS: A measure of the calcium salts dissolved in water.

CALCIUM ION: Is divalent because it has a valence of +2.

CALCIUM, MAGNESIUM AND IRON: The three elements that cause hardness in water.

CaOCl2.4H2O: The molecular formula of Calcium hypochlorite.

CARBON DIOXIDE GAS: The pH will decrease and alkalinity will change as measured by the Langelier index after pumping carbon dioxide gas into water.

CARBONATE HARDNESS: Carbonate hardness is the measure of Calcium and Magnesium and other hard ions associated with carbonate (CO32-) and bicarbonate (HCO3-) ions contained in a solution, usually water. It is usually expressed either as parts per million (ppm or mg/L), or in degrees (KH - from the German "Karbonathärte"). One German degree of carbonate hardness is equivalent to about 17.8575 mg/L. Both measurements (mg/L or KH) are usually expressed "as CaCO3" – meaning the amount of hardness expressed as if calcium carbonate was the sole source of hardness. Every bicarbonate ion only counts for half as much carbonate hardness as a carbonate ion does. If a solution contained 1 liter of water and 50 mg NaHCO3 (baking soda), it would have a carbonate hardness of about 18 mg/L as CaCO3. If you had a liter of water containing 50 mg of Na2CO3, it would have a carbonate hardness of about 29 mg/L as CaCO3.

CARBONATE ROCK: Rock that is composed primarily of calcium carbonate.

CARBONATE, BICARBONATE AND HYDROXIDE: Chemicals that are responsible for the alkalinity of water.
CATALYST : A chemical compound used to change the rate (either to speed up or slow down) of a reaction, but is regenerated at the end of the reaction.
CATHODIC PROTECTION: An operator should protect against corrosion of the anode and/or the cathode by painting the copper cathode. Cathodic protection interrupts corrosion by supplying an electrical current to overcome the corrosion-producing mechanism. Guards against stray current corrosion.
CATION : Positively charged ion.
CAUSTIC SODA: Also known as sodium hydroxide and is used to raise pH.
CAUSTIC: NaOH (also called Sodium Hydroxide) is a strong chemical used in the treatment process to neutralize acidity, increase alkalinity or raise the pH value.
CEILING AREA: The specific gravity of ammonia gas is 0.60. If released, this gas will accumulate first at the ceiling area. Cl2 gas will settle on the floor.
CELL POTENIAL : The force in a galvanic cell that pulls electron through reducing agent to oxidizing agent.
CENTRIFUGE: Equipment used to separate substances based on density by rotating the tubes around a centered axis
CESIUM (also Caesium): Symbol Cs- A soft, silvery-white ductile metal, liquid at room temperature, the most electropositive and alkaline of the elements, used in photoelectric cells and to catalyze hydrogenation of some organic compounds.
CHAIN OF CUSTODY (COC): A record of each person involved in the possession of a sample from the person who collects the sample to the person who analyzes the sample in the laboratory.
CHELATION: A chemical process used to control scale formation in which a chelating agent "captures" scale-causing ions and holds them in solution.
CHEMICAL FEED RATE: Chemicals are added to the water in order to improve the subsequent treatment processes. These may include pH adjusters and coagulants. Coagulants are chemicals, such as alum, that neutralize positive or negative charges on small particles, allowing them to stick together and form larger particles that are more easily removed by sedimentation (settling) or filtration. A variety of devices, such as baffles, static mixers, impellers and in-line sprays, can be used to mix the water and distribute the chemicals evenly.
CHEMICAL LAW: Certain rules that pertain to the laws of nature and chemistry.
CHEMICAL OXIDIZER: KMnO4 or Potassium Permanganate is used for taste and odor control because it is a strong oxidizer which eliminates many organic compounds.
CHEMICAL REACTION RATE: In general, when the temperature decreases, the chemical reaction rate also decreases. The opposite is true for when the temperature increases.
CHEMICAL REACTION: The change of one or more substances into another or multiple substances.
CHEMISORPTION: (or chemical adsorption) Is adsorption in which the forces involved are valence forces of the same kind as those operating in the formation of chemical compounds.
CHLORAMINATION: Treating drinking water by applying chlorine before or after ammonia. This creates a persistent disinfectant residual called chloramines.
CHLORAMINES: A group of chlorine ammonia compounds formed when chlorine combines with organic wastes in the water. Chloramines are not effective as disinfectants and are responsible for eye and skin irritation as well as strong chlorine odors.

CHLORINATION: The process in water treatment of adding chlorine (gas or solid hypochlorite) for purposes of disinfection.
CHLORINE DEMAND: Amount of chlorine required to react on various water impurities before a residual is obtained. Also, means the amount of chlorine required to produce a free chlorine residual of 0.1 mg/l after a contact time of fifteen minutes as measured by iodometric method of a sample at a temperature of twenty degrees in conformance with Standard methods.
CHLORINE FEED: Chlorine may be delivered by vacuum-controlled solution feed chlorinators. The chlorine gas is controlled, metered, introduced into a stream of injector water and then conducted as a solution to the point of application.
CHLORINE, FREE: Chlorine available to kill bacteria or algae. The amount of chlorine available for sanitization after the chlorine demand has been met. Also known as chlorine residual.
CHLORINE: A chemical used to disinfect water. Chlorine is extremely reactive, and when it comes in contact with microorganisms in water it kills them. Chlorine is added to swimming pools to keep the water safe for swimming. Chlorine is available as solid tablets for swimming pools. Some public water system's drinking water treatment plants use chlorine in a gas form because of the large volumes required. Chlorine is very effective against algae, bacteria and viruses. Protozoa are resistant to chlorine because they have thick coats; protozoa are removed from drinking water by filtration.
CHRONIC: A stimulus that lingers or continues for a relatively long period of time, often one-tenth of the life span or more. Chronic should be considered a relative term depending on the life span of an organism. The measurement of chronic effect can be reduced growth, reduced reproduction, etc., in addition to lethality.
ClO2: The molecular formula of Chlorine dioxide.
COAGULATION: The best pH range for coagulation is between 5 and 7. Mixing is an important part of the coagulation process you want to complete the coagulation process as quickly as possible.
COLLIOD : Mixture of evenly dispersed substances, such as many milks.
COLLOIDAL SUSPENSIONS: Because both iron and manganese react with dissolved oxygen to form insoluble compounds, they are not found in high concentrations in waters containing dissolved oxygen except as colloidal suspensions of the oxide.
COLORIMETRIC MEASUREMENT: A means of measuring an unknown chemical concentration in water by measuring a sample's color intensity.
COMBINED CHLORINE: The reaction product of chlorine with ammonia or other pollutants, also known as chloramines.
COMBUSTION : An exothermic reaction between an oxidant and fuel with heat and often light
COMMUNITY WATER SYSTEM: A water system which supplies drinking water to 25 or more of the same people year-round in their residences.
COMPLETION (WELL COMPLETION): Refers to the final construction of the well including the installation of pumping equipment.
COMPLIANCE CYCLE: A 9-calendar year time-frame during which a public water system is required to monitor. Each compliance cycle consists of 3 compliance periods.
COMPLIANCE PERIOD: A 3-calendar year time-frame within a compliance cycle.
COMPOSITE SAMPLE: A water sample that is a combination of a group of samples collected at various intervals during the day.
COMPOUND : A substance that is made up of two or more chemically bonded elements.
CONDENSATION : The phase change from gas to liquid. The process that changes water vapor to tiny droplets or ice crystals.
CONDUCTOR : Material that allows electric flow more freely.

CONTACT TIME, pH and LOW TURBIDITY: Factors which are important in providing good disinfection using chlorine.
CONTACT TIME: If the water temperature decreases from 70°F (21°C) to 40°F (4°C). The operator needs to increase the detention time to maintain good disinfection of the water.
CONTAINS THE ELEMENT CARBON: A simple definition of an organic compound.
CONTAMINANT: Any natural or man-made physical, chemical, biological, or radiological substance or matter in water, which is at a level that may have an adverse effect on public health, and which is known or anticipated to occur in public water systems.
CONTAMINATE: 1. To make impure or unclean by contact or mixture. 2. To expose to or permeate with radioactivity.
CONTAMINATION: A degradation in the quality of groundwater in result of the it's becoming polluted with unnatural or previously non-existent constituents.
Control algae and slime growth, Control mud ball formation, Improve coagulation, Precipate iron. The addition of chlorine to the water prior to any other plant treatment processes.
CONTROL TASTE AND ODOR PROBLEMS: $KMnO_4$ Potassium permanganate is a strong oxidizer commonly used to control taste and odor problems.
COPPER: The chemical name for the symbol Cu.
CORROSION: The removal of metal from copper, other metal surfaces and concrete surfaces in a destructive manner. Corrosion is caused by improperly balanced water or excessive water velocity through piping or heat exchangers.
CORROSIVITY: The Langelier Index measures corrosivity.
COVALENT BOND : Chemical bond that involves sharing electrons.
CRYSTAL : A solid that is packed with ions, molecules or atoms in an orderly fashion.
CUVETTE : Glassware used in spectroscopic experiments. It is usually made of plastic, glass or quartz and should be as clean and clear as possible.
CYANURIC ACID: White, crystalline, water-soluble solid, $C_3H_3O_3N_3 \cdot 2H_2O$, used chiefly in organic synthesis. Chemical used to prevent the decomposition of chlorine by ultraviolet (UV) light.

D
DAILY MAXIMUM LIMITATIONS: The maximum allowable discharge of pollutants during a 24 hour period. Where daily maximum limitations are expressed in units of mass, the daily discharge is the total mass discharged over the course of the day. Where daily maximum limitations are expressed in terms of a concentration, the daily discharge is the arithmetic average measurement of the pollutant concentration derived from all measurements taken that day.
DANGEROUS CHEMICALS: The most suitable protection when working with a chemical that produces dangerous fumes is to work under an air hood or fume hood.
DARCY'S LAW: (Q=KIA) A fundamental equation used in the groundwater sciences to determine aquifer characteristics, where Q=Flux, K=Hydraulic Conductivity (Permeability), I = Hydraulic Gradient (change in head), and A = Cross Sectional Area of flow.
DECIBELS: The unit of measurement for sound.
DECOMPOSE: To decay or rot.
DECOMPOSITION OF ORGANIC MATERIAL: The decomposition of organic material in water produces taste and odors.
DEIONIZATION : The removal of ions, and in water's case mineral ions such as sodium, iron and calcium.

DELIQUESCENE : Substances that absorb water from the atmosphere to form liquid solutions.
DEMINERALIZATION PROCESS: Mineral concentration of the feed water is the most important consideration in the selection of a demineralization process. Acid feed is the most common method of scale control in a membrane demineralization treatment system.
DENTAL CARIES PREVENTION IN CHILDREN: The main reason that fluoride is added to a water supply.
DEPOLARIZATION: The removal of hydrogen from a cathode.
DEPOSITION : Settling of particles within a solution or mixture.
DESICCANT: When shutting down equipment which may be damaged by moisture, the unit may be protected by sealing it in a tight container. This container should contain a desiccant.
DESORPTION: Desorption is a phenomenon whereby a substance is released from or through a surface. The process is the opposite of sorption (that is, adsorption and absorption). This occurs in a system being in the state of sorption equilibrium between bulk phase (fluid, i.e. gas or liquid solution) and an adsorbing surface (solid or boundary separating two fluids). When the concentration (or pressure) of substance in the bulk phase is lowered, some of the sorbed substance changes to the bulk state. In chemistry, especially chromatography, desorption is the ability for a chemical to move with the mobile phase. The more a chemical desorbs, the less likely it will adsorb, thus instead of sticking to the stationary phase, the chemical moves up with the solvent front. In chemical separation processes, stripping is also referred to as desorption as one component of a liquid stream moves by mass transfer into a vapor phase through the liquid-vapor interface.
DETENTION LAG TIME: The minimum detention time range recommended for flocculation is 5 – 20 minutes for direct filtration and up to 30 minutes for conventional filtration.
DETENTION LAG: Is the period of time between the moment of change in a chlorinator control system and the moment when the change is sensed by the chlorine residual indicator.
DEVELOPMENT: The cleaning of the well and bore once construction is complete.
DIATOMACEOUS EARTH: A fine silica material containing the skeletal remains of algae.
DIPOLE : Electric or magnetic separation of charge.
DIPOLE MOMENT : The polarity of a polar covalent bond.
DIRECT CURRENT: A source of direct current (DC) may be used for standby lighting in a water treatment facility. The electrical current used in a DC system may come from a battery.
DISINFECT: The application of a chemical to kill most, but not all, microorganisms that may be present. Chlorine is added to public water drinking systems drinking water for disinfection. Depending on your state rule, drinking water must contain a minimum of 0.2 mg/L free chlorine. Disinfection makes drinking water safe to consume from the standpoint of killing pathogenic microorganisms including bacteria and viruses. Disinfection does not remove all bacteria from drinking water, but the bacteria that can survive disinfection with chlorine are not pathogenic bacteria that can cause disease in normal healthy humans.
DISINFECTION BY-PRODUCTS (DBPs): The products created due to the reaction of chlorine with organic materials (e.g. leaves, soil) present in raw water during the water treatment process. The EPA has determined that these DBPs can cause cancer. Chlorine is added to drinking water to kill or inactivate harmful organisms that cause

various diseases. This process is called disinfection. However, chlorine is a very active substance and it reacts with naturally occurring substances to form compounds known as disinfection byproducts (DBPs). The most common DBPs formed when chlorine is used are trihalomethanes (THMs), and haloacetic acids (HAAs).
DISINFECTION: The treatment of water to inactivate, destroy, and/or remove pathogenic bacteria, viruses, protozoa, and other parasites.
DISSOLUTION or SOLVATION : The spread of ions in a monosacharide.
DISSOLVED OXYGEN: Can be added to zones within a lake or reservoir that would normally become anaerobic during periods of thermal stratification.
DISTILLATION, REVERSE OSMOSIS AND FREEZING: Processes that can be used to remove minerals from the water.
DOUBLE BOND : Sharing of two pairs of electradodes.
DRY ACID: A granular chemical used to lower pH and or total alkalinity.

E

E. COLI, Escherichia coli: A bacterium commonly found in the human intestine. For water quality analyses purposes, it is considered an indicator organism. These are considered evidence of water contamination. Indicator organisms may be accompanied by pathogens, but do not necessarily cause disease themselves.
EARTH METAL : See alkaline earth metal.
EFFECTIVENESS OF CHLORINE: The factors which influence the effectiveness of chlorination the most are pH, turbidity and temperature. Effectiveness of Chlorine decreases occurs during disinfection in source water with excessive turbidity.
ELECTRIC CHARGE: A measured property (coulombs) that determine electromagnetic interaction
ELECTROCHEMICAL CELL: Using a chemical reaction's current, electromotive force is made
ELECTROLYTE: A solution that conducts a certain amount of current and can be split categorically as weak and strong electrolytes.
ELECTROMAGNETIC RADIATION: A type of wave that can go through vacuums as well as material and classified as a self-propagating wave.
ELECTROMAGNETISM : Fields that have electric charge and electric properties that change the way that particles move and interact.
ELECTROMOTIVE FORCE : A device that gains energy as electric charges pass through it.
ELECTRON : A subatomic particle with a net charge that is negative.
ELECTRON SHELLS: An orbital around the atom's nucleus that has a fixed number electrons (usually two or eight).
ELECTRON: The name of a negatively charged atomic particle.
ELEMENT : An atom that is defined by its atomic number.
ELEMENTARY BUSINESS PLAN: Technical Capacity, Managerial Capacity, and Financial Capacity make up the elementary business plan. To become a new public water system, an owner shall file an elementary business plan for review and approval by state environmental agency.
EMERGENCY RESPONSE TEAM: A local team that is thoroughly trained and equipped to deal with emergencies, e.g. chlorine gas leak. In case of a chlorine gas leak, get out of the area and notify your local emergency response team in case of a large uncontrolled chlorine leak.
EMPOROCAL FORMULA : Also called the simplest formula, gives the simplest whole :number ratio of atoms of each element present in a compound.
ENERGY : A system's ability to do work.

ENHANCED COAGULATION: The process of joining together particles in water to help remove organic matter.
ENTHALPY: Measure of the total energy of a thermodynamic system (usually symbolized as *H*).
ENTROPY: The amount of energy not available for work in a closed thermodynamic system (usually symbolized as *S*).
ENZYME : A protein that speeds up (catalyzes) a reaction.
EPPENDORF TUBE : Generalized and trademarked term used for a type of tube; see microcentrifuge.

F

F: The chemical symbol of Fluorine.
FARADAY CONSTANT : A unit of electrical charge widely used in electrochemistry and equal to ~ 96,500 coulombs. It represents 1 mol of electrons, or the Avogadro number of electrons: 6.022×10^{23} electrons. F = 96 485.339 9(24) C/mol.
FARADAY'S LAW OF ELECTROLYSIS: A two part law that Michael Faraday published about electrolysis. The mass of a substance altered at an electrode during electrolysis is directly proportional to the quantity of electricity transferred at that electrode. The mass of an elemental material altered at an electrode is directly proportional to the element's equivalent weight.
FAUCET WITH AN AERATOR: When collecting a water sample from a distribution system, a faucet with an aerator should not be used as a sample location.
FECAL COLIFORM: A group of bacteria that may indicate the presence of human or animal fecal matter in water. Total coliform, fecal coliform, and E. coli are all indicators of drinking water quality. The total coliform group is a large collection of different kinds of bacteria. Fecal coliforms are types of total coliform that mostly exist in feces. E. coli is a sub-group of fecal coliform. When a water sample is sent to a lab, it is tested for total coliform. If total coliform is present, the sample will also be tested for either fecal coliform or E. coli, depending on the lab testing method.
FILTER CLOGGING: An inability to meet demand may occur when filters are clogging.
FILTRATION METHODS: The conventional type of water treatment filtration method includes coagulation, flocculation, sedimentation, and filtration. Direct filtration method is similar to conventional except that the sedimentation step is omitted. Slow sand filtration process does not require pretreatment, has a flow of 0.1 gallons per minute per square foot of filter surface area, and is simple to operate and maintain. The Diatomaceous earth method uses a thin layer of fine siliceous material on a porous plate. This type of filtration medium is only used for water with low turbidity. Sedimentation, adsorption, and biological action treatment methods are filtration processes that involve a number of interrelated removal mechanisms. Demineralization is primarily used to remove total dissolved solids from industrial wastewater, municipal water, and seawater.
FILTRATION: The process of passing water through materials with very small holes to strain out particles. Most conventional water treatment plants used filters composed of gravel, sand, and anthracite. These materials settle into a compact mass that forms very small holes. Particles are filtered out as treated water passes through these holes. These holes are small enough to remove microorganisms including algae, bacteria, and protozoans, but not viruses. Viruses are eliminated from drinking water through the process of disinfection using chlorine. A series of processes that physically removes particles from water. A water treatment step used to remove turbidity, dissolved organics, odor, taste and color.
FINISHED WATER: Treated drinking water that meets minimum state and federal drinking water regulations.

FLOC SHEARING: Likely to happen to large floc particles when they reach the flocculation process.

FLOCCULANTS: Flocculants, or flocculating agents, are chemicals that promote flocculation by causing colloids and other suspended particles in liquids to aggregate, forming a floc. Flocculants are used in water treatment processes to improve the sedimentation or filterability of small particles. For example, a flocculant may be used in swimming pool or drinking water filtration to aid removal of microscopic particles which would otherwise cause the water to be cloudy and which would be difficult or impossible to remove by filtration alone. Many flocculants are multivalent cations such as aluminum, iron, calcium or magnesium. These positively charged molecules interact with negatively charged particles and molecules to reduce the barriers to aggregation. In addition, many of these chemicals, under appropriate pH and other conditions such as temperature and salinity, react with water to form insoluble hydroxides which, upon precipitating, link together to form long chains or meshes, physically trapping small particles into the larger floc. Long-chain polymer flocculants, such as modified polyacrylamides, are manufactured and sold by the flocculant producing business. These can be supplied in dry or liquid form for use in the flocculation process. The most common liquid polyacrylamide is supplied as an emulsion with 10-40 % actives and the rest is a carrier fluid, surfactants and latex. Emulsion polymers require activation to invert the emulsion and allow the electrolyte groups to be exposed.

FLOCCULATION BASIN: A compartmentalized basin with a reduction of speed in each compartment. This set-up or basin will give the best overall results.

FLOCCULATION: The process of bringing together destabilized or coagulated particles to form larger masses that can be settled and/or filtered out of the water being treated. Conventional coagulation–flocculation-sedimentation practices are essential pretreatments for many water purification systems—especially filtration treatments. These processes agglomerate suspended solids together into larger bodies so that physical filtration processes can more easily remove them. Particulate removal by these methods makes later filtering processes far more effective. The process is often followed by gravity separation (sedimentation or flotation) and is always followed by filtration. A chemical coagulant, such as iron salts, aluminum salts, or polymers, is added to source water to facilitate bonding among particulates. Coagulants work by creating a chemical reaction and eliminating the negative charges that cause particles to repel each other. The coagulant-source water mixture is then slowly stirred in a process known as flocculation. This water churning induces particles to collide and clump together into larger and more easily removable clots, or “flocs.” The process requires chemical knowledge of source water characteristics to ensure that an effective coagulant mix is employed. Improper coagulants make these treatment methods ineffective. The ultimate effectiveness of coagulation/flocculation is also determined by the efficiency of the filtering process with which it is paired.

FLOOD RIM: The point of an object where the water would run over the edge of something and begin to cause a flood.

FLOW MUST BE MEASURED: A recorder that measures flow is most likely to be located in a central location.

FLUORIDE FEEDING: Always review fluoride feeding system designs and specifications to determine whether locations for monitoring readouts and dosage controls are convenient to the operation center and easy to read and correct.

FLUORIDE: High levels of fluoride may stain the teeth of humans. This is called Mottling. This chemical must not be overfed due to a possible exposure to a high concentration of the chemical. The most important safety considerations to know about fluoride chemicals are that all fluoride chemicals are extremely corrosive. These are the substances most

commonly used to furnish fluoride ions to water: Sodium fluoride, Sodium silicofluoride and Hydrofluosilicic acid.
FLUX: The term flux describes the rate of water flow through a semipermeable membrane. When the water flux decreases through a semipermeable membrane, it means that the mineral concentration of the water is increasing.
FORMATION OF TUBERCLES: This condition is of the most concern regarding corrosive water effects on a water system. It is the creation of mounds of rust inside the water lines.
FREE CHLORINE RESIDUAL: Regardless of whether pre-chloration is practiced or not, a free chlorine residual of at least 10 mg/L should be maintained in the clear well or distribution reservoir immediately downstream from the point of post-chlorination. The reason for chlorinating past the breakpoint is to provide protection in case of backflow.
FREE CHLORINE: In disinfection, chlorine is used in the form of free chlorine or as hypochlorite ion.
FREEZING : Phase transition from liquid to solid.
FREQUENCY: Number of cycles per unit of time. Unit: 1 hertz = 1 cycle per 1 second.

G
GALVANIC CELL : Battery made up of electrochemical with two different metals connected by salt bridge.
GAS : Particles that fill their container though have no definite shape or volume.
GEOCHEMISTRY: The chemistry of and chemical composition of the Earth.
GIBBS ENERGY : Value that indicates the spontaneity of a reaction (usually symbolized as G).
GOOD CONTACT TIME, pH and LOW TURBIDITY: These are factors that are important in providing good disinfection when using chlorine.
GPM: Gallons per minute.
GRAB SAMPLE: A sample which is taken from a water or wastestream on a one-time basis with no regard to the flow of the water or wastestream and without consideration of time. A single grab sample should be taken over a period of time not to exceed 15 minutes.
GT: Represents (Detention time) x (mixing intensity) in flocculation.

H
H2SO4: The molecular formula of Sulfuric acid.
HALIDES: A halide is a binary compound, of which one part is a halogen atom and the other part is an element or radical that is less electronegative than the halogen, to make a fluoride, chloride, bromide, iodide, or astatide compound. Many salts are halides. All Group 1 metals form halides with the halogens and they are white solids. A halide ion is a halogen atom bearing a negative charge. The halide anions are fluoride (F), chloride (Cl), bromide (Br), iodide (I) and astatide (At). Such ions are present in all ionic halide salts.
HALL EFFECT: Refers to the potential difference (Hall voltage) on the opposite sides of an electrical conductor through which an electric current is flowing, created by a magnetic field applied perpendicular to the current. Edwin Hall discovered this effect in 1879.
HALOACETIC ACIDS: Haloacetic acids are carboxylic acids in which a halogen atom takes the place of a hydrogen atom in acetic acid. Thus, in a monohaloacetic acid, a single halogen would replace a hydrogen atom. For example, chloroacetic acid would have the structural formula CH2ClCO2H. In the same manner, in dichloroacetic acid two chlorine atoms would take the place of two hydrogen atoms (CHCl2CO2H).

HALOGENS : Group 7 on the Periodic Table and are all non-metals.
HARD WATER: Hard water causes a buildup of scale in household hot water heaters. Hard water is a type of water that has high mineral content (in contrast with soft water). Hard water primarily consists of calcium ($Ca2+$), and magnesium ($Mg2+$) metal cations, and sometimes other dissolved compounds such as bicarbonates and sulfates. Calcium usually enters the water as either calcium carbonate ($CaCO3$), in the form of limestone and chalk, or calcium sulfate ($CaSO4$), in the form of other mineral deposits. The predominant source of magnesium is dolomite ($CaMg(CO3)2$). Hard water is generally not harmful. The simplest way to determine the hardness of water is the lather/froth test: soap or toothpaste, when agitated, lathers easily in soft water but not in hard water. More exact measurements of hardness can be obtained through a wet titration. The total water 'hardness' (including both $Ca2+$ and $Mg2+$ ions) is read as parts per million or weight/volume (mg/L) of calcium carbonate ($CaCO3$) in the water. Although water hardness usually only measures the total concentrations of calcium and magnesium (the two most prevalent, divalent metal ions), iron, aluminum, and manganese may also be present at elevated levels in some geographical locations.
HARDNESS: A measure of the amount of calcium and magnesium salts in water. More calcium and magnesium lead to greater hardness. The term "hardness" comes from the fact that it is hard to get soap suds from soap or detergents in hard water. This happens because calcium and magnesium react strongly with negatively-charged chemicals like soap to form insoluble compounds.
HARTSHORN: The antler of a hart, formerly used as a source of ammonia. Ammonium carbonate.
HAZARDS OF POLYMERS: Slippery and difficult to clean-up are the most common hazards associated with the use of polymers in a water treatment plant.
HEAD: The measure of the pressure of water expressed in feet of height of water. 1 PSI = 2.31 feet of water or 1 foot of head equals about a half a pound of pressure or .433 PSI. There are various types of heads of water depending upon what is being measured. Static (water at rest) and Residual (water at flow conditions).
HEADWORKS: The facility at the "head" of the water source where water is first treated and routed into the distribution system.
HEALTH ADVISORY: An EPA document that provides guidance and information on contaminants that can affect human health and that may occur in drinking water, but which the EPA does not currently regulate in drinking water.
HEAT : Energy transferred from one system to another by thermal interaction.
HERTZ: The term used to describe the frequency of cycles in an alternating current (AC) circuit.
HF: The molecular formula of Hydrofluoric acid.
HIGH TURBIDITY CAUSING INCREASED CHLORINE DEMAND: May occur or be caused by the inadequate disinfection of water.
HOMOPOLAR: Of uniform polarity; not separated or changed into ions; not polar in activity. Electricity. unipolar.
HYDRIDES: Hydride is the name given to the negative ion of hydrogen, H. Although this ion does not exist except in extraordinary conditions, the term hydride is widely applied to describe compounds of hydrogen with other elements, particularly those of groups 1–16. The variety of compounds formed by hydrogen is vast, arguably greater than that of any other element. Various metal hydrides are currently being studied for use as a means of hydrogen storage in fuel cell-powered electric cars and batteries. They also have important uses in organic chemistry as powerful reducing agents, and many promising uses in hydrogen economy.

HYDROCHLORIC AND HYPOCHLOROUS ACIDS: HCL and HOCL The compounds that are formed in water when chlorine gas is introduced.
HYDROFLUOSILICIC ACID: (H_2SiF_6) a clear, fuming corrosive liquid with a pH ranging from 1 to 1.5. Used in water treatment to fluoridate drinking water.
HYDROGEN SULFIDE OR CHLORINE GAS: These chemicals can cause olfactory fatigue.
Hydrologic Cycle: (Water Cycle) The continual process of precipitation (rain and snowfall), evaporation (primarily from the oceans), peculation (recharge to groundwater), runoff (surface water), and transpiration (plants) constituting the renew ability and recycling of each component.
HYDROPHOBIC: Does not mix readily with water.
HYGROSCOPIC: Absorbing or attracting moisture from the air.
HYPOCHLORITE (OCL-) AND ORGANIC MATERIALS: Heat and possibly fire may occur when hypochlorite is brought into contact with an organic material.
HYPOLIMNION: The layer of water in a thermally stratified lake that lies below the thermocline, is noncirculating, and remains perpetually cold.

I
IMPELLERS: The semi-open or closed props or blades of a turbine pump that when rotated generate the pumping force.
IMPERVIOUS: Not allowing, or allowing only with great difficulty, the movement of water.
INDICATOR : A special compound added to solution that changes color depending on the acidity of the solution; different indicators have different colors and effective pH ranges.
INFECTIOUS PATHOGENS/MICROBES/GERMS: Are considered disease-producing bacteria, viruses and other microorganisms.
INFORMATION COLLECTION RULE: ICR EPA collected data required by the Information Collection Rule (May 14, 1996) to support future regulation of microbial contaminants, disinfectants, and disinfection byproducts. The rule was intended to provide EPA with information on chemical byproducts that form when disinfectants used for microbial control react with chemicals already present in source water (disinfection byproducts (DBPs)); disease-causing microorganisms (pathogens), including Cryptosporidium; and engineering data to control these contaminants.
INITIAL MONITORING YEAR: An initial monitoring year is the calendar year designated by the Department within a compliance period in which a public water system conducts initial monitoring at a point of entry.
INORGANIC CHEMISTRY: A part of chemistry concerned with inorganic compounds.
INORGANIC COMPUND: Compounds that do not contain carbon, though there are exceptions.
INORGANIC CONTAMINANTS: Mineral-based compounds such as metals, nitrates, and asbestos. These contaminants are naturally-occurring in some water, but can also get into water through farming, chemical manufacturing, and other human activities. EPA has set legal limits on 15 inorganic contaminants.
INORGANIC IONS: Present in all waters. Inorganic ions are essential for human health in small quantities, but in larger quantities they can cause unpleasant taste and odor or even illness. Most community water systems will commonly test for the concentrations of seven inorganic ions: nitrate, nitrite, fluoride, phosphate, sulfate, chloride, and bromide. Nitrate and nitrite can cause an illness in infants called methemoglobinemia. Fluoride is actually added to the drinking water in some public water systems to promote dental health. Phosphate, sulfate, chloride, and bromide have little direct effect on health, but high concentrations of inorganic ions can give water a salty or briny taste.

INSOLUBLE COMPOUNDS: Are types of compounds cannot be dissolved. When iron or manganese reacts with dissolved oxygen (DO) insoluble compound are formed.
INSULATOR: Material that resists the flow of electric current.
INTAKE FACILITIES: One of the more important considerations in the construction of intake facilities is the ease of operation and maintenance over the expected lifetime of the facility. Every intake structure must be constructed with consideration for operator safety and for cathodic protection.
ION : A molecule that has gained or lost one or more electrons.
ION EXCHANGE: An effective treatment process used to remove iron and manganese in a water supply. The hardness of the source water affects the amount of water an ion exchange softener may treat before the bed requires regeneration.
IONIC BOND: Electrostatic attraction between oppositely charged ions.
IONIZATION :The breaking up of a compound into separate ions.
IRON AND MANGANESE: Fe and Mn In water they can usually be detected by observing the color of the inside walls of filters and the filter media. If the raw water is pre-chlorinated, there will be black stains on the walls below the water level and a black coating over the top portion of the sand filter bed. When significant levels of dissolved oxygen are present, iron and manganese exist in an oxidized state and normally precipitate into the reservoir bottom sediments. The presence of iron and manganese in water promote the growth of Iron bacteria. Only when a water sample has been acidified then you can perform the analysis beyond the 48 hour holding time. Iron and Manganese in water may be detected by observing the color of the of the filter media. Maintaining a free chlorine residual and regular flushing of water mains may control the growth of iron bacteria in a water distribution system.
IRON BACTERIA: Perhaps the most troublesome consequence of iron and manganese in the water is they promote the growth of a group of microorganism known as Iron Bacteria.
IRON FOULING: You should look for an orange color on the resin and backwash water when checking an ion exchange unit for iron fouling
IRON: Fe The elements iron and manganese are undesirable in water because they cause stains and promote the growth of iron bacteria.
IUPAC: International Union of Pure and Applied Chemistry

J
JODIUM: Latin name of the halogen element iodine.
JOULE:: The SI unit of energy, defined as a newton-meter.

K
KILL = C X T: Where other factors are constant, the disinfecting action may be represented by: Kill=C x T. C= Chlorine T= Contact time.
KINETIC ENERGY : The energy of an object due to its motion.
KINETIC ENERGY: The ability of an object to do work by virtue of its motion. The energy terms that are used to describe the operation of a pump are pressure and head.
KINETICS : A sub-field of chemistry specializing in reaction rates.

L

L.O.T.O.: Lock Out, Tag Out. If a piece of equipment is locked out, the key to the lock-out device the key should be held by the person who is working on the equipment. The tag is an identification device and the lock is a physical restraint.

LACRIMATION: The secretion of tears, esp. in abnormal abundance Also, lachrymation, lacrimation.

LANGELIER INDEX: A measurement of Corrosivity. The water is becoming corrosive in the distribution system causing rusty water if the Langelier index indicates that the pH has decreased from the equilibrium point. Mathematically derived factor obtained from the values of calcium hardness, total alkalinity, and pH at a given temperature. A Langelier index of zero indicates perfect water balance (i.e., neither corroding nor scaling). The Langelier Saturation Index (sometimes Langelier Stability Index) is a calculated number used to predict the calcium carbonate stability of water. It indicates whether the water will precipitate, dissolve, or be in equilibrium with calcium carbonate. Langelier developed a method for predicting the pH at which water is saturated in calcium carbonate (called pHs). The LSI is expressed as the difference between the actual system pH and the saturation pH.

LANTHANIDES : Elements 57 through 71.

LATTICE : Unique arrangement of atoms or molecules in a crystalline liquid or solid.

LAW OF MOTION :A object in motion stay in motion an object in rest stays in rest unless an unbalanced force acts on it.

LEACHING: A chemical reaction between water and metals that allows for removal of soluble materials.

LEAD AND COPPER: Initial tap water monitoring for lead and copper must be conducted during 2 consecutive 6-month periods.

LIGHT : Portion of the electromagnetic spectrum which is visible to the naked eye. Also called "visible light."

LIME SODA SOFTENING: In a lime soda softening process, to the pH of the water is raised to 11.0. In a lime softening process, excess lime is frequently added to remove Calcium and Magnesium Bicarbonate. The minimum hardness which can be achieved by the lime-soda ash process is 30 to 40 mg/L as calcium carbonate. The hardness due to noncarbonate hardness is most likely to determine the choice between lime softening and ion exchange to remove hardness.

LIME SOFTENING: Lime softening is primarily used to “soften” water—that is to remove calcium and magnesium mineral salts. But it also removes harmful toxins like radon and arsenic. Though there is no consensus, some studies have even suggested that lime softening is effective at removal of Giardia. Hard water is a common condition responsible for numerous problems. Users often recognize hard water because it prevents their soap from lathering properly. However, it can also cause buildup (“scale”) in hot water heaters, boilers, and hot water pipes. Because of these inconveniences, many treatment facilities use lime softening to soften hard water for consumer use. Before lime softening can be used, managers must determine the softening chemistry required. This is a relatively easy task for groundwater sources, which remain more constant in their composition. Surface waters, however, fluctuate widely in quality and may require frequent changes to the softening chemical mix. In lime softening, lime and sometimes sodium carbonate are added to the water as it enters a combination solids contact clarifier. This raises the pH (i.e., increases alkalinity) and leads to the precipitation of calcium carbonate. Later, the pH of the effluent from the clarifier is reduced again, and the water is then filtered through a granular media filter. The water chemistry requirements of these systems require knowledgeable operators, which may make lime softening an economic challenge for some very small systems.

LIME: Is a chemical that may be added to water to reduce the corrosivity. When an operator adds lime to water, Calcium and magnesium become less soluble.
LIQUID : A state of matter which takes the shape of its container.
LONDON DISERSION FORCES : A weak intermolecular force.
LSI = pH – pHs.

M
M.S.D.S.: Material Safety Data Sheet, now S.D.S. (Safety Data Sheet). A safety document must an employer provide to an operator upon request.
MAGNESIUM HARDNESS: Measure of the magnesium salts dissolved in water – it is not a factor in water balance.
MARBLE AND LANGELIER TESTS: Are used to measure or determine the corrosiveness of a water source.
MAXIMUM CONTAMINANT LEVEL (MCLs): The maximum allowable level of a contaminant that federal or state regulations allow in a public water system. If the MCL is exceeded, the water system must treat the water so that it meets the MCL.
MAXIMUM CONTAMINANT LEVEL GOAL (MCLG): The level of a contaminant at which there would be no risk to human health. This goal is not always economically or technologically feasible, and the goal is not legally enforceable.
MCL for TURBIDITY: Turbidity is undesirable because it causes health hazards. An MCL for turbidity was established by the EPA because turbidity does not allow for proper disinfection.
MEASURE CORROSION DAMAGE: A coupon such as a strip of metal and is placed to measure corrosion damage in the distribution system in a water main.
MEDIUM WATER SYSTEM: More than 3,300 persons and 50,000 or fewer persons.
MELTING : The phase change from a solid to a liquid.
M-ENDO BROTH: The coliform group is used as indicators of fecal pollution in water, for assessing the effectiveness of water treatment and disinfection, and for monitoring water quality. m-Endo Broth is used for selectively isolating coliform bacteria from water and other specimens using the membrane filtration technique. m-Endo Broth is prepared according to the formula of Fifield and Schaufus.1 It is recommended by the American Public Health Association in standard total coliform membrane filtration procedure for testing water, wastewater, and foods.2,3 The US EPA specifies using m-Endo Broth in the total coliform methods for testing water using single-step, two-step, and delayed incubation membrane filtration methods.
M-ENDO BROTH: The media shall be brought to the boiling point when preparing M-Endo broth to be used in the membrane filter test for total coliform.
METAL: Chemical element that is a good conductor of both electricity and heat and forms cations and ionic bonds with non-metals.
METALIMNION: Thermocline, middle layer of a thermally stratified lake which is characterized by a rapid decrease in temperature in proportion to depth.
METALLOID : A substance possessing both the properties of metals and non-metals.
METALLOID: Metalloid is a term used in chemistry when classifying the chemical elements. On the basis of their general physical and chemical properties, nearly every element in the periodic table can be termed either a metal or a nonmetal. A few elements with intermediate properties are, however, referred to as metalloids. (In Greek metallon = metal and eidos = sort)
METHANE: Methane is a chemical compound with the molecular formula CH_4. It is the simplest alkane, and the principal component of natural gas. Methane's bond angles are 109.5 degrees. Burning methane in the presence of oxygen produces carbon dioxide and water. The relative abundance of methane and its clean burning process makes it a

very attractive fuel. However, because it is a gas at normal temperature and pressure, methane is difficult to transport from its source. In its natural gas form, it is generally transported in bulk by pipeline or LNG carriers; few countries still transport it by truck.

METHLENE BLUE : A heterocyclic aromatic chemical compound with the molecular formula $C_{16}H_{18}N_3SCl$.

Mg/L: Stands for "milligrams per liter." A common unit of chemical concentration. It expresses the mass of a chemical that is present in a given volume of water. A milligram (one one-thousandth of a gram) is equivalent to about 18 grains of table salt. A liter is equivalent to about one quart.

MICROBE OR MICROBIAL: Any minute, simple, single-celled form of life, especially one that causes disease.

MICROBIAL CONTAMINANTS: Microscopic organisms present in untreated water that can cause waterborne diseases.

MICROBIOLOGICAL: Is a type of analysis in which a composite sample unacceptable.

MICROCENTRIFUGE : A small plastic container that is used to store small amounts of liquid.

MICROORGANISMS: Very small animals and plants that are too small to be seen by the naked eye and must be observed using a microscope. Microorganisms in water include algae, bacteria, viruses, and protozoa. Algae growing in surface waters can cause off-taste and odor by producing the chemicals MIB and geosmin. Certain types of bacteria, viruses, and protozoa can cause disease in humans. Bacteria are the most common microorganisms found in treated drinking water. The great majority of bacteria are not harmful. In fact, humans would not be able to live without the bacteria that inhabit the intestines. However, certain types of bacteria called coliform bacteria can signal the presence of possible drinking water contamination.

MILLILITER: One one-thousandth of a liter. A liter is a little more than a quart. A milliliter is about two drops from an eye dropper.

MILLILITER: One one-thousandth of a liter; A liter is a little more than a quart. A milliliter is about two drops from an eye dropper.

MOISTURE AND POTASSIUM PERMANGANATE: The combination of moisture and potassium permanganate produces heat.

MOISTURE: If a material is hygroscopic, it must it be protected from water.

MOLE : Abbreviated mol : a measurement of an amount of substance; a single mole contains approximately 6.022×10^{23} units or entities .A mole of water contains 6.022×10^{23} H_2O molecules.

MOLECULAR ORBITAL : Region where an electron can be found in a molecule (as opposed to an atom).

MOLECULAR WEIGHT: The molecular mass (abbreviated Mr) of a substance, formerly also called molecular weight and abbreviated as MW, is the mass of one molecule of that substance, relative to the unified atomic mass unit u (equal to 1/12 the mass of one atom of carbon-12). This is distinct from the relative molecular mass of a molecule, which is the ratio of the mass of that molecule to 1/12 of the mass of carbon 12 and is a dimensionless number. Relative molecular mass is abbreviated to Mr.

MOLECULE : A chemically bonded number of atoms that are electrically neutral.

MOTTLING: High levels of fluoride may stain the teeth of humans.

MURIATIC ACID: An acid used to reduce pH and alkalinity. Also used to remove stain and scale.

MYCOTOXIN: A toxin produced by a fungus.

N

NaOCl: Is the molecular formula of Sodium hypochlorite.

NaOH: Is the molecular formula of Sodium hydroxide.

NASCENT: Coming into existence; emerging.

NEAT : Conditions with a liquid reagent or gas performed with no added solvent or co-solvent.

NEUTRINO : A particle that can travel at speeds close to the speed of light and are created as a result of radioactive decay.

NEUTRON : A neutral unit or subatomic particle that has no net charge.

NH3: The molecular formula of Ammonia.

NH4+: The molecular formula of the Ammonium ion.

NITRATES: A dissolved form of nitrogen found in fertilizers and sewage by-products that may leach into groundwater and other water sources. Nitrates may also occur naturally in some waters. Over time, nitrates can accumulate in aquifers and contaminate groundwater.

NITROGEN AND PHOSPHORUS: Pairs of elements and major plant nutrients that cause algae to grow.

NITROGEN: Nitrogen is a nonmetal, with an electronegativity of 3.0. It has five electrons in its outer shell and is therefore trivalent in most compounds. The triple bond in molecular nitrogen (N2) is one of the strongest in nature. The resulting difficulty of converting (N2) into other compounds, and the ease (and associated high energy release) of converting nitrogen compounds into elemental N2, have dominated the role of nitrogen in both nature and human economic activities.

NO3-: The molecular formula of the Nitrate ion.

NOBLE GASES : Group 18 elements, those whose outer electron shell is filled.

NON-CARBONATE HARDNESS: The portion of the total hardness in excess of the alkalinity.

NON-CARBONATE IONS: Water contains non-carbonate ions if it cannot be softened to a desired level through the use of lime only.

NON-METAL : An element which is not metallic.

NON-POINT SOURCE POLLUTION: Air pollution may leave contaminants on highway surfaces. This non-point source pollution adversely impacts reservoir water and groundwater quality.

NON-TRANSIENT, NON-COMMUNITY WATER SYSTEM: A water system which supplies water to 25 or more of the same people at least six months per year in places other than their residences. Some examples are schools, factories, office buildings, and hospitals which have their own water systems.

NORMALITY: It is the number of equivalent weights of solute per liter of solution. Normality highlights the chemical nature of salts: in solution, salts dissociate into distinct reactive species (ions such as H+, Fe3+, or Cl-). Normality accounts for any discrepancy between the concentrations of the various ionic species in a solution. For example, in a salt such as MgCl2, there are two moles of Cl- for every mole of Mg2+, so the concentration of Cl- as well as of Mg2+ is said to be 2 N (read: "two normal"). Further examples are given below. A normal is one gram equivalent of a solute per liter of solution. The definition of a gram equivalent varies depending on the type of chemical reaction that is discussed - it can refer to acids, bases, redox species, and ions that will precipitate. It is critical to note that normality measures a single ion which takes part in an overall solute. For example, one could determine the normality of hydroxide or sodium in an aqueous solution of sodium hydroxide, but the normality of sodium hydroxide itself has no meaning. Nevertheless it is often used to describe solutions of acids or bases, in those cases it is implied that the normality refers to the H+ or OH- ion.

For example, 2 Normal sulfuric acid (H_2SO_4), means that the normality of H^+ ions is 2, or that the molarity of the sulfuric acid is 1. Similarly for 1 Molar H_3PO_4 the normality is 3 as it contains three H^+ ions.
NTNCWS: Non-transient non-community water system.
NTU (Nephelometric turbidity unit): A measure of the clarity or cloudiness of water.
NUCLEAR MAGNETIC RESONANCE SPECTROSCOPY: Technique that exploits the magnetic properties of certain nuclei, useful for identifying unknown compounds.
NUCLEAR: Of or pertaining to the atomic nucleus.
NUCLEUS : The center of an atom made up of neutrons and protons, with a net positive charge.
NUMBER DENSITY: A measure of concentration of countable objects (atoms, molecules, etc.) in space; number per volume.

O

O_3: The molecular formula of ozone.
OLIGOTROPHIC: A reservoir that is nutrient-poor and contains little plant or animal life. An oligotrophic ecosystem or environment is one that offers little to sustain life. The term is commonly utilized to describe bodies of water or soils with very low nutrient levels. It derives etymologically from the Greek oligo (small, little, few) and trophe (nutrients, food). Oligotrophic environments are of special interest for the alternative energy sources and survival strategies upon which life could rely.
ORBITAL : May refer to either an atomic orbital or a molecular orbital.
ORGANIC CHEMISTRY : A part of chemistry concerned with organic compounds.
ORGANIC COMPOUND : Compounds that contain carbon.
ORGANIC PRECURSORS: Natural or man-made compounds with chemical structures based upon carbon that, upon combination with chlorine, leading to trihalomethane formation.
OSMOSIS: Osmosis is the process by which water moves across a semi permeable membrane from a low concentration solute to a high concentration solute to satisfy the pressure differences caused by the solute.
OXIDE: An oxide is a chemical compound containing at least one oxygen atom as well as at least one other element. Most of the Earth's crust consists of oxides. Oxides result when elements are oxidized by oxygen in air. Combustion of hydrocarbons affords the two principal oxides of carbon, carbon monoxide and carbon dioxide. Even materials that are considered to be pure elements often contain a coating of oxides. For example, aluminum foil has a thin skin of Al_2O_3 that protects the foil from further corrosion.
OXIDIZED:
OXIDIZING: The process of breaking down organic wastes into simpler elemental forms or by products. Also used to separate combined chlorine and convert it into free chlorine.
OXYGEN DEFICIENT ENVIRONMENT: One of the most dangerous threats to an operator upon entering a manhole.
OZONE DOES NOT PROVIDE A RESIDUAL: One of the major drawbacks to using ozone as a disinfectant.
OZONE, CHLORINE DIOXIDE, UV, CHLORAMINES: These chemicals may be used as alternative disinfectants.
OZONE: Ozone or trioxygen (O_3) is a triatomic molecule, consisting of three oxygen atoms. It is an allotrope of oxygen that is much less stable than the diatomic O_2. Ground-level ozone is an air pollutant with harmful effects on the respiratory systems of animals. Ozone in the upper atmosphere filters potentially damaging ultraviolet light from reaching the Earth's surface. It is present in low concentrations throughout the Earth's atmosphere. It has many industrial and consumer applications. Ozone, the first allotrope

of a chemical element to be recognized by science, was proposed as a distinct chemical compound by Christian Friedrich Schönbein in 1840, who named it after the Greek word for smell (ozein), from the peculiar odor in lightning storms. The formula for ozone, O_3, was not determined until 1865 by Jacques-Louis Soret and confirmed by Schönbein in 1867. Ozone is a powerful oxidizing agent, far better than dioxygen. It is also unstable at high concentrations, decaying to ordinary diatomic oxygen (in about half an hour in atmospheric conditions):$2\ O_3 = 3\ O_2$.

PAC: A disadvantage of using PAC is it is very abrasive and requires careful maintenance of equipment. One precaution that should be taken in storing PAC is that bags of carbon should not be stored near bags of HTH. Removes tastes and odors by adsorption only. Powered activated carbon frequently used for taste and odor control because PAC is non-specific and removes a broad range of compounds. Jar tests and threshold odor number testing determines the application rate for powdered activated carbon. Powdered activated carbon, or PAC, commonly used for in a water treatment plant for taste and odor control. Powdered activated carbon may be used with some success in removing the precursors of THMs

PATHOGENS: Disease-causing pathogens; waterborne pathogens A pathogen may contaminate water and cause waterborne disease.

P

Pb: The chemical symbol of Lead.

PCE: Perchloroethylene. Known also as perc or tetrachloroethylene, perchloroethylene is a clear, colorless liquid with a distinctive, somewhat ether-like odor. It is non-flammable, having no measurable flashpoint or flammable limits in air. Effective over a wide range of applications, perchloroethylene is supported by closed loop transfer systems, stabilizers and employee exposure monitoring.

pCi/L: Picocuries per liter A curie is the amount of radiation released by a set amount of a certain compound. A picocurie is one quadrillionth of a curie.

PERKINESIS: The aggregation resulting from random thermal motion of fluid molecules.

PERMEATE: The term for water which has passed through the membrane of a reverse osmosis unit.

pH OF SATURATION: The ideal pH for perfect water balance in relation to a particular total alkalinity level and a particular calcium hardness level, at a particular temperature. The pH where the Langelier Index equals zero.

pH: A unit of measure which describes the degree of acidity or alkalinity of a solution. The pH scale runs from 0 to 14 with 7 being the mid-point or neutral. A pH of less than 7 is on the acid side of the scale with 0 as the point of greatest acid activity. A pH of more than 7 is on the basic (alkaline) side of the scale with 14 as the point of greatest basic activity. The term pH is derived from "p", the mathematical symbol of the negative logarithm, and "H", the chemical symbol of Hydrogen. The definition of pH is the negative logarithm of the Hydrogen ion activity. $pH=-\log[H^+]$.

PHENOL RED: Chemical reagent used for testing pH in the range of 6.8 - 8.4.

PHENOLPHTHALEIN/TOTAL ALKALINITY: The relationship between the alkalinity constituent's bicarbonate, carbonate, and hydroxide can be based on the P and T alkalinity measurement.

PHOSPHATE, NITRATE AND ORGANIC NITROGEN: Nutrients in a domestic water supply reservoir may cause water quality problems if they occur in moderate or large quantities.

PHOTON: A carrier of electromagnetic radiation of all wavelength (such as gamma rays and radio waves).

PHYSISORPTION: (Or physical adsorption) Is adsorption in which the forces involved are intermolecular forces (van der Waals forces) of the same kind as those responsible for the imperfection of real gases and the condensation of vapors, and which do not involve a significant change in the electronic orbital patterns of the species involved. The term van der Waals adsorption is synonymous with physical adsorption, but its use is not recommended.
PICOCURIE: A unit of radioactivity. "Pico" is a metric prefix that means one one-millionth of one one-millionth. A picocurie is one one-millionth of one one-millionth of a Curie. A Curie is that quantity of any radioactive substance that undergoes 37 billion nuclear disintegrations per second. Thus a picocurie is that quantity of any radioactive substance that undergoes 0.037 nuclear disintegrations per second.
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PITLESS ADAPTER: A fitting installed on a section of column pipe and well casing permitting piping from the well to be installed below grade. (Often requires a special permit for construction)
PLANKTON: The aggregate of passively floating, drifting, or somewhat motile organisms occurring in a body of water, primarily comprising microscopic algae and protozoa.
PLASMA : State of matter similar to gas in which a certain portion of the particles are ionized.
POINT OF ENTRY: POE.
POLLUTION: To make something unclean or impure. See Contaminated.
POLYMER: A type of chemical when combined with other types of coagulants aid in binding small suspended particles to larger particles to help in the settling and filtering processes.
POLYPHOSPHATES: Chemicals that may be added to remove low levels of iron and manganese.
POST-CHLORINE: Where the water is chlorinated to make sure it holds a residual in the distribution system.
POTABLE: Good water which is safe for drinking or cooking purposes. Non-Potable: A liquid or water that is not approved for drinking.
POTENTIAL ENERGY: Energy stored in a body or in a system due to its position in a force field or due to its configuration.
POTENTIAL ENERGY: The energy that a body has by virtue of its position or state enabling it to do work.
Potentiometric surface: An imaginary surface representing the height a column of water will reach at any location within a confined aquifer. The measured surface of a confined aquifer related to the aquifer’s pressure head.
PPM: Abbreviation for parts per million.
PRE-CHLORINATION: The addition of chlorine before the filtration process will help:
PRE-CHLORINE: Where the raw water is dosed with a large concentration of chlorine.
PRESIPATATE : Formation of a solid in a solution or inside another solid during a chemical reaction or by diffusion in a solid.
PRESISION : How close the results of multiple experimental trials are. See also accuracy.
PREVENTION: To take action; stop something before it happens.
PROTON : A positive unit or subatomic particle that has a positive charge.

PROTON, NEUTRON AND ELECTRON: Are the 3 fundamental particles of an atom.
PROTONATION : The addition of a proton (H^+) to an atom, molecule, or ion.
PUBLIC NOTIFICATION: An advisory that EPA requires a water system to distribute to affected consumers when the system has violated MCLs or other regulations. The notice advises consumers what precautions, if any, they should take to protect their health.
PUBLIC WATER SYSTEM (PWS): Any water system which provides water to at least 25 people for at least 60 days annually. There are more than 170,000 PWSs providing water from wells, rivers and other sources to about 250 million Americans. The others drink water from private wells. There are differing standards for PWSs of different sizes and types.
PWS: 3 types of public water systems. Community water system, non-transient non-community water system, transient non-community water system.

Q
QUANTA: It is the minimum amount of bundle of energy.
QUANTUM MECHANICS : The study of how atoms, molecules, subatomic particles, etc. behave and are structured.
QUARKS : Elementary particle and a fundamental constituent of matter.

R
RADIATION : Energy in the form of waves or subatomic particles when there is a change from high energy to low energy states.
RADIOACTIVE DECAY : The process of an unstable atomic nucleus losing energy by emitting radiation.
RADIOCHEMICALS: (Or radioactive chemicals) Occur in natural waters. Naturally radioactive ores are particularly common in the Southwestern United States, and some streams and wells can have dangerously high levels of radioactivity. Total alpha and beta radioactivity and isotopes of radium and strontium are the major tests performed for radiochemicals. The federal drinking water standard for gross alpha radioactivity is set at 5 picocuries per liter.
RAW TURBIDITY: The turbidity of the water coming to the treatment plant from the raw water source.
RAW WATER: Water that has not been treated in any way; it is generally considered to be unsafe to drink.
REAGENT: A substance used in a chemical reaction to measure, detect, examine, or produce other substances.
RECHARGE: The infiltration component of the hydrologic cycle. Often used in the context of referring to: The infiltration of water back into an aquifer, resulting in the restoration of lost storage and water levels which had been decreased due to pumping and/or natural discharges from the aquifer.
RECORDER, FLOW: A flow recorder that measures flow is most likely to be located anywhere in the plant where a flow must be measured and in a central location.
RED WATER AND SLIME: Iron bacteria are undesirable in a water distribution system because of red water and slime complaints.
REDOX POTENTIAL: Reduction potential (also known as redox potential, oxidation / reduction potential or ORP) is the tendency of a chemical species to acquire electrons and thereby be reduced. Each species has its own intrinsic reduction potential; the more positive the potential, the greater the species' affinity for electrons and tendency to be reduced. In aqueous solutions, the reduction potential is the tendency of the solution to either gain or lose electrons when it is subject to change by introduction of a new species. A solution with a higher (more positive) reduction potential than the new

species will have a tendency to gain electrons from the new species (i.e. to be reduced by oxidizing the new species) and a solution with a lower (more negative) reduction potential will have a tendency to lose electrons to the new species (i.e. to be oxidized by reducing the new species).
RELAY LOGIC: The name of a popular method of automatically controlling a pump, valve, chemical feeder, and other devices.
RESERVOIR: An impoundment used to store water.
RESIDUAL DISINFECTION PROTECTION: A required level of disinfectant that remains in treated water to ensure disinfection protection and prevent recontamination throughout the distribution system (i.e., pipes).
REVERSE OSMOSIS: Forces water through membranes that contain holes so small that even salts cannot pass through. Reverse osmosis removes microorganisms, organic chemicals, and inorganic chemicals, producing very pure water. For some people, drinking highly purified water exclusively can upset the natural balance of salts in the body. Reverse osmosis units require regular maintenance or they can become a health hazard.
ROTAMETER: The name of transparent tube with a tapered bore containing a ball is often used to measure the rate of flow of a gas or liquid.

S
S- BLOCK ELEMENTS : Group 1 and 2 elements (alkali and alkaline metals), which includes Hydrogen and Helium.
S.T.P.: Standard temperature and pressure standard temperature and pressure the temperature of 0°C and pressure of 1 atmosphere, usually taken as the conditions when stating properties of gases.
SALINE SOLUTION : General term for NaCl in water.
SALT BRIDGE : Devices used to connection reduction with oxidation half-cells in an electrochemical cell.
SALTS : Ionic compounds composed of anions and cations.
SALTS ARE ABSENT: Is a strange characteristic that is unique to water vapor in the atmosphere.
SAMPLE: The water that is analyzed for the presence of EPA-regulated drinking water contaminants. Depending on the regulation, EPA requires water systems and states to take samples from source water, from water leaving the treatment facility, or from the taps of selected consumers.
SAMPLING LOCATION: A location where soil or cuttings samples may be readily and accurately collected.
SANITARY SURVEY: Persons trained in public health engineering and the epidemiology of waterborne diseases should conduct the sanitary survey. The importance of a detailed sanitary survey of a new water source cannot be overemphasized. An on-site review of the water sources, facilities, equipment, operation, and maintenance of a public water systems for the purpose of evaluating the adequacy of the facilities for producing and distributing safe drinking water. The purpose of a non-regulatory sanitary survey is to identify possible biological and chemical pollutants which might affect a water supply.
SANITIZER: A disinfectant or chemical which disinfects (kills bacteria), kills algae and oxidizes organic matter.
SATURATION INDEX: See Langelier's Index.
SATURATOR: A device which produces a fluoride solution for the fluoride process. Crystal-grade types of sodium fluoride should be fed with a saturator. Overfeeding must be prevented to protect public health when using a fluoridation system.

SCALE: Crust of calcium carbonate, the result of unbalanced water. Hard insoluble minerals deposited (usually calcium bicarbonate) which forms on pool and spa surfaces and clog filters, heaters and pumps. Scale is caused by high calcium hardness and/or high pH. The regular use of stain prevention chemicals can prevent scale.
SCHMUTZDECKE: German, "grime or filth cover", sometimes spelt schmutzedecke) is a complex biological layer formed on the surface of a slow sand filter. The schmutzdecke is the layer that provides the effective purification in potable water treatment, the underlying sand providing the support medium for this biological treatment layer. The composition of any particular schmutzdecke varies, but will typically consist of a gelatinous biofilm matrix of bacteria, fungi, protozoa, rotifera and a range of aquatic insect larvae. As a schmutzdecke ages, more algae tend to develop, and larger aquatic organisms may be present including some bryozoa, snails and annelid worms.
SCHRODINGER EQUATION: Quantum state equation which represents the behavior of an election around an atom.
SCROLL AND BASKET: The two basic types of centrifuges used in water treatment.
SECONDARY DRINKING WATER STANDARDS: Non-enforceable federal guidelines regarding cosmetic effects (such as tooth or skin discoloration) or aesthetic effects (such as taste, odor, or color) of drinking water.
SEDIMENTATION BASIN: Where the thickest and greatest concentration of sludge will be found. Twice a year sedimentation tanks should be drained and cleaned if the sludge buildup interferes with the treatment process.
SEDIMENTATION: The process of suspended solid particles settling out (going to the bottom of the vessel) in water.
SEMICONDUCTOR : An electrically conductive solid that is between a conductor and an insulator.
SHOCK: Also known as superchlorination or break point chlorination. Ridding a water of organic waste through oxidization by the addition of significant quantities of a halogen.
SHORT-CIRCUITING: Short Circuiting is a condition that occurs in tanks or basins when some of the water travels faster than the rest of the flowing water. This is usually undesirable since it may result in shorter contact, reaction or settling times in comparison with the presumed detention times.
SINGLE BOND: Sharing of one pair of electrons.
SINUSOID: A curve described by the equation $y = a \sin x$, the ordinate being proportional to the sine of the abscissa.
SINUSOIDAL: Mathematics. Of or pertaining to a sinusoid. Having a magnitude that varies as the sine of an independent variable: a sinusoidal current.
SLUDGE BASINS: After cleaning sludge basins and before returning the tanks into service the tanks should be inspected, repaired if necessary, and disinfected.
SLUDGE REDUCTION: Organic polymers are used to reduce the quantity of sludge. If a plant produces a large volume of sludge, the sludge could be dewatered, thickened, or conditioned to decrease the volume of sludge. Turbidity of source water, dosage, and type of coagulant used are the most important factors which determine the amount of sludge produced in a treatment of water.
Slurry: A mixture of crushed rock and water.
SMALL WATER SYSTEM: 3,300 or fewer persons.
SOC: Synthetic organic chemical. A common way for a synthetic organic chemical such as dioxin to be introduced to a surface water supply is from an industrial discharge, agricultural drainage, or a spill.
SODA ASH: Chemical used to raise pH and total alkalinity (sodium carbonate)
SODIUM BICARBONATE: Commonly used to increase alkalinity of water and stabilize pH.

SODIUM BISULFATE: Chemical used to lower pH and total alkalinity (dry acid).
SODIUM HYDROXIDE: Also known as caustic soda, a by-product chlorine generation and often used to raise pH.
SOFTENING WATER: When the water has a low alkalinity it is advantageous to use soda ash instead of caustic soda for softening water.
SOFTENING: The process that removes the ions which cause hardness in water.
SOL : A suspension of solid particles in liquid. Artificial examples include sol-gels.
SOLAR DRYING BEDS OR LAGOONS: Are shallow, small-volume storage pond where sludge is concentrated and stored for an extended periods.
SOLAR DRYING BEDS, CENTRIFUGES AND FILTER PRESSES: Are procedures used in the dewatering of sludge.
SOLID : One of the states of matter, where the molecules are packed close together, there is a resistance of movement/deformation and volume change; see Young's modulus.
SOLID, LIQUID AND VAPOR: 3 forms of matter.
SOLUTE: The part of the solution that is mixed into the solvent (NaCl in saline water).
SOLUTION : Homogeneous mixture made up of multiple substances. It is made up of solutes and solvents.
SOLVENT : The part of the solution that dissolves the solute (H_2O in saline water).
SPADNS: The lab reagent called SPADNS solution is used in performing the Fluoride test.
SPECTROSCOPY : Study of radiation and matter, such as X:ray absorption and emission spectroscopy.
SPEED OF LIGHT : The speed of anything that has zero rest mass ($\text{Energy}_{\text{rest}} = mc^2$ where m is the mass and c is the speed of light).
SPIRIT OF HARTSHORN: A colorless, pungent, suffocating, aqueous solution of about 28.5 percent ammonia gas: used chiefly as a detergent, for removing stains and extracting certain vegetable coloring agents, and in the manufacture of ammonium salts.
SPLIT FLOW CONTROL SYSTEM: This type of control system is to control the flow to each filter influent which is divided by a weir.
SPRAY BOTTLE OF AMMONIA: An operator should use ammonia to test for a chlorine leak around a valve or pipe. You will see white smoke if there is a leak.
STANDARD CONDITIONS FOR TEMPERATURE AND PRESSURE or SATP : A standardization used in order compare experimental results (25 °C and 100.000 kPa).
STANDPIPE: A water tank that is taller than it is wide. Should not be found in low point.
STATE OF MATTER : Matter having a homogeneous, macroscopic phase; gas, plasma, liquid, and solid are the most well-known (in increasing concentration).
STERILIZED GLASSWARE: The only type of glassware that should be used in testing for coliform bacteria.
STORAGE TANKS: Three types of water usage that determine the volume of a storage tank are fire suppression storage, equalization storage, and emergency storage. Equalization storage is the volume of water needed to supply the system for periods when demand exceeds supply. Generally, a water storage tank's interior coating (paint) protects the interior about 3-5 years.
SUBATOMIC PARTICLES : Particles that are smaller than an atom; examples are protons, neutrons and electrons.
SUBLIMATION: A phase transition from solid to limewater fuel or gas.
SUBSTANCE : Material with definite chemical composition.
SULFATE: Will readily dissolve in water to form an anion. Sulfate is a substance that occurs naturally in drinking water. Health concerns regarding sulfate in drinking water have been raised because of reports that diarrhea may be associated with the ingestion

of water containing high levels of sulfate. Of particular concern are groups within the general population that may be at greater risk from the laxative effects of sulfate when they experience an abrupt change from drinking water with low sulfate concentrations to drinking water with high sulfate concentrations. Sulfate in drinking water currently has a secondary maximum contaminant level (SMCL) of 250 milligrams per liter (mg/L), based on aesthetic effects (i.e., taste and odor). This regulation is not a federally enforceable standard, but is provided as a guideline for States and public water systems. EPA estimates that about 3% of the public drinking water systems in the country may have sulfate levels of 250 mg/L or greater. The Safe Drinking Water Act (SDWA), as amended in 1996, directs the U.S. Environmental Protection Agency (EPA) and the Centers for Disease Control and Prevention (CDC) to jointly conduct a study to establish a reliable dose-response relationship for the adverse human health effects from exposure to sulfate in drinking water, including the health effects that may be experienced by sensitive subpopulations (infants and travelers).

SULFIDE: The term sulfide refers to several types of chemical compounds containing sulfur in its lowest oxidation number of -2. Formally, "sulfide" is the dianion, S2-, which exists in strongly alkaline aqueous solutions formed from H2S or alkali metal salts such as Li2S, Na2S, and K2S. Sulfide is exceptionally basic and, with a pKa > 14, it does not exist in appreciable concentrations even in highly alkaline water, being undetectable at pH < ~15 (8 M NaOH). Instead, sulfide combines with electrons in hydrogen to form HS, which is variously called hydrogen sulfide ion, hydrosulfide ion, sulfhydryl ion, or bisulfide ion. At still lower pH's (<7), HS- converts to H2S, hydrogen sulfide. Thus, the exact sulfur species obtained upon dissolving sulfide salts depends on the pH of the final solution. Aqueous solutions of transition metals cations react with sulfide sources (H2S, NaSH, Na2S) to precipitate solid sulfides. Such inorganic sulfides typically have very low solubility in water and many are related to minerals. One famous example is the bright yellow species CdS or "cadmium yellow". The black tarnish formed on sterling silver is Ag2S. Such species are sometimes referred to as salts. In fact, the bonding in transition metal sulfides is highly covalent, which gives rise to their semiconductor properties, which in turn is related to the practical applications of many sulfide materials.

SUPERNATANT: The liquid layer which forms above the sludge in a settling basin.

SURFACTANT: Surfactants reduce the surface tension of water by adsorbing at the liquid-gas interface. They also reduce the interfacial tension between oil and water by adsorbing at the liquid-liquid interface. Many surfactants can also assemble in the bulk solution into aggregates. Examples of such aggregates are vesicles and micelles. The concentration at which surfactants begin to form micelles is known as the critical micelle concentration or CMC. When micelles form in water, their tails form a core that can encapsulate an oil droplet, and their (ionic/polar) heads form an outer shell that maintains favorable contact with water. When surfactants assemble in oil, the aggregate is referred to as a reverse micelle. In a reverse micelle, the heads are in the core and the tails maintain favorable contact with oil. Surfactants are also often classified into four primary groups; anionic, cationic, non-ionic, and zwitterionic (dual charge).

SUSCEPTIBILITY WAIVER: A waiver that is granted based upon the results of a vulnerability assessment.

SYNCHRONY: Simultaneous occurrence; synchronism.

T

TALC : A mineral representing the *one* on the Mohs Scale and composed of hydrated magnesium silicate with the chemical formula $H_2Mg_3(SiO_3)_4$ or $Mg_3Si_4O_{10}(OH)_2$.

TASTE AND ODORS: The primary purpose to use potassium permanganate in water treatment is to control taste and odors. Anaerobic water undesirable for drinking water purposes because of color and odor problems are more likely to occur under these conditions. Taste and odor problems in the water may happen if sludge and other debris are allowed to accumulate in a water treatment plant.

TCE, trichloroethylene: A solvent and degreaser used for many purposes; for example dry cleaning, it is a common groundwater contaminant. Trichloroethylene is a colorless liquid which is used as a solvent for cleaning metal parts. Drinking or breathing high levels of trichloroethylene may cause nervous system effects, liver and lung damage, abnormal heartbeat, coma, and possibly death. Trichloroethylene has been found in at least 852 of the 1,430 National Priorities List sites identified by the Environmental Protection Agency (EPA).

TDS-TOTAL DISSOLVED SOLIDS: An expression for the combined content of all inorganic and organic substances contained in a liquid which are present in a molecular, ionized or micro-granular (colloidal sol) suspended form. Generally, the operational definition is that the solids (often abbreviated TDS) must be small enough to survive filtration through a sieve size of two micrometers. Total dissolved solids are normally only discussed for freshwater systems, since salinity comprises some of the ions constituting the definition of TDS. The principal application of TDS is in the study of water quality for streams, rivers and lakes, although TDS is generally considered not as a primary pollutant (e.g. it is not deemed to be associated with health effects), but it is rather used as an indication of aesthetic characteristics of drinking water and as an aggregate indicator of presence of a broad array of chemical contaminants. Ion exchange is an effective treatment process used to remove iron and manganese in a water supply. This process is ideal as long as the water does not contain a large amount of TDS. When determining the total dissolved solids, a sample should be filtered before being poured into an evaporating dish and dried. Demineralization may be necessary in a treatment process if the water has a very high value Total Dissolved Solids.

TEMPERATURE : The average energy of microscopic motions of particles.

TEMPERATURE SAMPLE: This test should be performed immediately in the field, this is a grab sample.

THE RATE DECREASES: In general, when the temperature decreases, the chemical reaction rate decreases also.

THEORY: A model describing the nature of a phenomenon.

THERMAL CONDUCTIVITY: A property of a material to conduct heat (often noted as k).

THERMOCHEMISTRY: The study of absorption/release of heat within a chemical reaction.

THERMODYNAMIC STABILITY : When a system is in its lowest energy state with its environment (equilibrium).

THERMODYNAMICS : The study of the effects of changing temperature, volume or pressure (or work, heat, and energy) on a macroscopic scale.

THERMOMETER : Device that measures the average energy of a system.

THICKENING, CONDITIONING AND DEWATERING: Common processes that are utilized to reduce the volume of sludge.

This reaction proceeds more rapidly with increasing temperature and decreasing pressure. Deflagration of ozone can be triggered by a spark, and can occur in ozone concentrations of 10 wt% or higher.

TIME FOR TURBIDITY BREAKTHROUGH AND MAXIMUM HEADLOSS: Are the two factors which determine whether or not a change in filter media size should be made.
TITRATION : The process of titrating one solution with another, also called volumetric analysis.
TITRATION: A method of testing by adding a reagent of known strength to a water sample until a specific color change indicates the completion of the reaction.
TITRIMETRIC: Chemistry. Using or obtained by titration. Titrimetrically, adverb.
TORR : A unit to measure pressure (1 Torr is equivalent to 133.322 Pa or 1.3158×10^{-3} atm).
TOTAL ALKALINITY: A measure of the acid-neutralizing capacity of water which indicates its buffering ability, i.e. measure of its resistance to a change in pH. Generally, the higher the total alkalinity, the greater the resistance to pH change.
TOTAL COLIFORM: Total coliform, fecal coliform, and E. coli are all indicators of drinking water quality. The total coliform group is a large collection of different kinds of bacteria. Fecal coliforms are types of total coliform that mostly exist in feces. E. coli is a sub-group of fecal coliform. When a water sample is sent to a lab, it is tested for total coliform. If total coliform is present, the sample will also be tested for either fecal coliform or E. coli, depending on the lab testing method.
TOTAL DISSOLVED SOLIDS (TDS): The accumulated total of all solids that might be dissolved in water.
TRANSIENT, NON-COMMUNITY WATER SYSTEM: TNCWS A water system which provides water in a place such as a gas station or campground where people do not remain for long periods of time. These systems do not have to test or treat their water for contaminants which pose long-term health risks because fewer than 25 people drink the water over a long period. They still must test their water for microbes and several chemicals. A Transient Non-community Water System: Is not required to sample for VOC’s.
TRANSITION METAL : Elements that have incomplete d sub-shells, but also may be referred to as the d-block elements.
TRANSURANIC ELEMENT : Element with atomic number greater than 92; none of the transuranic elements are stable.
TREATED WATER: Disinfected and/or filtered water served to water system customers. It must meet or surpass all drinking water standards to be considered safe to drink.
TRIHALOMETHANES (THM): Four separate compounds including chloroform, dichlorobromomethane, dibromochloromethane, and bromoform. The most common class of disinfection by-products created when chemical disinfectants react with organic matter in water during the disinfection process. See Disinfectant Byproducts.
TRIPLE BOND: The sharing of three pairs of electrons within a covalent bond (example N_2).
TRIPLE POINT : The place where temperature and pressure of three phases are the same (Water has a special phase diagram).
TUBE SETTLERS: This modification of the conventional process contains many metal tubes that are placed in the sedimentation basin, or clarifier. These tubes are approximately 1 inch deep and 36 inches long, split-hexagonal shape and installed at an angle of 60 degrees or less. These tubes provide for a very large surface area upon which particles may settle as the water flows upward. The slope of the tubes facilitates gravity settling of the solids to the bottom of the basin, where they can be collected and removed. The large surface settling area also means that adequate clarification can be obtained with detention times of 15 minutes or less. As with conventional treatment, this sedimentation step is followed by filtration through mixed media.

TUBERCLES: The creation of this condition is of the most concern regarding corrosive water effects on a water system. Tubercles are formed due to joining dissimilar metals, causing electro-chemical reactions. Like iron to copper pipe. We have all seen these little rust mounds inside cast iron pipe.
TUNDALL EFFECT : The effect of light scattering by colloidal (mixture where one substance is dispersed evenly through another) or suspended particles.
TURBIDIMETER: Monitoring the filter effluent turbidity on a continuous basis with an in-line instrument is a recommended practice. Turbidimeter is best suited to perform this measurement.
TURBIDITY: A measure of the cloudiness of water caused by suspended particles.

U
U.S. ENVIRONMENTAL PROTECTION AGENCY: In the United States, this agency responsible for setting drinking water standards and for ensuring their enforcement. This agency sets federal regulations which all state and local agencies must enforce.
UN NUMBER: A four digit code used to note hazardous and flammable substances.
UNCERTAINTY : A characteristic that any measurement that involves estimation of any amount cannot be exactly reproducible.
UNCERTAINTY PRINCIPLE : Knowing the location of a particle makes the momentum uncertain, while knowing the momentum of a particle makes the location uncertain.
UNIT CELL : The smallest repeating unit of a lattice.
UNIT FACTOR : Statements used in converting between units.
UNIT FILTER RUN VOLUME (UFRV): One of the most popular ways to compare filter runs. This technique is the best way to compare water treatment filter runs.
UNIVERSAL OR IDEAL GAS CONSTANT : Proportionality constant in the ideal gas law (0.08206 L·atm/(K·mol)).

V
VALENCE BOND THEORY: A theory explaining the chemical bonding within molecules by discussing valencies, the number of chemical bonds formed by an atom.
VALENCE ELECTRON : The outermost electrons of an atom, which are located in electron shells.
VAN DER WAALS FORCE : One of the forces (attraction/repulsion) between molecules.
VAN'T HOFF FACTOR : Ratio of moles of particles in solution to moles of solute dissolved.
VAPOR PRESSURE : Pressure of vapor over a liquid at equilibrium.
VAPOR: When a substance is below the critical temperature while in the gas phase.
VAPORIZATION: Phase change from liquid to gas.
VENTURI: If water flows through a pipeline at a high velocity, the pressure in the pipeline is reduced. Velocities can be increased to a point that a partial vacuum is created.
VIRION: A complete viral particle, consisting of RNA or DNA surrounded by a protein shell and constituting the infective form of a virus.
VIRUSES: Are very small disease-causing microorganisms that are too small to be seen even with microscopes. Viruses cannot multiply or produce disease outside of a living cell.
VIRUSES: Very small disease-causing microorganisms that are too small to be seen even with microscopes. Viruses cannot multiply or produce disease outside of a living cell.
VISCOSITY : The resistance of a liquid to flow (oil).

VITRIFICATION: Vitrification is a process of converting a material into a glass-like amorphous solid that is free from any crystalline structure, either by the quick removal or addition of heat, or by mixing with an additive. Solidification of a vitreous solid occurs at the glass transition temperature (which is lower than melting temperature, Tm, due to supercooling). When the starting material is solid, vitrification usually involves heating the substances to very high temperatures. Many ceramics are produced in such a manner. Vitrification may also occur naturally when lightning strikes sand, where the extreme and immediate heat can create hollow, branching rootlike structures of glass, called fulgurite. When applied to whiteware ceramics, vitreous means the material has an extremely low permeability to liquids, often but not always water, when determined by a specified test regime. The microstructure of whiteware ceramics frequently contain both amorphous and crystalline phases.

VOC WAIVER: The longest term VOC waiver that a public water system using groundwater could receive is 9 years.

VOLATILE ORGANIC COMPOUNDS: (VOCs) Solvents used as degreasers or cleaning agents. Improper disposal of VOCs can lead to contamination of natural waters. VOCs tend to evaporate very easily. This characteristic gives VOCs very distinct chemical odors like gasoline, kerosene, lighter fluid, or dry cleaning fluid. Some VOCs are suspected cancer-causing agents. Volatile organic compounds (VOCs) are organic chemical compounds that have high enough vapor pressures under normal conditions to significantly vaporize and enter the atmosphere. A wide range of carbon-based molecules, such as aldehydes, ketones, and other light hydrocarbons are VOCs. The term often is used in a legal or regulatory context and in such cases the precise definition is a matter of law. These definitions can be contradictory and may contain "loopholes"; e.g. exceptions, exemptions, and exclusions. The United States Environmental Protection Agency defines a VOC as any organic compound that participates in a photoreaction; others believe this definition is very broad and vague as organics that are not volatile in the sense that they vaporize under normal conditions can be considered volatile by this EPA definition. The term may refer both to well characterized organic compounds and to mixtures of variable composition.

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VOLT : One joule of work per coulomb : the unit of electrical potential transferred.

VOLTAGE: Voltage (sometimes also called electric or electrical tension) is the difference of electrical potential between two points of an electrical or electronic circuit, expressed in volts. It measures the potential energy of an electric field to cause an electric current in an electrical conductor. Depending on the difference of electrical potential it is called extra low voltage, low voltage, high voltage or extra high voltage. Specifically Voltage is equal to energy per unit charge.

VOLTIMETER : Instrument that measures the cell potential.

VOLUMETERIC ANALYSIS: See *titration.*

VULNERABILITY ASSESSMENT: An evaluation of drinking water source quality and its vulnerability to contamination by pathogens and toxic chemicals.

W

WAIVERS: Monitoring waivers for nitrate and nitrite are prohibited.

WATER : H_2O : A chemical substance, a major part of cells and Earth, and covalently bonded.

WATER PURVEYOR: The individuals or organization responsible to help provide, supply, and furnish quality water to a community.

WATER QUALITY CRITERIA: Comprised of both numeric and narrative criteria. Numeric criteria are scientifically derived ambient concentrations developed by EPA or States for various pollutants of concern to protect human health and aquatic life. Narrative criteria are statements that describe the desired water quality goal.

WATER QUALITY STANDARD: A statute or regulation that consists of the beneficial designated use or uses of a waterbody, the numeric and narrative water quality criteria that are necessary to protect the use or uses of that particular waterbody, and an antidegradation statement.

WATER QUALITY: The 4 broad categories of water quality are: Physical, chemical, biological, radiological. Pathogens are disease causing organisms such as bacteria and viruses. A positive bacteriological sample indicates the presence of bacteriological contamination. Source water monitoring for lead and copper be performed when a public water system exceeds an action level for lead of copper.

WATER VAPOR: A characteristic that is unique to water vapor in the atmosphere is that water does not contain any salts.

WATERBORNE DISEASE: A disease, caused by a virus, bacterium, protozoan, or other microorganism, capable of being transmitted by water (e.g., typhoid fever, cholera, amoebic dysentery, gastroenteritis).

WAVE FUNCTION: A function describing the electron's position in a three-dimensional space.

WHOLE EFFLUENT TOXICITY: The total toxic effect of an effluent measured directly with a toxicity test.

WORK : The amount of force over distance and is in terms of joules (energy).

X

X-RAY : Form of ionizing, electromagnetic radiation, between gamma and UV rays.

X-RAY DIFFRACTION: A method for establishing structures of *crystalline* solids using singe wavelength X:rays and looking at diffraction pattern.

X-RAY PHOTOELECTRON SPECTROSCOPY: A spectroscopic technique to measure composition of a material.

Y

YIELD : The amount of product produced during a chemical reaction.

Z

ZONE MELTING: A way to remove impurities from an element by melting it and slowly travel down an ingot (cast).

ZWITTERION: Is a chemical compound whose net charge is zero and hence is electrically neutral. But there are some positive and negative charges in it, due to the formal charge, owing to the partial charges of its constituent atoms.

References

Agency for Toxic Substances and Disease Registry. 1998. Draft Toxicological Profile for Arsenic. Prepared for the US Department of Health and Human Services by the Research Triangle Institute.

Albores, A., M. E. Cebrian, I. Tellez and B. Valdez. 1979. Comparative Study of Chronic Hydroarsenicism in Two Rural Communities in the Region Lagunra of Mexico. [In Spanish]. Bol. Oficina Sanit. Panam. 86:196-205.

American Public Health Association (APHA). 1992 and 1995. Standard Methods for the Examination of Water and Wastewater. 18th Edition, American Public Health Association, 1015 Fifteenth Street N.W., Washington, DC 20005.

American Society for Testing and Materials (ASTM). 1994 and 1996. Annual Book of ASTM Standards.

Vol. 11.01 and 11.02, American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103.

Aposhian, H.V., E.S. Gurzau, X.C. Le, A. Gurzau, S.H. Healy, X. Lu, M. Ma, R.A. Zakharyan, R.M. Maiorino, R.C. Dart, M.G. Tircus, D. Gonzalez-Remariz, D.L. Morgan, D. Avram, D. and M.M. Aposhian. 2000. Occurrence of monomethylarsonous acid in urine of humans exposed to inorganic arsenic. Chemical Research Toxicology 13:693-697.

Borgono, J.M, P. Vincent, H. Venturino, and A. Infante. 1977. Arsenic in the Drinking Water of the City of Antofagasta: Epidemiological and Clinical Study before and after the Installation of a Treatment Plant. Environmental Health Perspectives 19:103-105. August, 1997.

Borzsonyi, M., A. Berecsky, P. Rudnai, M. Csanady and A. Horvath. 1992. Epidemiological Studies on Human Subjects Exposed to Arsenic in Drinking Water in Southeast Hungary. Archives of Toxicology. 66:77-78.

Buchanan, W. D. 1962. Toxicity of Arsenic Compounds. Amsterdam, Elsevier Scientific Publishers. Pp v-viii.

Buchet, J.P. and D. Lison. 1998. Mortality by cancer in groups of the Belgium population with a moderately increases intake of arsenic. International Archives Occupational Environmental Health 71:125-130.

Carmignani, M., P. Boscolo and A. Iannaccone. 1983. Effects of chronic exposure to arsenate on the cardiovascular function of rats. British Journal Industrial Medicine 40:280-284.

Casale, R. and M. LeChevallier. 2000. Contaminants in Drinking Water Treatment Chemicals: A Survey of the American Water Works System. Proceedings American Water Works Association Water Quality Technology Conference. Salt Lake City, UT. November 5-9.

Cebrian, M. 1987. Some Potential Problems in Assessing the Effects of Chronic Arsenic Exposure in North Mexico [preprint extended abstract]. New Orleans, LA, American Chemical Society.

August 2002 Arsenic Guidance Appendix M-4

Cebrian, M. E., A. Albores, M. Aguilar and E. Blakely. 1983. Chronic Arsenic Poisoning in the North of Mexico. Human Toxicology. 2:121-133.

Chen, C.J., Y.C. Chuang, T.M. Lin, and H.Y. Wu. 1985. Malignant neoplasms among residents of a blackfoot disease-endemic area in Taiwan: high arsenic artesian well water and cancers.

Chen, C.J., M.. Wu, S.S. Lee, J.D. Wang, S.H. Cheng, and H.Y. Wu. 1988. Atherogenicity and carcinogenicity of high- arsenic artesian well water. Multiple risk factors and related malignant neoplasms of blackfoot disease. Arteriosclerosis. 8:452-460.

Chen, C.J. and C.J. Wang. 1990. Ecological correlation between arsenic level in well water and age adjusted mortality from malignant neoplasms. Cancer Research 50:5470–5474.

Chen, C.J., C.W. Chen, M.M. Wu, and T.L. Kuo. 1992. Cancer potential in liver, lung, bladder and kidney due to ingested inorganic arsenic in drinking water. British Journal of Cancer 66:888-892.

Chen, C.J., R.M. Hsueh, M.S. Lai, M.P. Shu, S.Y. Chen, M.M. Wu, T.L. Kuo, and T.Y. Tai. 1995. Increased prevalence of hypertension and long-term arsenic exposure. Hypertension 25:53-60.

Chen, G.-Q, J. Zhu, X-G. Shi, J.H. Ni, H.-J. Zhong, G-Y. Si, X.-L. Jin, W. Tang, X.-S. Li, S.-M. Xong,

Z.-X. She, G.-L. Sun, J. Ma, P. Zhang, T.-D. Zhang, C. Gazin, T. Naoe, S.-J. Chen, and Z. Chen.

1996. In vitro studies on cellular and molecular mechanisms of arsenic trioxide (As2O3) in the treatment of acute promyleocytic leukemia: As2O3 induces NB43 cell apoptosis with down regulation of Bcl-2 expression and modulation of PQL-RAR"/PML proteins. Blood 83:1053-1061.

Chen, C.J., H.Y. Chiou, M.H. Chiang, L.J. Lin and T.Y. Tai. 1996. Dose-Response Relationship Between Ischemic Heart Disease Mortality and Long-Term Arsenic Exposure. Arteriosclerosis, Thrombosis, and Vascular Biology. 16(4):504-510.

Chen. Personal correspondence to Herman Gibb, January 3, 2000.

Clifford, D. and Z. Zhang. 1994. Arsenic Chemistry and Speciation. American Water Works Association Annual Conference. New York, NY. June 19-23.

Clifford, D., G. Ghurye, A. Tripp, J. Tong. 1997. Final Report: Phases 1 and 2, City of Albuquerque Arsenic Study. Field Studies on Arsenic Removal in Albuquerque, New Mexico Using the University of Houston/EPA Mobile Drinking Water Treatment Research Facility. Prepared for John Stromp, IIII, Water Resources Manager, City of Albuquerque. December 1997.

Clifford, D., G. Ghurye, A. Tripp, T. Jian. 1998. Final Report: Phase 3 City of Albuquerque Arsenic Study. Field Studies on Arsenic Removal in Albuquerque, New Mexico using the University of Houston/EPA Mobile Drinking Water Treatment Research Facility. Prepared for John Stomp, Water Resources Manager, City of Albuquerque. August, 1998.

Cogliano, V.J., E.D. Kroese, G.A. Zapponi, L. Attias and I. Marcello. 1999. Chapter 1. Introduction. In: Cogliano, V.J., E.G. Luebeck and G.A. Zapponi eds., 1999. Perspectives on Biologically Based Cancer Risk Assessment. NATO: Challenges of Modern Society, Plenum Press. pp. 1-20.

Arsenic Guidance August 2002 Appendix M-5

Cox, D.R. and D. Oakes. 1984. Analysis of Survival Data. London: Chapman and Hall.

Cropper, M.L and U. Subramanian. 1999. Public Choices Between Lifesaving Programs: How Important Are Lives Saved? Valuing Environmental Benefits: Selected Essays of Maureen Cropper.

Cheltenham, United Kingdom. Edward Elgar.

Cuzick, J., S. Evans, M. Gillman, and D. A. Price Evans. 1982. Medicinal Arsenic and Internal Malignancies. British Journal of Cancer. 45:904-911.

Cuzick, J., P. Sasieni, and S. Evans. 1992. Ingested arsenic, keratoses, and bladder cancer. American Journal of Epidemiology. 136(4):417–421.

Desi, I. 1992. Arsenic Contamination of Drinking Water in South-East Hungary. Geographia Medica. 22:45-53.

Eaton, A.D. 1994 Determining the practical quantitation level for arsenic. Journal AWWA. Pgs. 100- 114

Engel, R.R., and H.H. Smith. 1994. Arsenic in drinking water and mortality from vascular disease: An ecological analysis in 30 countries in the United States. Arch. Environmental Health. 49:418-427.

Frey, M., J. Chwirka, S. Kommineni, and Z. Chowdhury. “Cost Implications of A Lower Arsenic MCL”.

May 5, 2000. American Water Works Association Research Foundation, Denver Co. (included as an attachment to comment I-G1.466)

Frey, M., J. Chwirka, S. Kommineni, and Z. Chowdhury. “Update Cost Implications Of A Lower Arsenic MCL”. October 10, 2000.

Frey, M. M. and M. A. Edwards. 1997. Surveying Arsenic Occurrence. Journal of the American Water Works Association. 89(3):105-117.

Guha Mazumder, D. N., J. Das Gupta, A. Santra, A. Pal, A. Ghose, S. Sarkar, N. Chattopadhaya and D. Chakraborty. 1997. Non-Cancer Effects of Chronic Arsenicosis with Special Reference to Liver Damage. In Arsenic: Exposure and Health Effects. Abernathy, C. O., Calderon, R. L. and Chappell, W., Eds. London, Chapman and Hall: pp. 112-123.

Guha Mazumder, D.N., B.K. De, A. Santra, J. Dasgupta, N. Ghosh, B.K. Roy, U.C. Ghoshal, J. Saha, A. Chatterjee, S. Dutta, R. Haque, A.H. Smith, D. Chakraborty, C.R. Angle and J.A. Centeno. 1999.

Chronic arsenic toxicity: Epidemiology, natural history and treatment. In Chappell, W.R., C.O.

Abernathy and R.L. Calderon, eds. Arsenic Exposure and Health Effects. Elsevier. Amsterdam. pp. 335-347.
Hindmarsh, J. T., O. R. McLetchie, L. P. M. Heffernan, O. A. Hayne, H. A. Ellenberger, R. F. McCurdy and H. J. Thiebaux. 1977. Electromyographic Abnormalities in Chronic Environmental Arsenicalism. Analytical Toxicology. 1:270-276.
Hopenhayn-Rich, C., M. L. Biggs, A. Fuchs, R. Bergoglio, E. E. Tello, H. Nicolli and A. H. Smith. 1996.
Bladder Cancer Mortality Associated With Arsenic in Drinking Water in Argentina. Epidemiology. 7(2):117-124.
August 2002 Arsenic Guidance Appendix M-6
Hopenhayn-Rich, C., M. L. Biggs and A. H. Smith. 1998. Lung and Kidney Cancer Mortality Associated with Arsenic in Drinking Water in Cordoba, Argentina. Epidemiology. 27:561-569.
Hopenhayn-Rich, C., S.R. Browning, I. Hertz-Picciotto, C. Ferreccio, C. Peralta, and H. Gibb. 2000.
Chronic Arsenic Exposure and Risk of Infant Mortality in Two Areas of Chile. Environmental Health Perspectives 108:667-673. July 2000.
Kempic, J.B. 2000. Centrally managed POU/POE Option for Compliance with the Arsenic Regulation.
AWWA Inorganic Contaminants Workshop, Albuquerque, NM, February 27 - 29, 2000.
Kurttio, P, E. Pukkala, H. Kahelin, A. Auvinen, and J. Pekkanen. 1999. Arsenic Concentrations in Well Water and Risk of Bladder and Kidney Cancer in Finland. Environmental Health Perspectives 107(9):705-710
Lai, M.S., Y.M. Hsueh, C.J. Chien, M.P. Shyu, S.Y. Chen, T.L. Kuo, M.M. Wu, and T.Y. Tai. 1994. Ingested Inorganic Arsenic and Prevalence of Diabetes Mellitus. American Journal of Epidemiology. 139(5):484-492.
Le, X.C., M. Ma, X. Lu, W.R. Cullen, H.V. Aposhian and B. Zheng. 2000. Determination of monomethylarsonous acid, a key arsenic methylation intermediate, in human urine. Environmental Health Perspectives. 108(11):1015-1018.
Lewis, D. R., J. W. Southwick, R. Ouellet-Hellstrom, J. Rench and R. L. Calderon. 1999. Drinking Water
Arsenic in Utah: A Cohort Mortality Study. Environmental Health Perspectives. 107(5):359-365.
McCullagh, P. and J.A. Nelder. 1989. Generalized Linear Models (2nd ed.). London: Chapman and Hall.
Morales, K.H., L. Ryan, T.-L. Kuo, M.-M. Wu and C.-J. Chen. 2000. Risk of internal cancers from arsenic in drinking water. Environmental Health Perspectives 108:655-661.
Morris, J.S., M. Schmid, S. Newman, P. J. Scheuer and S. Sherlock. 1974. Arsenic and Noncirrhotic
Portal Hypertension. Gastroenterology. 66:86-94.
Morton, W., G. Starr, D. Pohl, J. Stoner, S. Wagner and P. Weswig. 1976. Skin cancer and water arsenic in Lane County, Oregon. Cancer 37:2523-2532.
National Academy of Sciences (NAS). 1977. Arsenic. National Academy Press, Washington, DC, 332 pp.
National Cancer Institute (NCI), 1999. Ries, L.A. G., C.L. Kosary, B.A. Miller, L. Clegg and B.K. Edwards. SEER Cancer Statistics Review, 1973-1996, Bethesda, MD.
National Research Council (NRC). 1989. Recommended Dietary Allowances, 10th Edition . National Academy Press. Washington, DC, pp. 283.
National Research Council. 1999. Arsenic in Drinking Water. Washington, DC. National Academy Press.
Arsenic Guidance August 2002 Appendix M-7
Nevens, F., J. Fevery, W. Van Steenbergen, R. Sciot, V. Desmet and J. De Groote. 1990. Arsenic and Non cirrhotic Portal Hypertension: A Report of Eight Cases. Hepatology. 11:80-85.
Ng, J.C., A.A. Seawright, L. Qi, C.M. Garnett, B. Chiswell and M.M. Moore. 1999. Tumours in mice induced by exposure to sodium arsenate in drinking water. In Chappell, W.R., C.O. Abernathy and R.L. Calderon, eds. Arsenic Exposure and Health Effects. Elsevier. Amsterdam. pp. 217-223.

Petrick, J.S., A. Ayala-Fierro, W.R. Cullen, D.E. Carter and H.V. Aposhian. 2000. Monomethylarsonous acid (MMAIII) is more toxic than arsenite in Chang liver human hepatocytes. Toxicol. Appl. Pharmacol. 163:203-207.
Porter, M., I. Elliot, S. Marshall, J. Routh and R. Matousek. 2000. Large Scale Gas Generator Eliminates On-Site Chlorine Storage. Proceedings American Water Works Association Annual Conference.
Portier, C. 1987. Statistical properties of a two stage model of carcinogenesis. Environmental Health Perspectives 76:125-131.
Rahman, M. and J.O. Axelson. 1995. Diabetes Mellitus and Arsenic Exposure: a Second Look at Case- Control Data from a Swedish Copper Smelter. Occupational Environmental Medicine. 52:773-774.
Rahman, M., M. Tondel, S.A. Ahmad, and C. Axels. 1998. Diabetese Mellitus Associated with Arsenic Exposure in Bangladesh. American Journal of Epidemiology. 148(2):198-203.
Resevz, R.L. 1999. Environmental Regulation, Cost-Benefit Analysis, and the Discounting of Human Lives. Columbia Law Review. 99:941-1017.
Roth, F. 1956. Concerning Chronic Arsenic Poisoning of the Moselle Wine Growers with Special Emphasis on Arsenic Carcinomas. Krebsforschung. 61:287-319.
Sabbioni, E., M. Fischbach, G. Pozzi, R. Pietra, M. Gallorini and J. L. Piette. 1991. Cellular Retention, Toxicity and Carcinogenic Potential of Seafood Arsenic. I. Lack of Cytotoxicity and Transforming Activity of Arsenobetaine in the BALB/3T3 Cell Line. Carcinogenesis. 12:1287-1291.
Schoof, R.A., L.J. Yost, E. Crecelius, K. Irgolic, W. Goessler, H.R. Guo, and H. Green. 1998. Dietary arsenic intake in Taiwanese districts with elevated arsenic in drinking water. Human and Ecological Risk Assessment. 4 (1): 117–135.
Schoof, R.A., L.J. Yost, J. Eickhoff, E.A. Crecelius, D.W. Cragin, D. M. Meacher, and D.B. Menzel.
1999. A market basket survey of inorganic arsenic in food. Food and Chemical Toxicology. 37: 839–846.
Simms, J. and F. Azizian. 1997. Pilot Plant Trials on the Removal of Arsenic from Potable Water Using Activated Alumina. Proceedings AWWA Water Quality Technology Conference, November 9-12, 1997.
Simms, J., J. Upton, and J. Barnes. 2000. Arsenic Removal Studies and the Design of a 20,000 m3 per Day Plant in the UK. AWWA Inorganic Contaminants Workshop, Albuquerque, NM, February 27 - 29, 2000.
Smith, A.H., M. Goycolea, R. Haque and M. L. Biggs. 1998. Marked Increase in Bladder and Lung Cancer Mortality in a Region of Northern Chile Due to Arsenic in Drinking Water. American Journal of Epidemiology. 147(7):660-669.
Southwick, J. W., A. E. Western, M. M. Beck, T. Whitley, R. Isaacs, J. Petajan and C. D. Hansen. 1983.
An Epidemiological Study of Arsenic in Drinking Water in Millard County, Utah. In Arsenic: Industrial, Biomedical, Environmental Perspectives. Lederer, W. H. and Fensterheim, R. J., Eds. New York, Van Nostrand Reinhold: pp. 210-225.
Styblo, M., L.M. Del Razo, L. Vega, D.R. Germolic, E.L. LeChuyse, G.A. Hamilton, W. Reed, C. Wang,
W.R. Cullen and D.J. Thomas. 2000. Comparative toxicity of trivalent and pentavalent inorganic and methylated arsenicals in rat and human cells. Archives Toxicology 74:289-299.
Szinicz, L. and Forth, W. 1988. Effect of As2O3 on gluconeogenesis. Archives Toxicology 61:444-449.
Subramanian, K.S., T. Viraraghavan, T. Phommavong, and S. Tanjore. 1997. Manganese Greensand for Removal of Arsenic in Drinking Water. Water Quality Research Journal Canada. 32:3:551-561.
Tabacova, S., D. D. Baird, L. Balabaeve, D. Lolova and I. Petrov. 1994. Placental Arsenic and Cadmium in Relation to Lipid Peroxides and Glutathione Levels in Maternal-Infant Pairs From a Copper Smelter Area. Placenta. 15:873-881.
Talar-Williams, C., R.M. Hijazi, M.M. Walther, W.M. Linehan, C.W. Hallahan, I. Lubensky, G.S. Kerr,

G.S. Hoffman, A.S. Fauci and M.C. Sneller. 1996. Cyclophosphamide-induced cystitis and bladder cancer in patients with Wegener Granulomatosis.. Annals of Internal Medicine, 124:477-484.
Tay, C.H. and C.S. Seah. 1975. Arsenic Poisoning From Anti-Asthmatic Herbal Preparations. Medical Journal, Australia. 2:424-428.
Tsuda T., Babazono A., Yamamoto, E. , Krumatani, N., Mino,Y., Ogawa, T., Kishi, Y., Aoyama, H. 1995. Ingested arsenic and internal cancer: a historical cohort study followed for 33 years. Am. J. Epidemiol. 141:198-209.
US Census. 2000. (www.census.gov. Population Characteristics - Issued September, 2000).
US EPA. 1975. Water Programs: National Interim Primary Drinking Water Regulations. Federal Register. Vol. 40, No. 248, p. 59566. December 24, 1975.
US EPA. 1976. National Interim Primary Drinking Water Regulations. Office of Water Supply. EPA 570/9-76-003.
US EPA. 1980. Water Quality Criteria Documents; Availability. Federal Register. Vol. 45, No. 291, p. 79318. November 28, 1980.
US EPA. 1983. National Revised Primary Drinking Water Regulations; Advance Notice of Proposed Rulemaking. Federal Register. Vol. 48, No. 194, p. 45502. October 5, 1983.
US EPA. 1984. Health Assessment Document for Inorganic Arsenic. Office of Health and Environmental Assessment, Office of Research and Development. EPA-600/8-83-021F. March, 1984.
US EPA. 1985a. National Revised Primary Drinking Water Regulations; Synthetic Organic Chemicals, Inorganic Chemicals and Microorganisms; Proposed Rule. Federal Register. Vol. 50, No. 219, p. 46936. 1985.
US EPA. 1985b. National Primary Drinking Water Regulations; Volatile Synthetic Organic Chemicals; Proposed Rule. Federal Register. Vol. 50, No. 219, p. 46906. November 13, 1985.
US EPA. 1988. Special Report on Ingested Inorganic Arsenic: Skin Cancer; Nutritional Essentiality. Risk Assessment Forum. EPA/625/3-87/013. July 1988.
US EPA. 1989a. Cover letter dated August 14, 1989, from SAB to EPA. Ad Hoc Work Group, Drinking Water Subcommittee, Environmental Health Advisory Committee, Science Advisory Board Report: A Critical Examination of the Evidence for a Threshold For Cancer Risk in Humans from Inorganic Arsenic. Washington, DC. June 1989 report.
US EPA. 1989b. Cover letter dated September 28, 1989 from SAB to EPA. Science Advisory Board's Review of the Arsenic Issues Relating to the Phase II Proposed Regulations From the Office of Drinking Water. Science Advisory Board Committee: Drinking Water Subcommittee of the Environmental Health Committee.
US EPA. 1990. Revised Definition of Significant Noncomplier (SNC) and the Model for Escalating Responses to Violations for the PWSS Program. Water Supply Guidance No. 57. May 22, 1990. http://www.epa.gov/safewater/wsg/wsg_57.pdf.

US EPA. 1991a. National Primary Drinking Water Regulations - Synthetic Organic Chemicals and Inorganic Chemicals; Monitoring for Unregulated Contaminants; National Primary Drinking Water Regulations Implementation; National Secondary Drinking Water Regulations. Federal Register. Vol. 56, No. 20, p. 3526. January 30, 1991.
US EPA. 1991b. Arsenic IRIS File; Arsenic, Inorganic. February 1991. Used for 1992 National Toxics Rule, December 22, 1992, 57 FR 60848.
US EPA. 1991c. Arsenic Research Recommendations memorandum dated April 12, 1991 from John R. Fowle III, Chair of the Arsenic Research Recommendation Workgroup, Health Effects Research Laboratory.
US EPA. 1992a. Science Advisory Board Report: Review of the Office of Research and Development's Arsenic Research Recommendations. Washington, DC. Science Advisory Board. EPA-SABDWC- 92-018. May 1992.
US EPA. 1992b. National Primary Drinking Water Regulations; Synthetic Organic Chemicals and Inorganic Chemicals; Final Rule. Federal Register. Vol. 57, No. 138, p. 31776. July 17, 1992.
US EPA. 1992c. Water Quality Standards; Establishment of Numeric Criteria for Priority Toxic Pollutants; States' Compliance; Final Rule. Federal Register. Vol. 57, No. 246, p. 60848. December 22, 1992.

US EPA, 1992d. Bartley, C.B., P.M. Colucci, and T. Stevens. The Inorganic Chemical Characterization of Water Treatment Plant Residuals. EPA/600/SR-92-117, Cincinnati.
US EPA. 1992e. Occurrence Assessment for Arsenic in Public Drinking Water Sources. Prepared by Wade Miller Associates under contract to EPA. September 10, 1992.
US EPA 1993a. Small Water System Byproducts Treatment and Disposal Cost Document Washington,
DC Office of Ground Water and Drinking Water. April 1993.
US EPA 1993b. Water System Byproducts Treatment and Disposal Cost Document; Draft Final. Washington, DC. Office of Ground Water and Drinking Water. April 1993
US EPA. 1993c. Science Advisory Board Report: Review of the Draft Drinking Water Criteria Document on Inorganic Arsenic. Washington, DC. Science Advisory Board. EPA-SAB-DWC- 94-004.
US EPA. 1993d. Inorganic Arsenicals; Conclusion of Special Review. Federal Register. Vol. 58, No. 234, p. 64579. December 8, 1993.
US EPA. 1994a. EPA Method 200.15, Determination of Metals and Trace Elements in Water By Ultrasonic Nebulization Inductively Coupled Plasma-Atomic Emission Spectrometry. Methods for the Determination of Metals in Environmental Samples - Supplement I, Rev 1.2. EPA/600/R-94-111. May 1994.
US EPA. 1994b. Methods for the Determination of Metals in Environmental Samples - Supplement I. EPA/600/R-94-111, NTIS PB 94-184942.
US EPA. 1994c. SW-846 Method 6020, Inductively Coupled Plasma-Mass Spectrometry. Test Methods for Evaluating Solid Waste: Physical/Chemical Methods. Third Edition, September 1994 Update II.
US EPA. 1994d. SW-846 Method 7060A, Arsenic (Atomic Absorption, Furnace Technique). Test Methods for Evaluating Solid Waste: Physical/Chemical Methods. Third Edition, September 1994 Update II.
US EPA. 1994e. SW-846 Method 7062, Antimony and Arsenic (Atomic Absorption, Borohydride Reduction). Test Methods for Evaluating Solid Waste, Physical/Chemical Methods. Third Edition, September 1994 Update II.
US EPA. 1994f. National Primary and Secondary Drinking Water Regulations: Analytical Methods for Regulated Drinking Water Contaminants; Final Rule. Federal Register. Vol. 59, No. 232, p. 62456. December 5, 1994.
US EPA. 1995. Science Advisory Board Report: Review of Issues Related to the Regulation of Arsenic in Drinking Water. Washington, DC. Science Advisory Board. EPA-SAB-DWC-95-015. July 19, 1995.
US EPA. 1996a. Proposed Guidelines for Carcinogenic Risk Assessment; Notice. Federal Register. Vol 61, No. 79, p. 17960. April 23, 1996.
US EPA. 1996b. EPA Method 1632, Inorganic Arsenic In Water by Hydride Generation Quartz Furnace
Atomic Absorption. EPA/821/R-96-013. July 1996.
US EPA. 1996c. Performance Evaluation Studies Supporting Administration of the Clean Water Act and the Safe Drinking Water Act. Federal Register. Vol. 61, No. 139, p. 37464. July 18, 1996.
US EPA. 1996d. Investigator-Initiated Grants on Health Effects of Arsenic. Federal Register. Vol 61, No. 236, p. 64739. December 6, 1996.
US EPA. 1996e. SW-846 Method 7063, Arsenic in Aqueous Samples and Extracts by Anodic Stripping Voltammetry (ASV). Test Methods for Evaluating Solid Wastes, Physical/Chemical Methods. Third Edition, December 1996, Update III.
US EPA. 1997a. Drinking Water Infrastructure Needs Survey. First Report to Congress. EPA 812-R- 97-001. January, 1997.
US EPA. 1997b. Manual for the Certification of Laboratories Analyzing Drinking Water. EPA 815/B-97/001.
US EPA. 1997 c. March 1994 Workshop on Developing an Epidemiology Research Strategy for Arsenic in Drinking Water. Prepared for EPA's National Health and Environmental Effects Research Laboratory by SRA Technologies. April 14, 1997.

US EPA 1997d. Performance Evaluation Studies Supporting Administration of the Clean Water Act and the Safe Drinking Water Act. Federal Register. Vol. 62, No. 113, p. 32112. June 12, 1997.
US EPA. 1997e. National Center for Environmental Assessment. Report on the Expert Panel on Arsenic Carcinogenicity: Review and Workshop. Lexington, MA. Prepared by the Eastern Research Group under contract to US EPA. August 1997.
US EPA 1997f. SAB Report by the Environmental Health Committee: Guidelines for Cancer Risk Assessment. EPA-SAB-EHC-97-010 September 30, 1997.
US EPA. 1997g. Performance Based Measurement System. Federal Register. Vol. 62, No. 193, p. 52098.
US EPA. 1997h. Benefits and Costs of the Clean Air Act. 1970-1990. Clean Air Act §812. Report Prepared for U.S. Congress by US EPA Office of Air and Radiation. Chapter 6. October. EPA 410-R-97-002.
US EPA. 1998a. Information for States on Developing Affordability Criteria for Drinking Water. EPA 816-R-98-002. February 1998.
US EPA. 1998b. Research Plan for Arsenic in Drinking Water. Office of Research and Development, National Center for Environmental Assessment. EPA/600/R-98/042. www.epa.gov/ORD/WebPubs/final/arsenic.pdf February 1998.
US EPA. 1998c. National Primary Drinking Water Regulations: Consumer Confidence Reports. Proposed Rule. Federal Register. Vol. 63, No. p. 7605. February 13, 1998.
US EPA. 1998d. Environmental Justice Stakeholders Meeting March 12, 1998 Meeting Summary.
US EPA. 1998e. Locating and Estimating Air Emissions From Sources of Arsenic and Arsenic Compounds. Research Triangle Park, NC. Office of Air Quality Planning and Standards. EPA-454-R-98-013. 1998.
US EPA. 1998f. Removal of the Prohibition on the Use of Point of Use Devices for Compliance with National Primary Drinking Water Regulations. Federal Register (63 FR 31934). June 11, 1998.
US EPA. 1998g. Guidance on Implementing the Capacity Development Provisions of the Safe Drinking Water Act Amendments of 1996. EPA 816-R-98-006. July 1998.
US EPA. 1998h. Announcement of Small System Compliance Technology Lists for Existing National Primary Drinking Water Regulations and Findings Concerning Variance Technologies. Notice of Lists of Technologies and Upcoming Release of Guidance and Supporting Documents. Federal Register. Vol. 63, No. 153, p. 42032 at 43045. August 6, 1998.
US EPA. 1998i. National Primary Drinking Water Regulations: Consumer Confidence Reports. Final Rule. Federal Register. Vol. 63, No. 160, p. 44512. August 19, 1998.
US EPA, 1998j. National-Level Affordability Criteria Under the 1996 Amendments to the Safe Drinking
Water Act (Final Draft Report). Prepared by International Consultants, Inc., Hagler Bailly Services, Inc., & Janice A. Beecher, PhD under contract 68-C6-0039. August 19, 1998.
US EPA 1998k. National Primary Drinking Water Regulations: Analytical Methods for Regulated Drinking Water Contaminants; Final and Proposed Rule. Federal Register. Vol. 63, No. 171, p. 47097.
US EPA. 1998l. Variance Technology Findings for Contaminants Regulated Before 1996. Office of Water. EPA 815-R-98-003. September 1998.
US EPA. 1998m. Information for Small Entity Representatives Regarding the Arsenic in Drinking Water Rule. December 3, 1998.
US EPA. 1998n. Cost of Illness Handbook. Office of Pollution Prevention and Toxics. Chapter V Cost of Lung Cancer. September, 1998
US EPA. 1999a. Drinking Water Baseline Handbook. Prepared by International Consultants, Inc. under contract with EPA OGWDW, Standards and Risk Management Division. February 24, 1999.
US EPA. 1999b. Technologies and Costs for the Removal of Arsenic From Drinking Water. Prepared by International Consultants, Inc. and Malcolm Pirnie, Inc. under contract 68-C-C6–0039 with EPA OGWDW. April 1999.
US EPA 1999c. A Guidebook of Financial Tools: Paying for Sustainable Environmental Systems. April 1999.

US EPA. 1999d. National Primary Drinking Water Regulations: Public Notification Rule, Proposed Rule. Federal Register. Vol. 64, No. 92, p. 25964. May 13, 1999.
US EPA. 1999e. Report of the Small Business Advocacy Review Panel on EPA's Planned Proposal of the National Primary Drinking Water Regulation for Arsenic. Cover memo to the Administrator and the report. June 4, 1999.
US EPA. 1999f. Decision Tree for the Arsenic Rulemaking Process. Washington, DC. Office of Ground Water and Drinking Water. July 1999.
US EPA 1999g. SAB Report by the Executive Committee: Review of Revised Sections of the Proposed Guidelines for Carcinogen Risk Assessment. EPA-SAB-EC-99-015. July 29, 1999.
US EPA. 1999h. Radon and Arsenic Regulatory Compliance Costs for the 25 Largest Public Water Systems (With Treatment Plant Configurations) Prepared for U.S. EPA by Science Applications International Corporation.
US EPA. 1999i. Geometries and Characteristics of Public Water Systems. Draft prepared by Science Applications International Corporation under contract with EPA OGWDW. August 15, 1999.
US EPA. 1999j. Cost of Illness Handbook. Office of Pollution Prevention and Toxics. Chapter 1 II.8. Cost of Bladder Cancer. September, 1999.
US EPA. 1999k. Cost of Illness Handbook. Office of Pollution Prevention and Toxics. Chapter V Cost of Lung Cancer. September, 1998.
US EPA. 1999l. Co-Occurrence of Drinking Water Contaminants. Prepared by Science Applications International Corporation under contract 68-C6-0059 for EPA OGWDW. EPA 815-R-00-025. September 30, 1999.
US EPA. 1999m. National Primary Drinking Water Regulations: Radon-222, Proposed Rule. Federal
Register. Vol. 64, No. 211, p. 59246. EPA 815-z-99-006. November 2, 1999.
US EPA. 1999n. Small Systems Compliance Technology List for the Arsenic Rule. Washington, DC.
Office of Ground Water and Drinking Water. November, 1999. EPA-815-R-00-011
US EPA. 1999o. Technologies and Costs for the Removal of Arsenic from Drinking Water. Washington,
DC. Office of Ground Water and Drinking Water. November, 1999. EPA-815-R-00-012.
US EPA. 1999p. National Primary Drinking Water Regulations: Analytical Methods for Chemical and Microbiological Contaminants and Revisions to Laboratory Certification Requirements; Final Rule. Federal Register. Vol. 64, No. 230, p. 67450. December 1, 1999.
US EPA. 1999q. Analytical Methods Support Document for Arsenic in Drinking Water. Prepared by Science Applications International Corporation under contract with EPA OGWDW, Standards and Risk Management Division. December, 1999. EPA-815-R-00-010
US EPA. 1999r. Arsenic Risk Characterization, Part 1. Prepared by ISSI Consulting Group, Inc. for EPA Office of Water, Office of Standards and Technology. December 22, 1999.
US EPA 2000a. Meeting Notice of the Environmental Economics Advisory Committee (EEAC) of the Science Advisory Board (SAB) on February 25, 2000. Federal Register. Volume 65, Number 24. February 4, 2000. Page 5638.
US EPA. 2000b. Drinking Water Baseline Handbook, Second Edition. 4th quarter 1998 SDWIS freeze. Prepared by International Consultants, Inc. under contract with EPA OGWDW, Standards and Risk Management Division. March 17, 2000.
US EPA. 2000c. Estimated Per Capita Water Ingestion in the United States: Based on Data Collected by the United States Department of Agriculture's (USDA) 1994-1996 Continuing Survey of Food Intakes by Individuals. Office of Water, Office of Standards and Technology. EPA-822-00-008.
US EPA 2000d. Review of the EPA's Draft Chloroform Risk Assessment by the Science Advisory Board Chloroform Risk Assessment Review Subcommittee. EPA-SAB-EC-00-009. April 28, 2000.
US EPA. 2000e. National Primary Drinking Water Regulations: Public Notification Rule; Final Rule.
Federal Register. Vol. 65, No. 87, p. 25982. May 4, 20000.
US EPA. 2000f. National Primary Drinking Water Regulations: Ground Water Rule; Proposed Rule.

Federal Register. Vol. 65, No. 91, p. 30193. May 10, 20000.
US EPA. 2000g. Arsenic Occurrence in Public Drinking Water Supplies. Public Comment Draft. Office of Water, Washington, D.C. EPA 815-D-00-001. May 2000.
US EPA. 2000h. Regulatory Impact Analysis (RIA) of the Arsenic Rule. May 2000. EPA 815-R-00- 013. Available online www.epa.gov/ogwdw.
US EPA. 2000i. National Primary Drinking Water Regulations; Arsenic and Clarifications to Compliance and New Source Contaminants Monitoring; Proposed Rule. Federal Register. Vol. 65, No. 121, p. 38888. June 22, 2000.
US EPA 2000j. SAB Report from the Environmental Economics Advisory Committee (EEAC) on EPA's White Paper "Valuing the Benefits of Fatal Cancer Risk Reduction. EPA-SAB-EEAC-00-013. July 27, 2000.
US EPA 2000k. Guidelines for Preparing Economic Analyses. EPA 240-R-00-003, September 2000.
US EPA 2000l. Internal Memorandum dated September 30, 2000 from Industrial Economics, Inc. to EPA. Update to Recommended Approach to Adjusting WTP Estimates to Reflect Changes in Real Income.
US EPA 2000m. National Primary Drinking Water Regulations; Arsenic and Clarifications to Compliance and New Source Contaminants Monitoring; Notice of Data Availability. Federal Register. Volume 65, Number 204. October 20, 2000. Page 63027-63035.
US EPA 2000n. National Primary Drinking Water Regulations; Arsenic and Clarifications to Compliance and New Source Contaminants Monitoring. Correction. Federal Register. Volume 65, Number 209. October 27, 2000.
US EPA 2000o. Arsenic Economic Analysis. Prepared by Abt Associate. EPA 815-R-00-026 December 2000.
US EPA 2000p National Primary Drinking Water Regulations; Radionuclides; Final Rule. Federal Register. Volume 65, Number 236. December 7, 2000.
US EPA 2000n. Arsenic Proposed Drinking Water Regulation: A Science Advisory Board Review of Certain Elements of the Proposal. EPA-SAB-DWC–1-001. December 12, 2000. www.epa.gov/sab.
US EPA 2000r. Arsenic Occurrence in Public Drinking Water Supplies. Prepared by ISSI for Office of Ground Water and Drinking Water. EPA 815-R-00-023. December 2000.
US EPA 2000s. Impact of the Arsenic Rule on the Technical, Managerial, and Financial Capacity of Public Water Systems. December 29, 2000.
US EPA 2000t. Arsenic Technologies and Costs for the Removal of Arsenic from Drinking Water. December 2000.
US EPA 2000u. Arsenic Response to Comments Document. December 2000.
US EPA. 2000v. Radon and Arsenic Regulatory Compliance Costs for the 25 Largest Public Water Systems (With Treatment Plant Configurations) Prepared for U.S. EPA by Science Applications International Corporation. December 2000.
US EPA. 2000w. Final Regulatory Flexibility Analysis (FRFA) for the Final Arsenic Rule. December 29, 2000.
US EPA. 2000x. A Re-Analysis of Arsenic-Related Bladder and Lung Cancer Mortality in Millard County, Utah. Office of Ground Water and Drinking Water, Washington, DC. EPA 815-R-00-027. December 2000.
US EPA. 2000y. Geometries and Characteristics of Public Water Systems. Final Report. Prepared by Science Applications International Corporation under contract with EPA OGWDW. EPA 815-R- 00-024. 2000.
US EPA. 2001. National Primary Drinking Water Regulations; Arsenic and Clarifications to Compliance and New Source Contaminants Monitoring; Final Rule. Federal Register. Vol. 66, No. 14, p. 6976. EPA-815-Z-01-001. January 22, 2001.
US EPA. 2001. National Primary Drinking Water Regulations; Arsenic and Clarifications to Compliance and New Source Contaminants Monitoring: Delay of Effective Date; Final Rule. Federal Register. Vol. 66, No. 99, p. 28342. May 22, 2001.
US GS. 1998. Reese, R.G. Jr. Arsenic. In United States Geological Survey Minerals Yearbook, Fairfax, VA, US Geological Survey.

US GS. 1999. Reese, R.G. Jr. Arsenic. In Mineral Commodity Summaries. Fairfax, VA, pgs. 26-27. US Geological l Survey. January 1999.
US GS. 2000. Focazio, M., A. Welch, S. Watkins, D. Helsel & M. Horn. A retrospective analysis of the occurrence of arsenic in ground water resources of the United States and limitations in drinking water supply characterizations. Water Resources Investigations Report:99-4279. May 2000.
US Public Health Service. 1943. Public Health Service Drinking Water Standards. Approved Revisions to the 1925 Drinking Water Standards on December 3, 1942. Public Health Reports. 58(3):69-82. January 15, 1943.
US Public Health Service. 1946. Public Health Service Drinking Water Standards. Approved Revisions to the 1942 Drinking Water Standards by the AWWA. Public Health Reports. 61(11):371-384. March 15, 1946.
Vahter, M. and E. Marafante. 1983. Intracellular interaction and metabolic fate of arsenite and arsenate in mice and rabbits. Chem.-Biol. Interact. 47:29-4.
Vahter, M. 1994. Species differences in the metabolism of arsenic. In: W.R. Chappell, C.O. Abernathy and C.R. Cothern, eds., Arsenic Exposure and Health, Science Technology Letters, Northwood, England. pp. 171-180.
Vahter, M. 1994. Species differences in the metabolism of arsenic compounds. Applied Organometallic Chemistry. 8:175-182.
Valentine, J.L., S.-H. He, L.S. Reisbord, and P. L. Lachenbruch. 1992. Health response by questionnaire in arsenic-exposed populations. Journal of Clinical Epidemiology 45:487-494.
Vallee, B. L., D. D. Ulmer and W. E. C. Wacker. 1960. Arsenic Toxicology and Biochemistry. AMA Arch. Ind. Med. 21:56-75.
Wester, R.C., H.I. Maibach, L. Sedik, J. Melendres and M. Wade. 1993. In vivo and in vitro percutaneous absorption and skin decontamination of arsenic from water and soil. Fundamental Applied Toxicology 20:336-340.
WHO (World Health Organization). 1981. Environmental Health Criteria 18 Arsenic. United Nations Environment Programme, International Labour Organization, and the World Health Organization.
WHO (World Health Organization). 1993. Guidelines for Drinking-Water Quality. Volume 1. Recommendations. World Health Organization. Geneva.
WHO (World Health Organization). 1998. International Agency for Research on Cancer, World Health Organization, “Cancer Survival in Developing Countries,” Publication No. 145, 1998.
Winship, K. A. 1984. Toxicity of Inorganic Arsenic Salts. Adverse Drug Reactions and Acute Poisoning Reviews. 3:129-160.
Wong, O., M.D. Whorton,D.E. Foliart and R. Lowengart. 1992. An ecologic study of skin cancer and environmental arsenic exposure. International Archives Occupational Environmental Health 64:235-241.
Woods, J.S. and B.A. Fowler. 1977. Environmental Health Perspectives 19:209-213.

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