# An Occupational Hygiene and Safety Primer, Volume 1

# An Occupational Hygiene and Safety Primer, Volume 1

*TIM RYAN*

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**OCCUPATIONAL HYGIENE & SAFETY**

*A college primer*

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# Preface

The cost of a college education has become excessive in the United States. Stories of students graduating with a decade or more of debt are not uncommon. Contributing to such debt are things like room and board, tuition, athletics fees, technology surcharges, and textbooks. Textbooks are not at the top of the list for expenses but considering how their costs have exceeded the rate of inflation of late, and how their contents can so readily become dated—or simply left unread by the student—certain steps can be taken to reduce at least this expense for the college student of the ‘20s. This open-sourced, non-copyrighted book is one such example of such a step. Produced in part with assistance of an Ohio University 1804 grant, this book seeks to limit direct college expenses to students who require the information it contains.

This book is intended to teach the basic tenets of occupational hygiene and safety to a wide variety of undergraduate college students with quite diverse backgrounds. Although helpful, chemistry, physics, biology and advanced math are not necessary to understanding and comprehension of the materials it contains. Most of the content is of a qualitative nature, and where more mathematical or engineering topics are covered, Google and YouTube are your friend.

Much of the technical content of Occupational Hygiene & Safety has been written based on over twenty years of teaching the topic at Ohio University. This includes the many graphics, tables, photos and thought questions pulled directly from my presentations developed, then repeatedly revised and updated, over the years. An almost equal volume of material has been reproduced from materials in the public domain in the United States of America. Primary sources for such text, photos, graphics and calculations include the National Institute for Occupational Safety and Health (NIOSH), the

Department of Labor's Occupational Safety and Health Administration (OSHA), the Environmental Protection Agency (EPA), and the US Centers for Disease Control and Prevention (CDC). Where appropriate, specific research articles and journal citations are provided. I am greatly indebted to the unsung authors of so many of the paragraphs and sections I unabashedly pulled from their websites, documents, reports, and examples. The writing, editing, and formatting of this text are due to the work of Olivia Bower (B.S., M.Ed) through Ohio University's 1804 grant.

What to include in a book such as this is quite subjective. To assist in that selection process a number of highly regarded textbooks and manuals of occupational health and industrial hygiene were screened. These included the classic and premier "White Book" titled The Industrial Environment – its Evaluation and Control published by NIOSH in 1973. Another classic was the so-called "new White Book" (officially titled The Occupational Environment: Its Evaluation, Control, and Management). Published by the American Industrial Hygiene Association first in 1997, it was updated in 2003 and substantially revised again in 2011. I looked to it for pertinent topics suitable for the intended audience of this book, and my chapter from that formed the basis for most of my biological safety content included here. Finally, the 1999 text by Debra K. Nims titled Basics of Industrial Hygiene, which I used extensively in the time I taught this class live in the classroom at Ohio University, was influential in organizing the topics included in this book. Noted by Nims to be written at the technician level, I consulted it both for topic presentation order and level of detail. To all of the authors and editors of these works I am much appreciative.

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PART I

# ANTICIPATION

# 1. Introduction and History

## Learning objectives and terms

Identify and explain what activities occupational health professions entail.

Identify common workplace safety issues.

Identify significant events in health and safety history in the last 2,000 years.

**Terms**

- Industrial/occupational hygiene
- Occupational Safety and Health Act
- Physical agents
- Chemical agents
- Biohazards
- Radiation
- Paracelsus
- De Morbis Artificum Diatriba
- Dr. Alice Hamilton

# Introduction

What is **occupational hygiene (OH)**? OH, or industrial hygiene (IH), as it is often referred to in the US, is the science and art devoted to the anticipation, recognition, evaluation, and control of environmental factors or stressors. It overlaps with several related areas, including environmental health and safety. Environmental health often encompasses both industrial/occupational hygiene and safety measures but tends to focus more on macro-environmental issues like air pollution, water pollution, hazardous and municipal wastes, sanitary water, and food issues. The definition of occupational safety is less precise. Like OH, it is concerned with the working population mostly, but it is focused more on accidents, losses, and the financial impacts. Occupational safety is slightly more code driven and less investigation-based in its approach to problem solving.

*Photo by Pop & Zebra.*

# Aspects of occupational hygiene

Occupational hygiene includes activities such as examining hazards of materials, conducting workplace surveys, training employees, reviewing programs, and keeping records. Occupational hygienists frequently find themselves asked to resolve critical matters related to employees' long-term health or safety, addressing questions such as:

- Is this chemical safe to handle without gloves?
- How loud is it in this room, and do I need hearing protection?
- What do I do with this leftover material we used to build our production model?
- How much of this chemical is in my workplace air? Will it harm me?
- Is this product going to make me sick or cause cancer?
- Can you do something to ventilate my workstation so it doesn't smell like paint?
- I was on the hospital elevator with an HIV patient—should I be worried?
- There is equipment here labeled with the radiation symbol…why?

# Regulatory framework

The major developmental American legislation for occupational health came in 1970 with the Department of Labor's Occupational Safety and Health Act (OSHA), which led to several present-day occupational health organizations. The regulations of this act include the creation of the Occupational Safety and Health

Administration (also OSHA), with several duties including inspecting workplaces. This is done with about 2,000 full-time OSHA employees. OSHA also issues and enforces rules and regulations, and states can have their own programs.

The areas covered under OSHA are general industry, construction, and maritime. General industry includes workers such as those who build or assemble things (i.e., widgets). The act created the National Institute for Occupational Safety and Health (NIOSH), which researches aspects for OSHA and recommends standard based on scientific findings.

## Types of health and safety issues

**Physical agents**

Physical agents include things like loud noise, vibration, almost all workplace-related muscle strains, sprains, and injuries caused by repeated motions, electrical hazards, and frequently hot and cold stress. Safety issues in this area can include workers' compensation and ergonomics, slips, trips, falls, amputations, and simple first aid.

Emphasizing loss prevention and risk management tactics may prevent issues involving workers’ compensation (WC). Problems in ergonomics may focus on repetitive stress diseases, like carpal tunnel syndrome, or job design.

*Photo by Chuttersnap.*

*Photo by Josue Isai Ramos Figueroa.*

**Chemical agents**


*Photo by Andre Robillard.*

The world is nothing if not chemicals. What most people are concerned about, however, are *toxic or hazardous* chemicals. Chemicals are everything and exposures to these is part of life itself. From the air we breathe to dirt on the ground, from the food we eat to the pills we take, from the materials used in our clothing to the things in our homes, all are formed from elements, compounds, and chemicals. For those agents that are particularly problematic, the OH is often involved in safe guarding employees as well as end-users from untoward effects.

Problematic chemical agents may include basic elements such as mercury, cadmium, lead, hydrogen, and beryllium, while additional safety issues may stem from compounds of elements like hydrogen chloride or benzene, and workplace mixtures like solder flux, Liquid Paper, or 409 Cleaner. Workplace chemical waste, if not disposed of properly, can also be hazardous both to those handling it as well as the world into which it is deposited. Everyday consumer products include multiple potentially hazardous materials, albeit in small quantities. Examples include cell phones, computers, touch displays, and even broken fluorescent bulbs.

The foods we eat—at industrial concentrations or in large quantities—can be a problem. The chemical diacetyl, often used to flavor food or drinks, can cause Popcorn Workers' Lung if inhaled by workers manufacturing microwave popcorn.

**Biohazards**

Fungi, bacteria, viruses and parasites are all considered biohazards, meaning they could infect and cause diseases or conditions to those exposed. These agents can be common place, such as Hepatitis A virus found in a daycare center population, or more arcane, such as Hepatitis B virus isolated in a hospital laboratory. Common biohazards include bloodborne pathogens, like those found in hospitals, clinics, airports, or other public areas, and infectious diseases, whether they are hazards to humans, crops, or animals.

*Photo by Drew Hays.*

**Radiation**

Radiation in the workplace may appear in the form of x-rays, in medical uses, as lasers, RF, radar, microwave, radio, television, cell phones, welding and in other appliances. Particle types are alpha, beta, love, and quarks, and they are found in reactors, accelerators, home uses, and weapons plants.

## History of occupational health

The history of occupational health is rich with thousands of years of trial and error, discovery, and innovation. This history dates back to 1,000,000 B.C. when flintknappers suffered cuts and eye injuries and bison hunters contracted anthrax. In 10,000 B.C., food-producing economies sparked the beginning of occupations. In 5,000 B.C., food producing occupations moved to metal work. Although Hippocrates dealt with the health of citizens and not primarily workers in 370 B.C., he was able to recognize lead poisoning in miners and metallurgists.

*Image via buffalolib.org.*

Moving steadily along, Plinius Secundus in 50 A.D. discovered the use of animal bladders in preventing inhalation of dust and lead fumes. In the tome De Re Metallica from Georgius Agricola in 1556, every facet of mining, smelting, and refining are displayed. In its many woodcut illustrations the book also depicts the risk of prevalent diseases, accidents, and means of prevention, like ventilation. In 1567, Paracelsus, remembered as the father of toxicology, described respiratory diseases among miners with an excellent description of mercury poisoning, writing, "All substances are poisons . . . the right dose differentiates a poison and a remedy."

Bernardino Ramazzini, the "father of occupational medicine," published the book *De Morbis Artificum Diatriba*

(Diseases of Workers) in 1700. Percival Pott in 1775 described occupational cancer among father and son chimney sweeps, identifying soot and the lack of hygiene measures as a cause of scrotal cancer. The result was the Chimney-Sweeps Act of 1788 passed in British Parliament.

*Image via cancer.gov.*

Occupational health continued developing into the 1900s with Dr. Alice Hamilton, who investigated dangerous occupations and wrote Exploring the Dangerous Trades about her work. This has a tremendous influence on early regulation of occupational hazards in the United States, and in 1919, Hamilton became the first woman faculty member at Harvard University.

Professional and governmental occupational health programs began taking shape in the early 1900s. In 1914, the United States Public Health Service organized the Division of Industrial Hygiene and Sanitation, and the American Public Health Association organized a section on industrial hygiene. In 1922, Harvard established an industrial hygiene degree program. The National Conference of Governmental Industrial Hygienists formed in 1938 and was later renamed the American Conference of Governmental Industrial Hygienists (ACGIH). Also in 1938, the American Standards Association and ACGIH prepared first list of standards for chemicals, the maximum allowable concentrations or MAC list. These later became the current Threshold Limit Values of the modern-day ACGIH. The American Industrial Hygiene Association

(AIHA) was formed only a year later than the ACGIH, in 1939, and is now widely regarded as the premier professional organization of OH and IH professionals worldwide.

## Questions and problems

1. This federal agency conducts occupational safety research and based on that function, recommends standards to OSHA for safe worker exposures.

    a. National Institute for Occupational Safety and Health, NIOSH

    b. American Conference of Governmental Industrial Hygienists, ACGIH

    c. Centers for Disease Control and Prevention, CDC

    d. National Centers for Injury Prevention and Control, NCIPC

2. The role of the IH in general is to:

    a. Anticipate or Prevent

    b. Recognize and Evaluate

    c. Control

    d. All of the above

3. OSHA refers to:

    a. The Occupational Safety and Health Administration

    b. A small town in Wisconsin

    c. The Occupational Safety and Health Act

d. Both A and C

4. Percival Potts determined that this cancer was caused by excessive exposure to soot in male chimney sweeps, which ultimately lead to legislation in England governing exposure.

a. Brain cancer

b. Prostate cancer

c. Skin cancer

d. Scrotum cancer

5. Explain the historical significance of:

a. Agricola

b. Paracelsus

c. Alice Hamilton

d. ACGIH

6. List the 4 major classes of workplace hazardous exposures, and give an example of one each.

7. True or false: OH is the same as IH

8. True or false: OH is the same as Safety

9. True or false: Environmental Health is the same as Safety

## Bibliography and resources

*Photos are individually linked to their sources when possible.*

*Information from Dr. Tim Ryan.*

PART II

# RECOGNITION

# 2. Regulations, Standards, and Legalities

## Learning objectives and terms

Define and understand purpose of Occupational Exposure Limits.

Understand the considerations that go into setting standards and limits.

Identify categories of limits and understand when they are used.

**Terms**

- Occupational Exposure Limits
- Local toxic effects
- Systemic toxic effects
- Acute toxicity
- Chronic toxicity
- Long term exposure limits
- Time Weighted Average
- Short term exposure limits

- Ceiling limits
- "Skin" notation
- Synergistic substances
- Additive substances
- Independent substances

# Introduction

**Setting of Hygiene Standards and Exposure Limits**

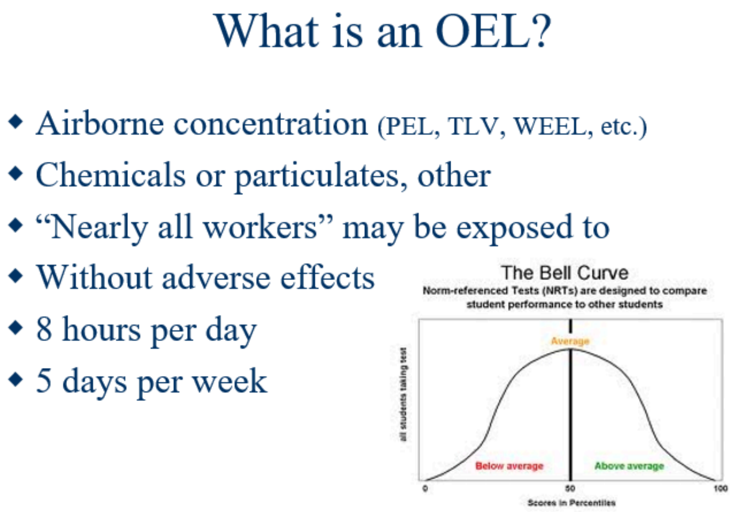
There are three main types of hygiene standards: chemical agents, physical agents, and biological exposure indices. Chemical agents include gases, vapors, fumes, mists, dusts, and aerosols. Physical agents include noise, vibration, heat, cold, and radiation (ionizing and non-ionizing).

When setting hygiene standards for hazardous agents, one must consider the effects the agents might have on the body. Such effects may be contact and **local toxic effects** at the site of contact (skin, eye, respiratory tract, etc.). Three more types of effects are **systemic toxic effects**, which are remote from the site of contact, meaning any organ system, like blood, bone, nervous system, or the kidneys; **acute toxicity**, which means the adverse effects occur within a short time of exposure to a single dose, or to multiple doses over 24 hours or less; and **chronic toxicity**. Effects of acute toxicity are irritation, asphyxiation, and narcosis. Other effects are absorption, transport, metabolism, storage, and excretion. Data for setting hygiene standards is gathered from many areas. These include animal studies, human research and experience, epidemiology, and analogy.

**Occupational Exposure Limits** (OELs) are not an index of toxicity and do not represent a fine demarcation between good and bad practice. They are based on the current best available information and are liable to change. If there is not a hygiene standard set for a chemical substance, it does not mean that substance is safe.

Good occupational hygiene practice is to keep airborne contaminants to the lowest level possible, not just below the relevant hygiene standard(s). OELs apply to occupational exposure of adults and are not applicable to environmental exposure where more susceptible groups, like pregnant women or children, exist. For chemicals, OELs generally relate to airborne concentrations—that is, they only take into account the inhalation route of entry. They generally refer to single substances, though some guidance may be given on mixed exposures.

OELs as used here is a generic term, when in practice there are at least four specific “brands” of OELs. The threshold limit values, or TLVs, are published by the American Conference of Governmental Industrial Hygienists (ACGIH) whereas the workplace environmental exposure limits, WEELs, have been put forth by the American Industrial Hygiene Association (AIHA). Each group has its own reasons for their values, and sometimes they are the same values and other times they are not. The government entity responsible for U.S. health and safety research, the National Institute for Occupational Safety and Health, NIOSH, routinely publishes recommended exposure limits (RELs) which the government enforcement agency, OSHA, can adopt or not as they see fit. Only when OSHA has promulgated an exposure standard called a permissible exposure limit, or PEL, is the OEL enforceable by law and subject to civil and criminal penalties for its violation.




## Quantifying airborne concentrations of chemical agents

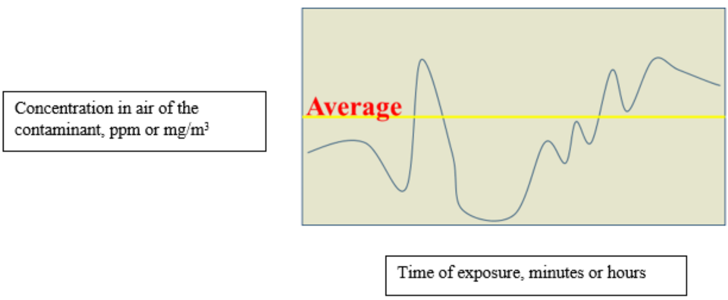
Airborne contaminants can be quantified in several ways. One way is by volume, which is measured in atmospheric concentration in parts per million (ppm). Another way is by weight, measured by milligrams of substance per cubic meter of air (mg.m3).

**Categories of Exposure Limits**

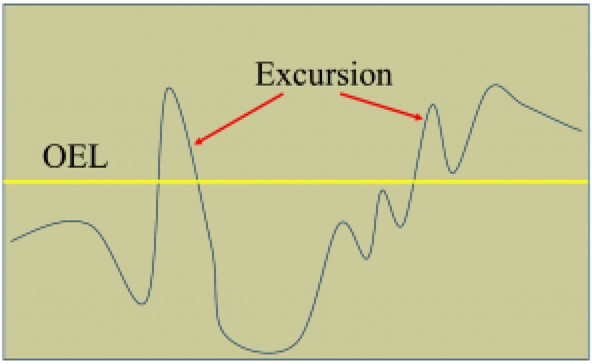
There are four categories of exposure limits: time weighted, short term, ceiling, and action levels. A **Time Weighted Average** (TWA) normally over an eight-hour period. See the TWA formula below. This allows for exposures to vary through the working day so long as the average exposure does not exceed the limit.

$$TWA = \frac{C_1T_1 + C_2T_2 + \ldots + C_NT_N}{T_1 + T_2 + \ldots + T_N}$$

In the formula, TWA is the time weighted average of concentrations C1-CN, which occurred for times T1-TN. Think of the TWA simply as an average, weighted by the individual concentrations and the times each of those existed during the exposure (yellow line in figure below).



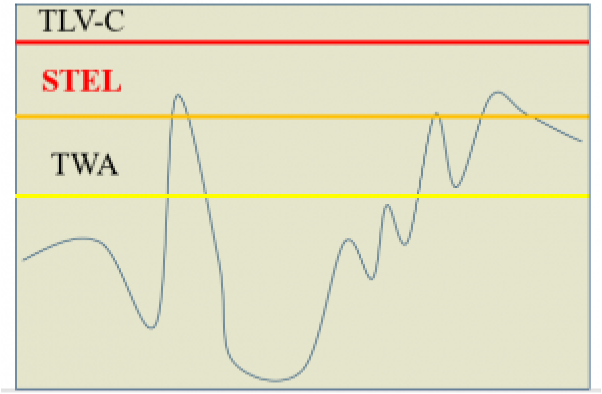

Any average exposure will have peaks and valleys, where the concentration exceeds and is below the TWA. Such excursions are permitted so long as they are not excessive in either amount or duration. Obviously very high or very long excursions would send the TWA above the OEL. **Excursions** in worker exposure levels may exceed three times the TWA for no more than a total of 30 minutes during a workday, and under no circumstances should they exceed five times the TWA, provided the TWA is not exceeded.



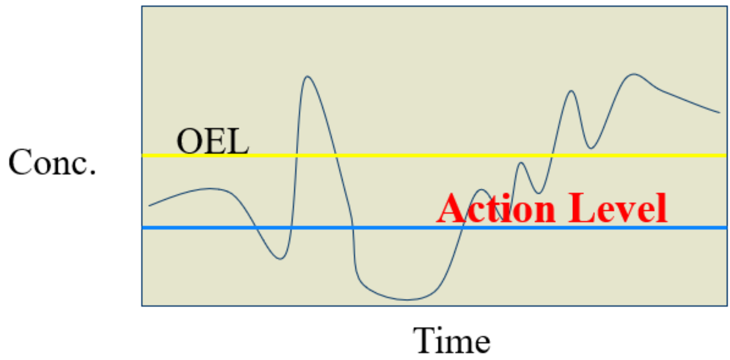

**Short Term Exposure Limits** (STELs, orange line in the figure below) are used when exposure for short periods of time occurs, normally over a 15-minute maximum period. A STEL is essentially a **limit of the peak** exposures permitted by TWAs. Where stipulated, STELs are intended for control of irritant effects especially. STELs are 'mini' TWAs, with exceedance limited to less than five times per day, with any exceedance followed by 60 minutes of no exceedance. STELs are concentrations to which workers can be exposed continuously for a short period of time without suffering from irritation, chronic or irreversible tissue damage, narcosis of sufficient degree to increase the likelihood of accidental injury, impaired self-rescue, or materially reduced work efficiency.

STEL exposure should be recorded as the average over the specified short-term reference period of 15 minutes and should normally be determined by sampling over that period. If the exposure period is less than 15 minutes, the sampling result should be averaged over 15 minutes. For example, if a five-minute sample produces a level of 150 ppm and is immediately followed by a period of zero exposure, then the 15-minute average exposure will be 50 ppm.

Related to the STEL is the **Ceiling limit, C**. **Ceiling Limits** are sometimes defined for concentrations that should not be exceeded during any part of the working exposure (red line in the figure below).




The last true OEL is called an **Action Level, or AL** (see the blue line in the figure below).  It is an airborne concentration in ppm or mg/m3 that is usually about half of the TWA, or half of the TWA for OELs not expressed as airborne concentrations (e.g., 85 dB-A for noise, where the PEL is 90 dB-A). The AL is a recommended exposure level at which to become more vigilant, typically half the TWA. For example, if the TWA is 1.0 ppm, an AL of 0.5 ppm would be typical. ALs are not that common but normally entail added compliance activities for the employer where stipulated.




While not a true or conventional OEL, **Skin Notation** is sometimes indicated for certain chemicals. "Skin" Notation means that substances can have a contributing exposure effect by the cutaneous route, including mucous membranes and eyes. There are no units for a Skin Notation chemical. "**SENSITIZER" Notation**, or 'SEN' refers to an agent has documented sensitizing potential that can result via inhalation or dermal route of exposure. Like Skin Notation, it is unitless and not a true OEL.

## Effects of mixed exposures

Many workplaces do not have single component exposures. Rather, the employees are routinely exposed to a mixture of chemicals used to create their end work piece. **Additive substances** are defined when and where there is reason to believe that the effects of the exposure mixture are additive and where the OELs are based on the same health effects. In this case, the mixed exposure should be assessed using the formula below, where C1-CN is the workplace concentration of chemicals 1-N, and T1-TN is the OEL for each such chemical. Using this mixture rule, one will note that if any single chemical 1-N exceeds the OEL, the workplace exposure to the entire mixture is violated. Its real benefit is for places where typically low concentrations of like substances (e.g., solvents) are used.

$$\frac{C_1}{T_1} + \frac{C_2}{T_2} + \ldots + \frac{C_N}{T_N} = K$$

**Independent substances** mean that no synergistic or additive effects are known or considered likely. In such a case, the constituents can be regarded as acting independently, and the measures needed to achieve adequate control can be assessed separately for each, irrespective of the mixture rule applied for additive substances. **Synergistic substances** are considerably less common than the other types of behavior in mixed exposures.

## Questions and problems

1. A. Consider an employee working in a pharmaceutical preparation area of a large corporation. She uses chemical "X" at the concentrations shown in the table below, or the amount of time shown for each. Sometimes it is not possible to record a single eight-hour exposure to generate a TWA value, and so we must use the TWA formula shown here.

| TIME PERIOD (NUMBER) | CONCENTRATION (PPM) | TIME (HOUR) |
|---|---|---|
| 1 | 80 | 2 |
| 2 | 110 | 4 |
| 3 | 55 | 2 |

$$TWA = \frac{C_1T_1 + C_2T_2 + \dots + C_NT_N}{\text{hours}}$$

Using the data in the table and the TWA formula, what is her exposure to this one chemical on this one day?

Solution:

$$TWA = \frac{(80 \text{ x } 2) + (110 \text{ x } 4) + (55 \text{ x } 2)}{2 + 4 + 2}$$

$$TWA = (160 + 440 + 110) \div 8$$

$$TWA = 88.75 \text{ ppm}$$

B. If the allowed OSHA PEL for chemical X is 100 ppm, is this employee overexposed?

C. Do you think the employee will be free from any toxicological effects at this concentration of exposure? Explain.

# Bibliography and resources

Information adapted from OH Learning course: Basic Principles in Occupational Hygiene.

# 3. Toxicology

## Learning objectives and terms

Define and understand the vernacular of modern toxicology.

Demonstrate the ability to evaluate the hazards of industrial toxicants.

Explain the strengths and weaknesses of toxicology as it pertains to occupational safety.

Terms

- Toxicology
- Biotransformation
- LD50
- LC50
- ED50
- Dose-response curve
- NOAEL
- NOEL
- Non-threshold model
- Acute toxicity
- Chronic toxicity

- Toxic models of chemical mixtures
- Target organ

## Introduction

Paracelsus (c. 1500 CE) stated that "all substances are poisons; there is none which is not a poison. The right dose differentiates a poison and a remedy." This expression is as true today as it was 500 years ago, but we often shorten it to simply say "the dose makes the poison."

There are perhaps a million chemicals in the world around us, with some 70,000 in global use at any given time. But less than 500 are directly regulated by OSHA under specific regulations. In many instances, the safe use of a new chemical or product will require professional evaluation of reports about the new material's chemical and biological properties. This is where toxicology comes into play. **Toxicology** studies the adverse effects of chemicals on living organisms. It measures the severity and frequency of effects—both good and bad—from exposure to chemicals. Depending on the end-use of such evaluations, they will pertain primarily to the professions of pharmacology and biochemistry, forensics, clinical toxicology, and/or industrial exposures related to OSHA Hazard Communication aspects.

## Routes of exposure

The majority of substances to which people are exposed fall into the well-recognized categories of foods and beverages. Since all substances on the planet are technically chemicals (i.e., atoms and elements, compounds, molecules, substances, or even formed products) most of our exposures to chemicals are from things we intentionally ingest, eat, and drink. Within the workplace, however, inhalation of airborne materials is the leading cause of exposures to a minority category of materials we can describe as potentially hazardous agents.

In addition to breathing in of gases, vapors of chemicals, or solid particulates, another major route of work-related chemical interaction is with the skin of the worker. In this age of increasing robotization of production floors, millions of humans are still employed to do important manufacturing jobs. Why? One reason is that people have great dexterity in their hands, and so people are uniquely qualified to process and adapt to intricate assembly needs. And with their hands touching products under production (e.g., painting, cleaning with solvents, treating metals in dip tanks), workers' hands and skin are frequently in contact with workplace chemicals. Even when protective gloves are used, liquids may find their way into the tops of the glove, or the gloves might become contaminated when shared between workers on different work shifts.

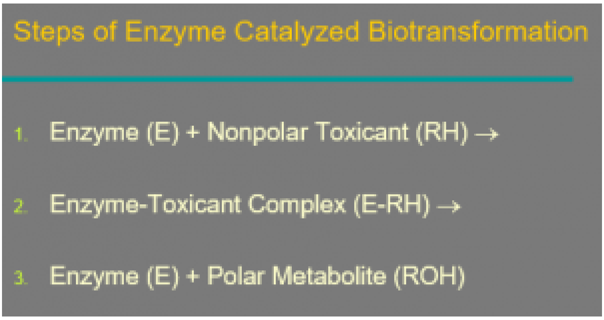
Within the healthcare sector, injection is a serious concern for exposure to workplace hazards. The most obvious example of this might be accidental injection by a dirty hypodermic needle or other sharp medical instrument. When needles contain toxic chemicals such as radiotherapy elixirs or chemotherapy drugs, injection is often the most likely route of an accidental occupational exposure.

# Fate of chemicals in the body

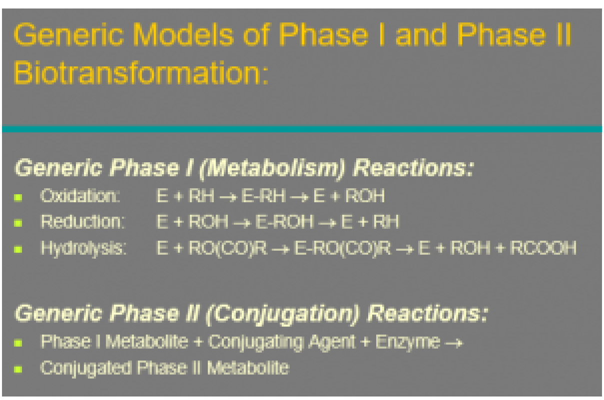
Once in the body a chemical agent is typically distributed via the blood to all areas of the body: heart, brain, lungs, kidneys, muscles, liver, and bones—by no means an exclusive list. Of these areas, the liver is frequently considered a “**target organ**” because it can be deleteriously affected by a great many agents. Since the liver has a relatively large blood volume or flow to it, bloodborne agents have greater contact with the cells of the liver (hepatocytes), and therefore those cells are more likely to suffer adverse effects.

The liver contains a multitude of biological enzymes that are used to metabolize, or breakdown, substances, whether they are beneficial or not. As a result, the enzymes constitute the frontline of chemical processing for many occupational toxicants. When a toxic chemical is acted upon by and enzyme (E, in the graphic below), the process is called **biotransformation** rather than the more general term metabolism. There are many enzymes and many types of reactions taking place in the liver, but most can be categorized as either Phase I (breaking chemicals down) or Phase II (building up chemicals), usually by the addition of a chemical group that makes the enzyme product more water soluble and easily removed.

Notice in the three-step process shown that it begins and ends with the enzyme, which in step three is again ready to transform another chemical. An enzyme called Cytochrome P450 is one of the most usual metabolizing enzymes responsible for the three-step oxidation reaction in the liver. The liver often acts upon a chemical (step one, RH, nonpolar toxicant) to make it more water soluble (step three, ROH, polar metabolite). In this way the liver is critical to the removal of many agents downstream, either as a direct liver product called bile or by later filtration of the water soluble ROH species into urine).




It was noted that the Phase I reaction shown above is just one of many possible enzyme and agent reactions. Several others are shown below and include reduction and hydrolysis. The Phase II reactions may act upon the Phase I products or act alone on the toxicant to form a Phase II conjugated metabolite as indicated.




The liver is not the sole means by which toxic chemicals are acted upon by the body. In fact, some agents may be eliminated from the body without much or any metabolic or biotransformation activity. The nitrogen which constitutes approximately 80 percent of the air we breathe is an example of one such chemical. Other materials brought into the body can be processed by the body within other organs (lungs, kidneys, skin) and eventually eliminated by means of action related to those specific avenues.

## Toxic measures

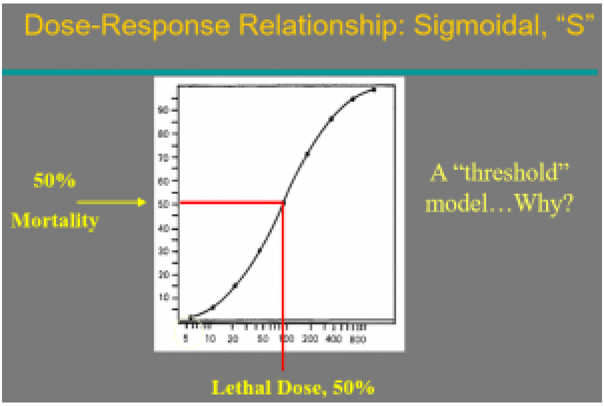
Once a chemical interacts with the human body, many outcomes are possible. There is usually a continuum of effects for many moderately toxic agents, meaning that the effects of exposure vary with dosage or amount and range from no or almost no observed effect all the way up to the most definitive of all outcomes: fatality. Because they are cheap, plentiful, easy to handle, genetically known, have traditionally been studied, are mammals (like humans), have relatively short life spans, and cannot regurgitate mixtures piped into their stomachs, the iconic laboratory rat is very often used to study the effects of new chemicals. Using such test subjects, the continuum of effects demonstrated upon exposures to ever larger amounts of agent might include:

- No effect
- No effect observable at the cellular level
- No effect to the naked eye
- A mild nervous system effect (e.g., longer times to run a maze, hostility)
- Serious, debilitating effects
- Unconsciousness
- Death

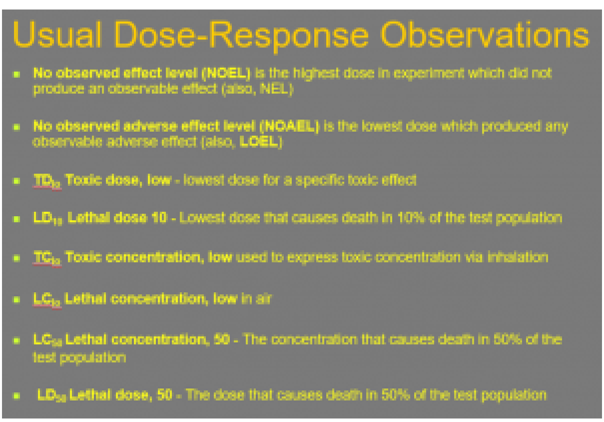
This graded response in relation to the amount of toxic agent administered is referred to as a "dose-response." As Paracelsus first noted, the more the dose of an agent, the more its toxicity. For example, a 300-pound man drinking a single alcoholic beer might not have any perceptible impairment in his driving ability, even though his response time could be tested and seen to be longer. But the same subject, after 12 beers would be greatly debilitated and unable to safely operate a motor vehicle. If he went on to consume even more alcohol—perhaps a case of beer in addition to one-ounce shots of high proof spirits—he would be risking alcohol poisoning, leading to death.

In the laboratory, toxicologists frequently carry out experiments where different groups of 10 rats are exposed to increasing amounts or concentrations of toxic agents. These are called **acute toxicity tests** when the dosages use lethality as the endpoint, or **chronic toxicity tests** when the effect chosen is lower on the spectrum of effects. In such tests, the researchers decide at the outset what effect will be measured; it is often fatality. They then add up the numbers of rats that die in each increasing dosage group and graph the results in order to create a dose-response curve as shown below. With such a graph, it is possible to identify the dose of the test chemical at which one-half of the rats live and one-half perish. This is defined as the "Lethal Dose – 50 percent" or simply the **LD50**.

Look at the Dose-Response Relationship graphic below. Notice that it might be described as a lazy S or sigmoidally shaped. At the lower left corner, you'll note that in this test data, there were no (zero) rat deaths at a dose of about five units of toxicant. Restated, there is a threshold for response to the chemical: at or below a certain exposure dose, no fatalities are seen. In this example, the dosages below five units would be labeled at the **"no observable adverse effect level"** (i.e., NOAEL).



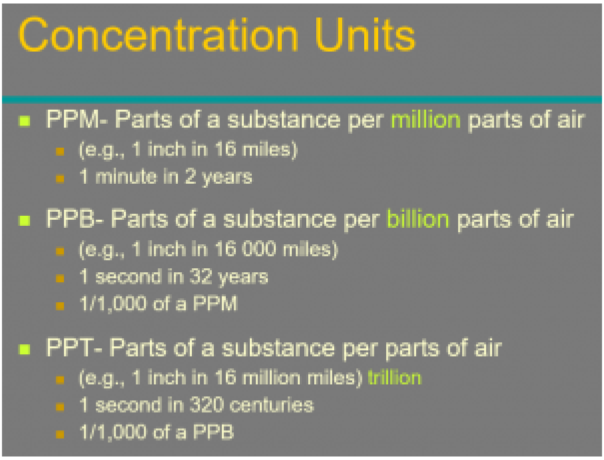

Other common toxicology measures can be defined using this sort of experimental approach. These include those shown below. It is up to the researching toxicologist to decide which measure to seek and report and decide upon an experimental approach that is appropriate to generate such data as necessary.



## Toxic units

Rats are not humans, and a two-pound rat requires much less of a given chemical to exhibit a toxic response than would our 300-pound man. To deal with this situation, we express the units of toxic dose on a mass of toxic agent per mass of body weight basis. Most often the units reported are mg/kg body weight, or mg/kg. When dosages are calculated based on the weight of the test subject, extrapolation of the results to similar, larger organisms is not only possible but also meaningful. As long as the test animal has key similarities to a human, we can mostly extrapolate such acute or chronic toxicity studies to people with the expectation that similar responses will be exhibited in people for a given dosage.

In stark contrast to pharmacological studies, where exposures are intentional for the purposes of treating symptoms or diseases, in occupational toxicology, we need to determine safe limits of exposure to fugitive emissions or incidental concentrations of toxic materials. Accordingly, data like LCLO values can be used in conjunction with assigned safety factors to further reduce allowable dosages. This determines safe concentrations of exposure to workplace chemicals. These concentrations are known by the general term Occupational Exposure Limits. They are normally expressed in very low units of measure—parts of toxicant per million parts of air (ppm) or even parts per billion (ppb). One ppb is a thousand times less than one ppb; there are 1,000 ppb of a chemical in 1 ppm of that same concentration.




## Questions and problems

1. If a dose-response curve is graphed with "response" increasing from bottom to top on the vertical axis, and with "dose" increasing from left to right on the horizontal axis, for the majority of chemicals the graph would typically show:

a. A sigmoidal, or "S" shaped curve going from upper left to lower right

b. A perfectly straight line going from upper left to lower right

c. A sigmoidal, or "S" shaped curve going from lower left to upper right

d. A perfectly straight line going from lower left to upper right

2. You are exposed to a teratogen. You have a valid, scientifically-based reason for concern if:

a. You are a male and worry you'll never be able to have children

b. You are a female and worry you will develop cancer

c. You are a female and worry your child will be deformed by the chemical

d. You are a regulator and worry that persons will smuggle the material to "get high"

3. If the LD50 of a chemical is 500 milligrams per kilogram of body weight, then when extrapolated to the toxicological standard man (i.e., a 70 kilogram person), a lethal dose of this chemical for half of a test population…

a. Would be about 500 x 70 = 35,000 milligrams, or 35 grams, for men

b. Would be less than 35 grams for the toxicological standard woman

c. Both A and B

d. Neither A or B

4. If chemical "A" is toxic and its effect is amplified or made much greater by chemical "B", but "B" has no toxic effect at the same concentration as chemical "A" {i.e., 1 + 0 = 2}, this would be a chemical interaction best described as:

a. Antagonism

b. Synergism

c. Additive effect

d. Potentiation

5. For Acute Toxicity Studies, various responses are used, including:

a. Death

b. Autopsy examination

c. Histological examination of tissues

d. Only A and B

e. All of the above

6. When a toxicant is transformed within the body to a more damaging material, the reaction is best termed:

a. Bioactivation

b. Biotransformation

c. Bioconcentration

d. Biochemistry

7. The relationship between 1,000 parts per billion (ppb) and 1 part per million (ppm) is:

a. The ppb level is 1,000 more concentrated than the ppm concentration

b. The ppb level is 1,000 less concentrated than the ppm concentration

c. They are equal

d. Both are within the "flammable range" for all chemicals

8. Rats are used in many toxicology studies because:

a. They can't vomit

b. They are mammals, as are humans

c. They are relatively cheap and inexpensive to care for

d. All of the above

9. Study the following generalized equation, where S = substrate and E = enzyme

$$E + SH \rightarrow E\text{-}SH \rightarrow E + SOH$$

Which of the following are TRUE of this reaction?

a. It shows a generalized oxidation reaction of biotransformation

b. It shows a generalized reduction reaction of biotransformation

c. It is categorized as a "Phase II" reaction

d. Both B and C

10. Who can be paraphrased as having said "the dose makes the poison?"

## Bibliography and resources

*Graphs, images, and information via Dr. Tim Ryan.*

PART III
# EVALUATION

# 4. Sampling for Gases and Vapors

## Learning objectives and terms

Understand the concept of volumetric air sample collection

Be able to correctly assemble a sampling train for a specific gas or vapor

Know how to calibrate air flow for a variety of pumps and media

Understand accuracy and precision

Identify primary and secondary calibration techniques and equipment

Terms

- Analyte
- Breathing Zone
- Bubble burette
- Calibrator
- Flow
- Grab samples

- Impingers
- Liquid absorbers
- NMAM
- Passive samplers
- Rotameter
- Sampling media
- Sorbent tubes
- VOC samplers

## Introduction

In terms of the four key elements of the occupational hygienist's duties—anticipation, recognition, evaluation, and control—the responsibilities for airborne hazards sampling and analysis fit most accurately into the area of evaluation. Sampling itself is part of the worksite analysis—an essential first step that helps an industrial hygienist determine what jobs and work stations are the sources of potential problems.

During the worksite analysis, the industrial hygienist measures and identifies exposures, problem tasks, and risks. The most effective worksite analyses include all jobs, operations, and work activities. The industrial hygienist inspects, researches, or analyzes how the particular chemicals or physical hazards at that worksite affect worker health. Only after the conduct of this quantitative workplace assessment can the industrial hygienist recommend the appropriate corrective actions. Usual specific reasons for air sampling are shown in Figure 1.


*Figure 1. Five most common reasons for air sample collection.*

To be effective in evaluating on-the-job hazards ahead of recommending any specific controls, hygienists must be familiar with the hazards' characteristics. Potential hazards can include ergonomic hazards, chemicals, biological agents, physical stressors, and the focus of this chapter: air contaminants.

Air contaminants are commonly classified as either particulate or gas and vapor contaminants. The most common particulate contaminants include dusts, fumes, mists, aerosols, and fibers and are the subject of a later section. Gases are formless fluids that expand to occupy the space or enclosure in which they are confined. They are atomic, diatomic, or molecular in nature, as opposed to droplets or particles, which are made up of millions of atoms or molecules. Through evaporation, liquids change into vapors and mix with the surrounding atmosphere. Vapors are the volatile form of substances that are normally in a solid or liquid state at room temperature and pressure. Vapors are gases in that true vapors are atomic or molecular in nature.

# Sampling

The approach to collecting a material from the air varies by the physical and chemical properties of the contaminant, characteristics of the air in which it is suspended, and the technology and equipment available for sampling. A variety of devices have been created for sampling, four of which are shown in Figure 2. Some sampling is done within a one-foot diameter of the worker's nose and mouth, in what is termed the **breathing zone**, or BZ. When BZ sampling is done, it normally requires the use of an air pump to move air from the environment through a device containing media that will trap the contaminants in the air, for later analysis. In Figure 2, the stainless steel (s.s.) tube and the charcoal tube are examples of such devices. Passive dosimeters, such as the 3M 3500® organic vapor monitor, do not require a pump for sample air collection, while the metered canister shown relies on vacuum pressure to collect air.

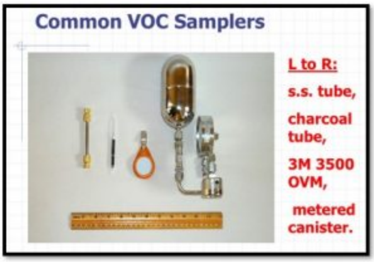



*Figure 2. Common devices for the collection of gases and volatile organic compounds* (VOCs).

Most IH samples that are collected for more than 15 minutes are considered time-weighted average (TWA) samples, while samples collected for exactly 15 minutes are done primarily to assesses adherence to the STEL limits (if established) for a chemical. Unlike TWA sampling performed frequently to check compliance with the OSHA PEL for a substance, grab samples are collected when a simple point-in-time airborne concentration of a substance would be helpful to know. Instances of this are when the IH has no idea what the area concentration of a substance might be and wants to establish a "ballpark" figure for further evaluation or when an unusual event has occurred, such as a spill or accidental release.

Of all the various approaches to trapping gases and vapors, the most familiar to IH/OH professionals is probably the charcoal tube (Figure 3) connected to a personal air sampler (PAS) pump (Figure 4). In combination, the PAS and tube are commonly referred to as a sampling train. While many different types of materials (i.e., sampling 'media') can be used in either the s.s. or glass tube, coconut shell charcoal has traditionally been the most frequently utilized. The typical charcoal tube is about three inches long and contains two separate sections of activated charcoal called the front and back sections.

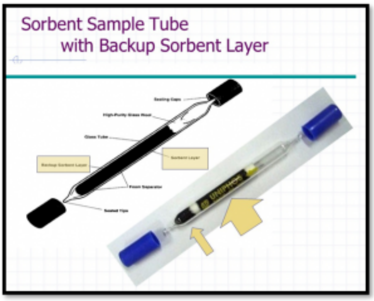



*Figure 3. Diagram of a sorbent tube (top) and actual charcoal filled glass sorbent tube (bottom). Thick yellow arrow indicates main section (front) and the thin arrow indicates the backup section (back) of tube. Circled in red is another very small arrow that points in the direction air is to move through the tube.*

*Figure 4. SKC brand of PAS pump. Note green lights indicate pump is running, and display shows a flow rate of 1.50 L/min. No sampling tube is connected to the inlet, the translucent round opening on the lower right side of the pump (red arrow).*

In practice, the PAS is operated at a known flow rate (often called "Q") for a known amount of time. By multiplying the flow rate of liters per minute (LPM) by the time (minutes), the total sample volume size is calculated. This volume is then used by the analytical laboratory to determine the concentration of airborne contaminant in the workplace and is expressed as either weight per volume (e.g., milligrams of contaminant/cubic meter air) or as parts per million of contaminant per million parts of air (e.g., ppm). For the analysis to be accurate the volume of air sampled must be accurately known. This is determined by the performance of sampling train calibration.

## Sampling train calibration

OSHA requires its agents to calibrate personal sampling pumps before and after each day of sampling using one of several techniques. If the sampling pump is equipped with a rotameter flow indicator, bear in mind that its accuracy is only approximate; it is intended primarily to facilitate crudely setting the flow rate for final calibration. Most of the following examples in this appendix use filter cassettes as the sampling media, but the examples are generally applicable to adsorbent tubes as well.

The basic calibration process measures the time air takes to move through a known volume. This can be accomplished with a soap film bubble burette, a graphite piston, or a precision rotameter. Actual calibration instructions from the OSHA instructions for calibration of several types of samplers are included as an appendix to this volume. Regardless of the equipment used, a flow rate Q is desired. Low flow rates are often expressed as milliliters per minute (mL/min) or as LPM.

Consider the Calibration Example below (Figure 5), in which a pump's rotameter is compared to a **bubble burette** (a type of soap film) calibrator. In this example the OH has observed that it required 55 seconds for a soap bubble to go from the zero (0) mark of a column to the 1,000 mL mark (i.e., 1 liter = 1,000 mL). That observed Q of 1,000 mL/55 seconds is somewhat difficult to appreciate, so it is converted first from seconds to minutes, then from mL to liters, resulting in the conventional way to express flows: Q = 1.09 LPM in this example.

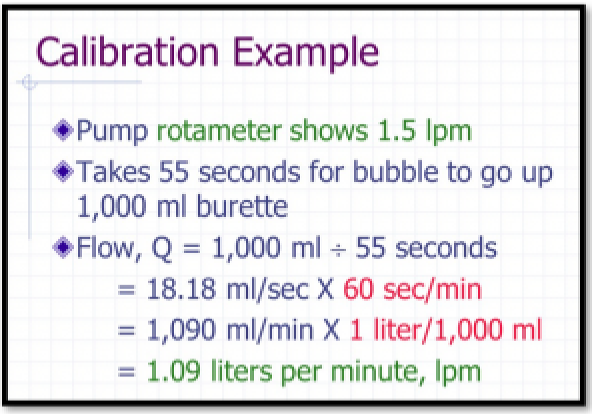



*Figure 5. Calibration Example.*

In any calibration, it is always important that the same type of sampling media is in-line during sampling pump calibration that will be used to sample in the field. It is also important that the PAS battery is fully charged and in good condition.

# Calibration error

*Fig. 6.*

In the calibration example above, it was stated that the pump's indicated flowrate on its rotameter (Figure 6) was 1.5 LPM, yet the true flow rate was only 1.09 LPM. Which is correct? Since the bubble meter is considered

a primary standard, in which a NIST-traceable, certified fixed volume is used in conjunction with a timer to accurately determine the flow, it is taken as the true measure. The rotameter is simply what was expected when adjusting the flow on the pump. In trying to ensure the validity of the OH measurement, the error associated with the sampling process is controlled so that it is both low (high accuracy) and predictable (high precision, also known as repeatability).

Consider again the Calibration Example (Figure 7). If we define the percent error of a measurement as the observed value less the expected value, divided by the expected value, we can quantitatively ascribe the proportion of difference attributable to the instrument being observed. Here, we used the rotameter to set our expected value of 1.5 LPM, but with the primary standard we observed the true Q as 1.09 LPM. This results in an error of almost 30 percent attributable to the pump's rotameter alone—very high indeed. (Multiplying our error proportion by 100 lets us express the error as a percentage.)  Note, too, that our error has a directionality to it, either over (+) or under (-) estimating our desired Q. In this example, if the IH had relied on the rotameter for her Q, she would have underestimated the amount of air contaminant in the work place by as much as 27.3 percent, and the possibility would exist that a worker would have been over exposed to that contaminant.

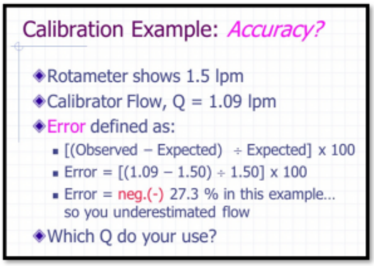



*Figure 7. Accuracy and error.*

## Electronic flow calibrators

Although it is helpful for understanding the concepts of volumetric air flow, calibration with a bubble burette as discussed above is not routinely done in the field. Typically, commercial soap-film or graphite piston calibrators are used, as depicted in Figures 8-A and 8-B. Properly functioning and calibrated units have an accuracy of approximately 99 percent, and the flow rates obtained from these devices can be reported to three significant figures. For example, a flow rate shown as 1.006 L/min should be reported as 1.01 L/min. Figure 9 shows a complete sampling train, including pump, hose, media connected to an electronic calibrator. After such a train is calibrated, it is detached from the calibrator, placed in pause or standby mode, then placed in the BZ of the employ before restarting in order to collect the sample.

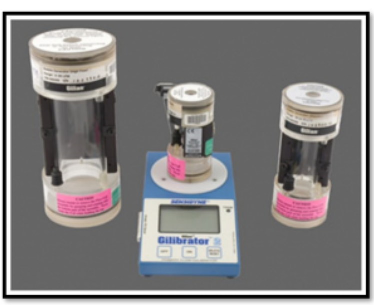



*Figure 8a. Commercial soap-film calibrator with 3 flow cell sizes. Via OSHA.*

Figure 8-A shows the Gilian Gilibrator® by Sensidyne®, an electronic bubble flow meter that provides instantaneous air-flow readings and cumulative averaging of multiple measurements. Such calibrators measure the flow rate and display the results as volume per unit of time (e.g., mL/min) and can be used to calibrate most air sampling pumps. Different flow cells are used to accommodate different flow

ranges. The middle-sized flow cell is typically used for personal sampling for particulates, while the largest cell is used for high volume area sampling and the smallest cell may be needed for certain low flow sorbent tube methods. The total range with the different flow cells is from 1 mL/min to 30 L/min.

The Bios Defender™ shown in Figure 8-B is an electronic dry-piston (graphite) flow meter used to calibrate sampling pumps that provides immediate and average readings. The device can be used to calibrate either pressure (labeled inlet) or vacuum (labeled outlet) flow sources. The vacuum port is used to calibrate sampling pumps, and the pressure port is used to calibrate the outlet of sampling pumps used to fill gas sampling bags. Different models of the instrument cover an optimum flow range of 5 mL/min to 30 L/min.


*Figure 8b. Commercial dry-piston pump calibrator.* Via OSHA.

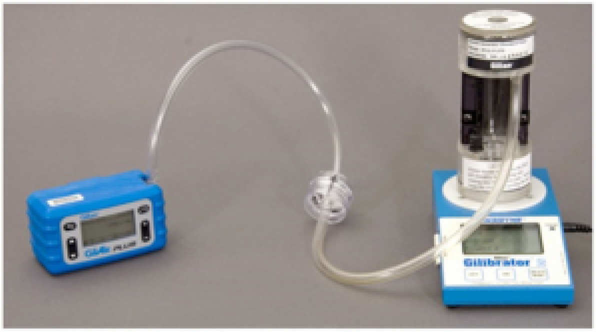


*Figure 9. A filtering cassette sampling train attached to a soap film calibrator. Via OSHA.*

# Analysis

In this chapter, we have only learned about how to accurately sample the air volumetrically. At the conclusion of our sampling, it is necessary to have the charcoal or other media expertly analyzed by an AIHA-accredited laboratory with the proven ability to state what was in the sampled air and how much of it was present. The variety of chemical analysis methods used to such ends is beyond the scope of this text, but a general description is possible.

After a sample has been submitted to the laboratory for analysis, the gas or vapor must be desorbed from the media. This desorption can be done by heating the tube under controlled conditions, or by removing the media from the tube, solvating the media to extract the collected sample, and then further processing the extract in an analytical device.

The specifics of every type of sample collection method and analysis are found in a document prepared and maintained by the research arm of the U.S. Department of Labor called the National Institute for Occupational Safety and Health (NIOSH). Their compendium of methods to be used is called the **NIOSH Manual of Analytical Methods** and is available via the web as a searchable database or in downloadable PDF formats. A cover page from of the NMAM for the sampling and analysis of alcohols, showing its organization and fields, is reproduced in Figure 10. In addition to this resource, the OH will also frequently consult the OSHA Technical Manual for instructions and guidance on both sample collection and analysis.

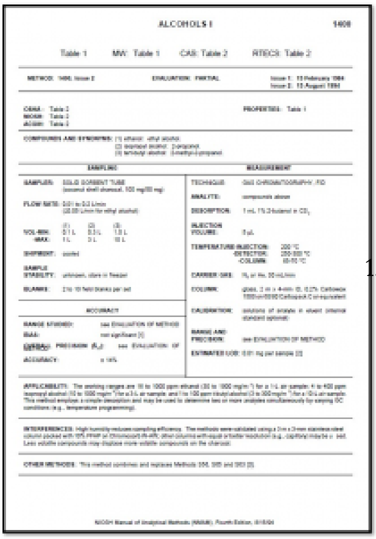

ALCOHOLS I 1400

Table 1 MW: Table 1 CAS: Table 2 RTECS: Table 2

*Figure 10. NMAM cover page for Alcohols I.*

# Questions and problems

1. The sampling train order for calibration of a solid sorbent tube is (airflow: →):

   a. Calibrator → sampling tube → sampling pump

   b. Tube → sampling pump → calibrator

   c. Pump → calibrator → tube

   d. Pump → tube → calibrator

2. If an air bubble requires 28 seconds to go from the zero ("0") mark of a calibration burette to the 100 milliliter mark, the flow rate ("Q") of the sampling train is:

   a. 3.57 ml/sec

   b. 214 ml/min

   c. 0.214 liters per minute

   d. All of the above

3. If you need to find out how to sample for airborne concentrations of PCBs, you would:

    a. Consult the NIOSH Manual of Analytical Methods

    b. Call OSHA for instructions

    c. Read the material safety data sheet for PCB

    d. Find the proper procedure in just about any textbook on IH sampling

4. This type of sample represents the instantaneous concentration of air in the place sampled, when the sample was collected.

    a. Short Term Exposure Limit

    b. Grab sample

    c. Diffusion badge sampler result

    d. Charcoal glass tube result if collected for about 8 hours

5. What is the percentage error if a sampling pump display shows 4.0 LPM but the calibrator for the sampling train to which the pump is attached indicates 4.30 LPM?

6. Would the analysis of a sample collected by the setup in the question above over-estimate or under-estimate the true concentration of the airborne contaminant?

# Bibliography and resources

OSHA Office of Training and Education. Industrial Hygiene (n.d.). Available at https://docplayer.net/17494871-Industrial-hygiene-osha-office-of-training-and-education.html

OSHA. OSHA Technical Manual. Available at https://www.osha.gov/dts/osta/otm/otm_ii/otm_ii_1.html#appendix_II_6

*Graphs and images via Dr. Tim Ryan.*

# 5. Noise

## Learning objectives and terms

Understand the physics of sound and relevant equations.

Understand the anatomy of the human ear and how sound is transmitted and interpreted.

Identify the types of hearing loss and the difficulties that stem from a noisy work environment.

Learn OSHA standards for noise exposure and develop knowledge of legislation leading up to current standards.

Develop an understanding of engineering, administrative, and personal protective equipment controls and when to appropriately implement each.

**Terms**

- Sound
- Noise
- Wavelength
- Frequency
- Speed
- Decibels
- Audiogram
- Conductive hearing loss
- Sensorineural hearing loss

- Presbycusis
- Noise-induced temporary threshold shift
- Noise-induced permanent threshold shift
- Acoustic trauma
- Tinnitus

## Introduction

Statistics from the U.S. Bureau of Labor Statistics' annual report in 2010 show that hearing loss represented 12 percent of the occupational illnesses. This represents more than 18,000 workers who experienced significant loss of hearing due to workplace noise exposure.

The Occupational Safety and Health Act (OSH Act) of 1970 built upon earlier attempts in the United States to regulate noise hazards associated with occupational hearing loss. In 1969, the Walsh-Healey Public Contract Act added the Occupational Noise Exposure Standard as an amendment, which set an 8-hour TWA of 90 dBA and a 5-dBA exchange rate. This effort to reduce occupational noise hazards was not far-reaching but was a first attempt to regulate noise hazards. The same 8-hour TWA and exchange rate are still used by OSHA today.

Also in 1969, the Bureau of Labor Standards promoted an occupational construction noise standard under the Construction Safety Act, which was adopted by OSHA in 1971. Soon after, in 1972, NIOSH published recommendations for an OSHA occupational noise standard, which included a recommended 8-hour TWA exposure limit of 85 dBA and a 5-dBA exchange rate.

In 1974, OSHA published a proposed occupational noise standard, which included a requirement for employers to provide a hearing conservation program for workers exposed to an 8-hour TWA of 85 dBA or more. This provision was adopted as part of the amendments of 1981 and 1983. The 8-hour TWA for OSHA's noise standard remained at 90 dBA with a 5-dBA exchange rate and included a requirement for a hearing conservation program for workers exposed to an 8-hour TWA of at least 85 dBA. While OSHA provided requirements for hearing conservation programs in general industry, the construction industry standard remained less specific in that regard. More recently, in the 2002 recordkeeping standard (29 CFR Part 1904), OSHA clarified the criteria for reporting cases involving occupational hearing loss.

## Physics of sounds

**Wavelength.** Wavelength (λ) is the distance traveled by the sound wave. This is important to know when considering engineering controls.

**Frequency.** Frequency (f) is the number of vibrations per second, measured in hertz (Hz). Sound frequency is how high or low a tone is and is significant when measuring hearing loss.

**Speed.** The speed of sound (c) is measured in meters per second or feet per second. This is determined by the density and elasticity of the medium through the sound is traveling. As the density increases and the elasticity decreases, the speed increases.

Wavelength, frequency, and speed can be found in the equation $\mathbf{c = f \lambda}$

Where ***c*** is velocity in feet per second, ***f*** is frequency in cycles per second (or Hertz), and ***λ*** is the wavelength of the sound wave in feet.

**Amplitude.** Amplitude is expressed as pressure, which is the force over an area. This can be measured in Newtons per square meter ($N/m^2$), Pascals (Pa), or Atmospheres (Atm).

**Decibels.** Noise is measured in decibels (dB), units of sound pressure.

The basic equation for decibels derived from $N/m^2$ is:

$$dB = 10 \log \frac{Q}{Q_{ref}}$$

Where $Q_{ref}$ is 0.00002 $N/m^2$ (also stated as $2 \times 10^{-5}$ $N/m^2$)

In the special case of finding the Sound Pressure Level, SPL, we use the equation:

$$Lp = 20 \log \frac{Q}{Q_{ref}}$$

This equation also gives Lp in units of dB.

When adding decibels it is easiest to use a method based on the differences between two values being added, according to the table below.

| Difference between two values being added, in dB: | Amount to add to the HIGHER of the two values: |
|---|---|
| 0-1 | 3 dB |
| 2-4 | 2 dB |
| 5-9 | 1 dB |
| 10 or more | 0 dB |

Notice that when two sound sources differ by more than about 10 dB, only the louder source is really important. This is why in the presence of a loud engine you must shout to be heard. If an engine is generating 95 dB and a nearby person is speaking at only 70 dB, the speaker is unheard or is "drowned out" by the louder noise source.

*Try solving these examples.*

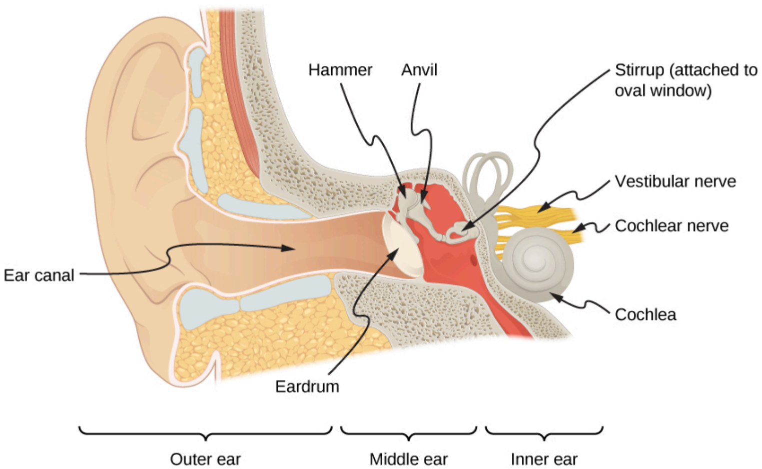
85 dB + 90 dB =

92 dB + 92 dB =

100 dB + 85 dB =

5 dB + 5 dB =

# Physiology of hearing




The human ear has three parts, the inner, middle, and outer ear. The ear gathers, transmits, and perceives sounds in three stages. Disruptions at any of these stages will cause problems with hearing.

**Modification.** The outer ear receives sound waves and directs them to the eardrum, where the waves are then received as variations in air pressure.

**Conversion and amplification.** The waves become vibrations in the eardrum, which are amplified and sent to the inner ear. The vibrations then travel as wave energy through the cochlea, the liquid of the inner ear.

**Transformation.** The waves become nerve impulses that travel to the brain, which perceives and interprets the impulses as sound. The auditory nerve of the ear transmits information for the brain to interpret as pitch and loudness.

The perception of sound by a person is not linear, meaning that we do not hear low frequency sounds as well as we hear higher frequency sounds.  Look at the following weighting table of human hearing (“relative response”) by frequency.  The “A” scale, or weighting curve, shows how most people hear moderate sound levels. The “C” scale is closest to linear, meaning the true sound pressure level is accurately heard by the person.

## Hearing loss

**Two types**

To categorize different types of hearing loss, the impairment is often described as either conductive or sensorineural, or a combination of the two.

**Conductive hearing loss** results from any condition in the outer or middle ear that interferes with sound passing to the inner ear. Excessive wax in the auditory canal, a ruptured eardrum, and other conditions of the outer or middle ear can produce conductive hearing loss. Although work-related conductive hearing loss is not common, it can occur when an accident results in a head injury or penetration of the eardrum by a sharp object, or by any event that ruptures the eardrum or breaks the ossicular chain formed by the small bones in the middle ear (e.g., impulsive noise caused by explosives or firearms). Conductive hearing loss may be reversible through medical or surgical treatment. It is characterized by relatively uniformly reduced hearing across all frequencies in tests of the ear, with no reduction during hearing tests that transmit sound through bone conduction.

**Sensorineural hearing loss** is a permanent condition that usually cannot be treated medically or surgically and is associated with irreversible damage to the inner ear. The normal aging process and excessive noise exposure are both notable causes of sensorineural hearing loss. Studies show that exposure to noise damages the sensory hair cells that line the cochlea. Even moderate noise can cause twisting and swelling of hair cells and biochemical changes that reduce the hair cell sensitivity to mechanical motion, resulting in auditory fatigue. As the severity of the noise exposure increases, hair cells and supporting cells disintegrate and the associated nerve fibers eventually disappear. Occupational noise exposure is a significant cause of sensorineural hearing loss, which appears on sequential audiograms as declining sensitivity to sound, typically first at high frequencies (above 2,000 Hz), and then lower frequencies as damage continues. Often the audiogram of a person with sensorineural hearing loss will show a "Notch" at 4,000 Hz. This is a dip in the person's hearing level at 4,000 Hz and is an early indicator of sensorineural hearing loss. Results are the same for hearing tests of the ear and bone conduction testing. Sensorineural hearing loss can also result from other causes, such as viruses (e.g., mumps), congenital defects, and some medications.

It is important to note that some hearing loss occurs over time as a normal condition of aging. Termed presbycusis, this gradual sensorineural loss decreases a person's ability to hear high frequencies. Presbycusis can make it difficult to diagnose noise-related hearing loss in older people because both affect the upper range of an audiogram. An 8,000-Hz "Notch" in an audiogram often indicates that the hearing loss is aged-related as opposed to noise-induced. As humans begin losing their hearing, they often first lose the ability to detect quiet sounds in this pitch range.

**Effects in the Occupational Setting**

Although noise-induced hearing loss is one of the most common occupational illnesses, it is often ignored because there are no visible effects. It usually develops over a long period of time, and, except in very rare cases, there is no pain. What does occur is a progressive loss of communication, socialization, and responsiveness to the environment. In its early stages (when hearing loss is above 2,000 Hz), it affects the ability to understand or discriminate speech. As it progresses to the lower frequencies, it begins to affect the ability to hear sounds in general.

The primary effects of workplace noise exposure include noise-induced temporary threshold shift, noise-induced permanent threshold shift, acoustic trauma, and tinnitus. A **noise-induced temporary threshold shift** is a short-term decrease in hearing sensitivity that displays as a downward shift in the audiogram output. It returns to the pre-exposed level in a matter of hours or days, assuming there is not continued exposure to excessive noise. If noise exposure continues, the shift can become a **noise-induced permanent threshold shift**, which is a decrease in hearing sensitivity that is not expected to improve over time. A standard threshold shift is a change in hearing thresholds of an average of 10 dB or more at 2,000, 3,000, and 4,000 Hz in either ear when compared to a baseline audiogram. Employers can conduct a follow-up audiogram within 30 days to confirm whether the standard threshold shift is permanent.

**Tinnitus**, or "ringing in the ears," can occur after long-term exposure to high sound levels, or sometimes from short-term exposure to very high sound levels, such as gunshots. Many other physical and physiological conditions also cause tinnitus. Regardless of the cause, this condition is actually a disturbance produced by the inner ear and interpreted by the brain as sound. Individuals with tinnitus describe it as a hum, buzz, roar, ring, or whistle, which can be short term or permanent. **Acoustic trauma** refers to a temporary or permanent hearing loss due to a sudden, intense acoustic or noise event, such as an explosion.

Other consequences of excessive workplace noise exposure include interference with communications and performance. Workers might find it difficult to understand speech or auditory signals in areas with high noise levels. Noisy environments also lead to a sense of isolation, annoyance, difficulty concentrating, lowered morale, reduced efficiency, absenteeism, and accidents.

In some individuals, excessive noise exposure can contribute to other physical effects. These can include muscle tension and increased blood pressure (hypertension). Noise exposure can also cause a stress reaction, interfere with sleep, and cause fatigue.

## Standards for exposure

**OSHA Standards**

Under 29 CFR 1910.95(g)(8), if workers experience standard threshold shifts, employers are required to fit or refit the workers with hearing protectors, train them in the use of the hearing protectors, and require the workers to use them. The effects of excessive noise exposure are made worse when workers have extended shifts (longer than 8 hours). With extended shifts, the duration of the noise exposure is longer and the amount of time between shifts is shorter. This means that the ears have less time to recover between noisy shifts. As a result, short-term effects, such as temporary threshold shifts, can become permanent more quickly than would occur with standard 8-hour workdays.

**General Industry**: This standard is designed to protect general industry workers, such as those working in the manufacturing, utilities, and service sectors. The General Industry standard establishes permissible noise exposures, requires the use of engineering and administrative controls, and sets out the requirements of a hearing conservation program.

The general industry noise standard contains two noise exposure limit tables. Each table serves a different purpose:

- Table G-16: This table applies to the engineering and administrative controls section, which provides a 90-dBA criterion for an 8-hour TWA PEL and is measured using a 90-dBA threshold (i.e., noise below 90 dBA is not integrated into the TWA). This table limits short-term noise exposure to a level not greater than 115 dBA (for up to 15 minutes).

- Table G-16A: This table, presented in Appendix A of 29 CFR 1910.95, provides information (e.g., reference durations) useful for calculating TWA exposures when the work shift noise exposure is composed of two or more periods of noise at different levels. Although this table lists noise levels exceeding 115 dBA, these listings are only intended as aids in calculating TWA exposure levels; the listings for higher noise exposure levels do not imply that these noise levels are acceptable. Additional information on the general industry standard is also available.

**Construction Industry:** Employers are required to use feasible engineering or workplace controls when workers are exposed to noise at or above permissible noise exposures. The PEL of 90 dBA for an 8-hour TWA is measured using a 90-dBA threshold (this is the only threshold used for the construction industry noise standards). 29 CFR 1926.101 requires employers to provide hearing protectors that have been individually fitted (or determined to fit) by a competent person if it is not feasible to reduce noise exposure below permissible levels using engineering or workplace controls.

**Agricultural Worksites:** There is no standard for occupational noise exposure in agriculture.

**Manual Maritime Worksites:** Marine terminals and longshoring operations fall under the requirements of the general industry noise standard.

## Measuring noise

Several types of equipment may be utilized to measure the levels of sound in a workplace. These include sound level meters, noise dosimeters, and octave band analyzers.

**Sound level meters.** Sound level meters provide a sort of first-glance, instant feedback as to where more in-depth noise evaluation should be performed. They can rate an individual worker's noise dose or identify sources of noise. A Type 1 meter is more precise than a Type 2 meter.

**Noise dosimeters.** Dosimeters are worn by workers to determine the individual's exposure to noise over the shift. Exposure is reported as an average of noise levels sampled. They can also be used to determine compliance to OSHA standards. With a dosimeter, 8 hours of exposure at 90 dB-A equates to 100% of the allowable dose, 4 hours at 85 dB-A equates to 50% of the PEL, and so on.  This is from the equation for a time-weighted average exposure:

$TWA = 16.61 \times \log(dose/100) + 90$ dB-A

**Octave band analyzers.** Octave band analyzers determine the mix of frequencies that make up a sound. These can be used to determine the effectiveness of different controls and hearing protection devices.

# Sound controls

Noise controls aim to protect workers while containing noise and minimizing or eliminating the hazard at the source. Many companies utilize three types of controls—engineering, administrative, and personal protective equipment.

The best prevention strategy is to eliminate noise exposure in the first place, but alternative methods can be arranging schedules to prevent excessive time in a noisy environment or placing a barrier between the worker and the noise.

Engineering and administrative controls are essential to an effective hearing loss prevention program. Though these controls are technologically possible for most noise sources, their economic feasibility must be determined on an individual basis. In some instances, the addition of simple noise-control technology can take care of the problem and render other methods, like hearing protection devices, unnecessary. In other cases, the noise reduction process may be more complex and must be accomplished in stages over a longer period of time.

## 1. *Engineering controls*

**Source Treatment—The Root Cause**

**Mechanical.** Lots of noise comes from the spinning part of a machine if the part is out of balance or the bearings are worn. One way to reduce the noise is through preventative maintenance, i.e. regularly lubricating and aligning parts. Because sounds increase when the speed of the part increases, another way to reduce sound is to decrease the speed of the equipment, though this may result in a lack of efficiency.

**Reduce high-velocity of fluid flow.** Noise or vibrations can be transferred when fluid travels quickly through piping or control valves. This noise can be minimized by limiting the velocity of the substance, eliminating sudden direction shifts or combinations of streams, or by using vibration insulation or a silencer.

**Reduce pneumatic and compressed air systems.** Pneumatic and compressed air commonly drive tools such as hand-held air guns, air valves, and cylinders in manufacturing equipment. To reduce noise, the air-pressure setting on these devices can be lowered as much as is practical.

**Surface- or Panel-Radiated Noise.** Sound can radiate from metal casings or panels when enough vibratory energy is produced. When casings or panels are the primary noise source, reduce the radiation efficiency. This can be done by adding small openings to solid panels; adding support to panels such as ducts; and adding vibration damping material.

**Retrofit applications.** Some products or applications can be added to minimize noise at the source. These include

- Vibration damping materials – hopper bins, product chutes, fan and blower housings
- Vibration isolation – pipe hangers, HVAC equipment, flex connectors
- Silencers – internal combustion engines, industrial fans, reciprocating compressors
- Pneumatic or compressed air silencers

**Path Treatment–The Sound Transmission**

**Sound absorption.** Sound absorption materials can treat the places in a room where sound reverberates, like walls or ceilings. The reverberations combine with the noise from the source to create an even higher noise level. Sound absorbing material reduces reverberation of sound and requires little maintenance after installation, but it does not treat the source and can deteriorate over several years.

**Acoustical enclosures.** These are solid enclosures that can treat multiple sources of noise at once. Although these structures reduce noise and can be installed quickly and at a reasonable cost, they limit visual and physical access to equipment and may incur damage over time and use.

**Receiver treatment–The Sound Recipient**

**Worker enclosures.** These rooms, like control booths, can be effective if workers spend the majority of the day there. Enclosures, also called personnel shelters, must maintain an interior sound level of 80 dBA to minimize noise exposure.

**Relocation.** When possible, the worker can be moved to a quieter area if they are not required to be immediately near the noise. Even moving five to seven feet back from equipment can reduce noise by a few decibels.

## 2. *Administrative controls*

Administrative solutions include managing the work schedule and training workers to reduce noise exposure. If possible, this can mean scheduling loud equipment to be used when fewer people are working or shifting a worker to a quieter environment after exposure. Additionally, having quiet spaces, like break rooms or lunch areas, will allow workers time away from the noise.

## 3. *Personal protective equipment (hearing protection)*

These can be used while other controls are being installed or if those other options are not possible. Generally, hearing protection devices only fully benefit workers when used in conjunction with other protection methods. Examples of these devices includes ear plugs, ear muffs, and hearing bands.

## Questions and problems

1. Indicate the sum for the following equation: 100 dB + 109 dB=?

    a. 110 dB

    b. 104.5 dB

    c. 105 dB

    d. 100 dB

2. If an employee's dosimeter indicates the total noise dose received is 100%, and he worked 4 hours to receive that dose, what was his time weighted average exposure?

    a. 200

    b. 95 dB

    c. Can only approximate it to somewhere between 96–101 dB

    d. 105 dB

3. A sound pressure of 1.0 $N/m^2$ [$Q_{ref}$ = 0.00002 $N/m^2$] is a sound pressure level (Lp) of:

    a. 50,000 N/m2

    b. 90.0 N/m2

    c. 93.9 dB

    d. 97.5 dB

4. If the OSHA PEL for continuous noise is 90 dB for 8 hours, and the exchange rate is 5 dB, indicate the allowable exposure for 1 hour.

a. 100 dB

b. 90 dB

c. 105 dB

d. 110 dB

5. Hearing loss related to excessive noise results from:

a. Prolonged exposure to high sound pressures, typically greater than 85dB-

b. Damaged hair cells in the cochlea

c. Conductive losses

d. Both A and B only

6. Two punch machines are operating next to each other. One machine has a measured noise level of 89 dB, and the other is 89 dB. If an employee spends 8 hours working between the two machines (assume no noise controls, muffs, plugs, etc.), is the worker overexposed to noise?

a. No, up to and including 90 dB is allowed and 90 dB is her true exposure

b. Yes, she is exposed to more than 90 dB

c. No, the 89 dB total exposure is below the allowed limit

d. Can't tell. Octave Band Analysis would be required

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# 6. Biohazards and Biosafety

## Learning objectives and terms

Understand the concept of biosafety and what materials are considered hazards.

Understand the concepts of primary and secondary containment.

Understand and identify differences between biosafety levels.

**Terms**

- Biosafety
- Chain of infection
- Containment, primary and secondary
- Biosafety levels 1, 2, 3, 4
- Biological safety cabinets

# Introduction

Biological hazards, or biohazards, constitute a relatively specialized aspect of OH that many in the profession are hard-pressed to practice. There is a highly specialized vernacular within the topic, and the biological diversity of the hazards can be quite daunting to even high-level traditional hygienists. Nevertheless, biohazards exist in both specialized healthcare settings and within the community at large, and therefore need to be recognized and controlled. The aim of **biosafety** is to reduce or eliminate exposure of individuals and the environment to potentially hazardous biological agents.

*via CDC.*

Recognizing biohazards can be both easy and difficult. In high tech areas like recombinant DNA laboratories, medical microbiology facilities, and testing units, one can readily expect to see the universal biohazard symbol shown here. But within other sectors of exposure—airports, bus terminals, residential care facilities, and small clinics like doctor and dentist offices—knowing what might be a biohazard and where to expect one can be difficult.

Perhaps it is easiest to say what a biohazard is not. Biohazards do not include guns or unused knives, broken domestic glass, moldy sandwiches or perished food, drugs, or other physical hazards to the human body not contaminated with human or pathological material. Restated, an object that is a hazard to a biological entity, like a person or animal, does not constitute a biohazard per se.

Traditionally the following are considered true biohazards:

- Bacteria
- Fungi
- Viruses
- Rickettsiae
- Parasites
- prions
- r-DNA
- endotoxins
- exotoxins
- blood and blood products
- urine and feces
- animals known to be carriers of zoonotic disease

*Photo by Trust "Tru" Katsande.*

Biohazard areas of concern fall into two categories: professional and community. Professional areas include research laboratories, production of enzymes for soaps, biomedical testing kits and reagents, medical diagnostic kit use areas, and public health service areas.

*Photo by Michael Schiffer.*

Community biohazards can be found in almost any public place where used needles and blood can be seen. These locations and the support services for them include police, fire, and EMS personnel, as well as airports, public toilets, and the workers in such places. To the extent a worker is covered by OSHA rules and regulations, they will similarly be subject to the protections of specific safeguards found in the OSHA Bloodborne Pathogens standard (29 CFR 1910.1030).

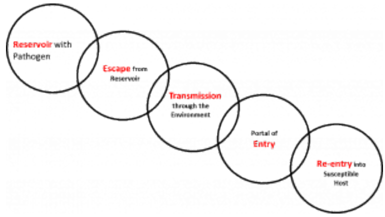
OSHA's Bloodborne Pathogens standard as amended pursuant to the Needlestick Safety and Prevention Act of 2000, prescribes safeguards to protect workers against the health hazards caused by bloodborne pathogens. Its requirements address items such as exposure control plans, universal precautions, engineering and work practice controls, personal protective equipment, housekeeping, laboratories, hepatitis B vaccination, post-exposure follow-up, hazard communication and training, and recordkeeping. The standard places requirements on employers whose workers can be reasonably anticipated to contact blood or other potentially infectious materials (OPIM), such as unfixed human tissues and certain body fluids.


*Photo by Raymond Wong.*

## Control

The overarching concept of biological safety is built upon the idea of the chain of infection. As the metaphor reveals, this "chain" is only as strong as its weakest or most easily controlled linkage. If safety professionals are able to interrupt or disrupt the chain, transmission and continued infection or disease dissemination will be prevented.

The **chain of infection** is described as follows. First, there is a *reservoir* containing the pathogen. Next, the pathogen *escapes* from the reservoir and is *transmitted* through the environment. Then there is a *portal* of entry and finally *re-entry* into the susceptible host. The chain shown here is sometimes called the RETER model, for Reservoir-Escape-Transmission-Entry-Reentry. Effective intervention at any one link will theoretically control the biohazard.



*via Tim Ryan.*

While the RETER control model is intuitive enough to understand, biological hazards control is anything but easy. If it were, sickness and infectious diseases would be conditions of the past; there would be no such thing as cold and flu season. Bioterrorism and biological weapons would be phantoms of science fiction alone. And so, when attempting to address biological safety matter, it is necessary to employ very specific, tested methods. These methods overlap to some extent but are distinguished here somewhat artificially as biosafety levels, containment, and sampling. It is also common to hear biosafety levels referred to as "practices," whereas containment often focuses on engineering or equipment measures.

## Biosafety levels


*via CDC.*

Biosafety Levels (BSLs) are a type of biosafety risk assessment that take into account the agent and activities involved. Biosafety levels determine laboratory practices, techniques, safety equipment, and laboratory facilities. BSL are not OSHA regulations. Rather, they are prescribed by the NIH and CDC, and all persons receiving federal grant money (i.e., all researchers except those in private industry for the most part) can lose such funding if BSL practices are not adhered to.

**Biosafety Level 1** is the lowest level and means there is no or minimal risk to healthy adults. Work may be carried out on an open bench top or easily cleanable labs surfaces. Eyewash stations and handwashing facilities should be available.

**Biosafety Level 2** comes with contact spread risk to healthy adults. The facility will have self-closing doors, biohazard sign posted, autoclave available in or near the lab, and class I or II biological safety cabinets. Gloves should be worn to prevent skin contamination.

*Photo by Ani Kolleshi.*

**Biosafety Level 3** has an airborne spread risk to healthy adults. The lab will have controlled access with change or shower areas, will be at negative pressure relative to surrounding areas, and will have supply or exhaust air or a dedicated system.

**Biosafety Level 4** is the highest level with airborne risk to healthy adults or animals from lethal pathogens or agents. There is physical isolation of the laboratory, airlock for access, and a two-person rule that no one works alone. There is also the use of class III BSCs and/or positive-pressure protective suits for work with high hazard agents or manipulations.

*Photo by Tim Llewellyn, Boston University.*

## Containment

Integral to the BSLs is effective biohazard containment. **Containment** entails using safe methods and equipment to manage infectious agents in the laboratory environment. Its purpose is to reduce or eliminate exposure of laboratory workers, support persons, and the outside environment to potentially hazardous agents.

Two types of containment are **primary containment** and **secondary containment.** Primary containment protects personnel and the immediate laboratory. This is provided by good microbiological technique and use of safety equipment. Secondary containment protects primary areas, population of the area, and the external environment. This is provided by facility design and operational practice.

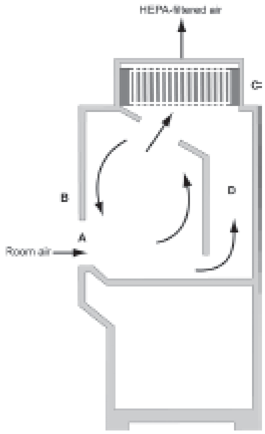
**Primary Containment**

Primary containment relies on standard microbiological techniques. The biological safety cabinet is a principal piece of equipment for containment of infectious splashes or aerosols. Additionally important are proper containers, tubes, and cups for the handling, use, and storage of biohazards.

Good microbiological technique includes a host of aspects, including training, biohazard signs, and handwashing after handling infectious material. One must also observe universal precautions for human blood and body fluids and utilize appropriate protective clothing, such as lab coats, gloves, and safety glasses. One must refrain from mouth pipetting or eating, drinking, smoking, or storing food, food utensils, cosmetics, or lip balm in lab area.

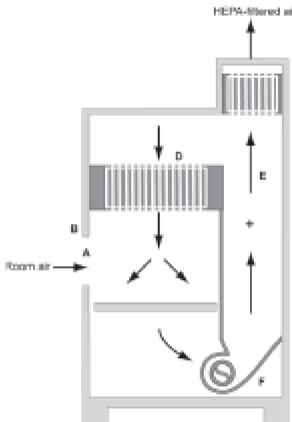
**Secondary Containment**

The focus of secondary containment is mostly facilities-centered or on design factors. Examples of this include decontamination facilities, like an autoclave, and directional air flow and air treatment systems. Aspects of secondary containment may also include controlled access zones, airlocks as laboratory entrances, or separate buildings. Extremely hazardous or economically important work may be done on islands, as in Plumb Island off-shore of Virginia and Galveston, Texas.

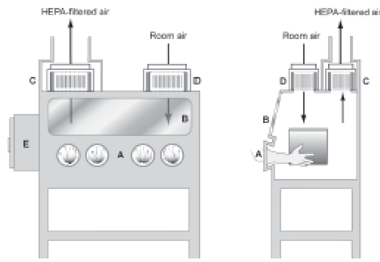



*Class I Biological Safety Cabinet, via CDC.*

One hallmark of work involving serious biohazards is secondary containment control of airborne hazards through specialized enclosures and cabinets called Laminar Flow Biological Safety cabinets (LFBSC). Known more commonly as safety cabinets, there are several different varieties of **biological safety cabinets (BSC).** One is a clean bench, which takes in ambient air and provides filtered air for a particle-free environment. These are only used to protect what is inside the cabinet from outside contaminants. They are usually used in pharmaceutical preparation, sterile laboratory media prep, and cleanroom areas. Class I safety cabinets are a second type of cabinet. They are used to protect personnel to a limited extent and use a single HEPA exhaust filter to protect the environment. Class II cabinets, a third type, have two HEPA filters, have an open front and protect personnel and the product by providing exhaust filtration as well as "sterile" airflow down onto the work surface. Class III cabinets are the fourth type of BSC. They are also known as gloveboxes, are totally enclosed, and protect personnel and the product.




*Class II Biological Safety Cabinet, via CDC.*




*Class III Biological Safety Cabinet, via CDC.*

# Biological sampling

Unlike sampling for industrial solvents and workplace contaminants used in production locations, biohazards sampling and analysis is relatively rarely performed. Most often biological sampling is done to confirm the presence of a known or suspected agent, as opposed to search for possible culprits causing vague symptoms or syndromes (e.g., Sick Building Syndrome, or SBS).

Sampling for biological materials can be both quite easy and difficult, depending on the agent of interest. For example, in a hospital setting where an on-site medical microbiology laboratory is housed, using a sterile swab to sample a surface is easy to accomplish and the analysis can be done in-house. Compare this to attempting to identify a virus present, where highly specialized sampling protocols specific for nano-sized viral particles must be used. For viruses specifically, the determination of viral numbers and identity is not a straight-forward practice, usually requiring research-level personnel and facilities capable of culturing viruses under exacting conditions.

*Sterile swab sampling of a suspected environmental sample, via Tim Ryan.*

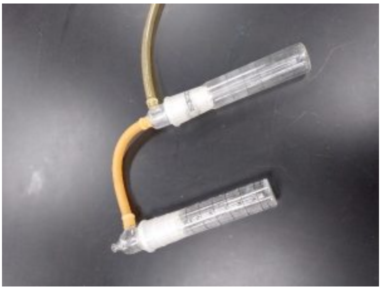
Two broad categories of sampling can be defined for biohazards: area and airborne. Area contamination means that a hazardous material has a surface presence, typically removable for culturing in a petri plate under laboratory conditions. Sampling here is done through sterile swab surveys and sterile wipe surveys, followed by culturing under prescribed conditions for the ideal resolution of the agent of concern.

Airborne biohazards (e.g., bacteria and fungi bioaerosols) can be assessed by a variety of commercially available devices, with the Anderson impactors, SKC N6, Casella slit, Reuters centrifugal, and all glass impinger (AGI) being among the most common. In the N6 impactor, air passes through tiny, precisely sized holes that result in any entrained particle to be forcefully deposited onto media such as agar. The agar plate is then grown out under prescribed conditions of temperature, lighting, moisture, and related variables, optimized for the preferred growth of the suspected agent. The tiny holes of the N6 plate are shown below, next to the exploded view of the full N6 sampling kit, including high volume (1 cfm; 28.3 LPM) pump.

*N6 sampling plate (left) showing hundreds of fine air holes, and sampling kit (right) with pump, base, plate, and inlet.*

*via Tim Ryan.*

Less frequently used these days are all glass impingers, or AGI. The benefit of such equipment is that media in liquid form can be used to collect the bioaerosol, and then the liquid is plated onto various types of petri-plated media that can enhance the growth of particular types of agents. Drying out of bacterial cells is less common with the AGI as compared to direct impact samplers, like the N6, because of the large volume of air moved in the latter. Both the AGI and the impactor (N6, Casella, Reuters) collect volumetrically valid samples, and the numbers of colonies that grow after sampling can therefore be quantified as “colony forming units per cubic liter [or meter] of air sampled.”



*All glass impinger, via Tim Ryan.*

One reason that air sampling for biohazards is uncommon is that there are no OSHA standards for acceptable or safe concentrations of airborne biohazards. In the absence of such limits, safety in dealing with such materials is generally provided through the proper practices and equipment already discussed.

## Questions and problems

1. Which of the following is not a biohazard?

   a. A used hypodermic syringe

   b. Moldy bread or cheese

   c. Blood and blood products

   d. Urine and feces

2. Containment is defined as a combination of these two elements for managing infectious agents in the laboratory environment

   a. Methods and equipment

b. Hoods and filters

c. Airflow and security

d. Product and personnel

3. Good microbiological technique is a requirement of the CDC-NIH publication “Biosafety in Microbiological and Biomedical Laboratories”, and includes which of the following?

a. Protective clothing, including lab coats and safety glasses

b. Prohibition of eating, drinking coffee, or applying lip balm in a laboratory

c. A ban on mouth pipetting of any substance for any reason

d. All of the above

4. The Biosafety Levels are designated from lowest to highest, as follows:

a. Levels I, II-A, II-B, and III

b. 1, 2, 3 and 4

c. A, B, C, and D

d. No hazard, low hazard, animal hazard, and human lethality potential

5. Work with hazardous biological agents requires a special type of hood called a Laminar Flow Biological Safety Cabinet, which uses HEPA filters to protect both the worker and environment.

a. True

b. False

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# 7. Ergonomics

## Learning objectives and terms

Understand the four ergonomics rubrics and how each applies to a workplace.

Know examples of musculoskeletal disorders, risk factors, and how they occur.

**Terms**

- Ergonomics
- Anthropometry
- Static measurements
- Dynamic measurements
- Psychology
- Biomechanics
- Kinesiology
- Physiology
- Musculoskeletal disorders (MSDs)
- Carpal tunnel syndrome
- Tendonitis
- Rotator cuff injuries
- Epicondylitis

- Trigger finger
- Muscle strains and low back injuries
- Risk factors
- Repetition
- Static loading
- Sustained exertion
- Awkward postures
- Mechanical contact stress

# Introduction

*Erg* means work, and *nomos* means laws, and from this we get the word ergonomics, or the laws of work. Nowadays ergonomics refers to how employees are required to perform workplace tasks and the injuries or long-term effects of such tasks.

Employers are responsible for providing a safe and healthful workplace for their workers. In the workplace, the number and severity of musculoskeletal disorders (MSDs) resulting from physical overexertion, and their associated costs, can be substantially reduced by applying ergonomic principles. These are also known as work-related stresses and strains, repetitive stress injuries (RSIs), or cumulative trauma diseases (CTDs). Employers seek to limit these events for moral, wellness, legal, OSHA compliance, and financial reasons, among others.

The graphic below shows where ergonomic hazards are the greatest by job category, both in terms of total numbers of non-fatal injuries (blue, right side) as well as rates of occurrence (yellow, left side).

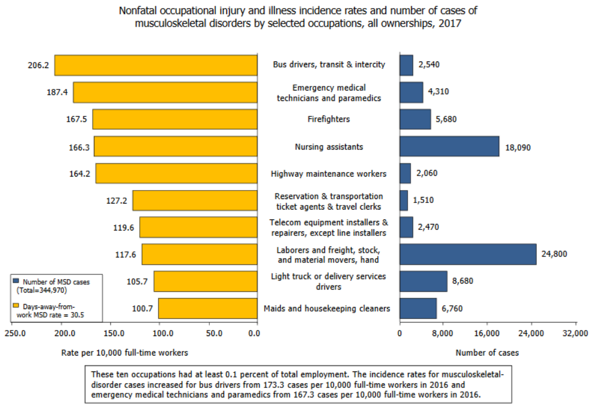



*Fig. 1.*

Work related MSDs are among the most frequently reported causes of lost or restricted work time. According to the Bureau of Labor Statistics (BLS) in 2018, MSD cases accounted for 33 percent of all worker injury and illness cases, and in 2017, there were a total of 344,970 MSDs reported.

Established evaluation and corrective action procedures are required to periodically assess the effectiveness of the ergonomic process and to ensure its continuous improvement and long-term success. As an ergonomic process is first developing, assessments should include determining whether goals set for the ergonomic process have been met and determining the success of the implemented ergonomic solutions.

# Ergonomics rubrics

*Photo by Hannah Lim.*

**Anthropometry** is the measurement of the human body, used in ergonomics to consider the variations in workers' abilities, sizes, and shapes. Anthropometric data can vary significantly by workforce, including variables such as gender, race, and workforce recruitment strategies (e.g., professional horse jockeys tend to be petite in stature whereas professional wrestlers are normally very large men!).

There are two classes of measurements, static and dynamic. **Static measurements** are when a person is sitting or standing and measures skeletal dimensions and the dimensions of soft tissues. **Dynamic measurements** are taken when the body is in motion.

**Psychology** in the workplace includes control coding—location, labels, color, shape, size, types of indicators, and knowledge of the extent of human capabilities compared to a machine. Distractions, information overload, and poor training or understanding of complex processes or environments can all contribute to the psychological environment of the worker.

**Biomechanics** is the study of function and movement in the human body. In ergonomics, this includes examining hand and wrist postures.

**Kinesiology** is the study of the human body in terms of motion or movement, looking specifically at velocity, force, and range. **Physiology** in ergonomics works in relation to biomechanics and workers' capabilities.

## Musculoskeletal disorders

Musculoskeletal disorders (MSDs) affect the muscles, nerves, blood vessels, ligaments and tendons. Workers in many different industries and occupations can be exposed to risk factors at work, such as lifting heavy items, bending, reaching overhead, pushing and pulling heavy loads, working in awkward body postures, and performing the same or similar tasks repetitively. Exposure to these known risk factors for MSDs increases a worker's risk of injury.

Work-related MSDs can be prevented. Ergonomics helps lessen muscle fatigue, increases productivity, and reduces the number and severity of work-related MSDs.

**Examples of Musculoskeletal Disorders (MSDs)**

**Carpal tunnel syndrome** brings pain, numbness, and tingling to the hand when major nerves are compressed or strained. **Tendinitis** is the inflammation of tendons, most common in wrists, elbows, knees, and shoulders. **Rotator cuff injuries**, affecting the shoulder, are usually caused by repeated overhead motions. **Epicondylitis**, also called tennis elbow, occurs when the tendons connecting the forearm and the elbow become inflamed. **Trigger finger** happens when the tendon in a finger, usually the thumb or ring finger, becomes inflamed and the finger is stuck in a bent position. **Muscle strains and low back injuries** occur when a muscle is overstretched or torn.

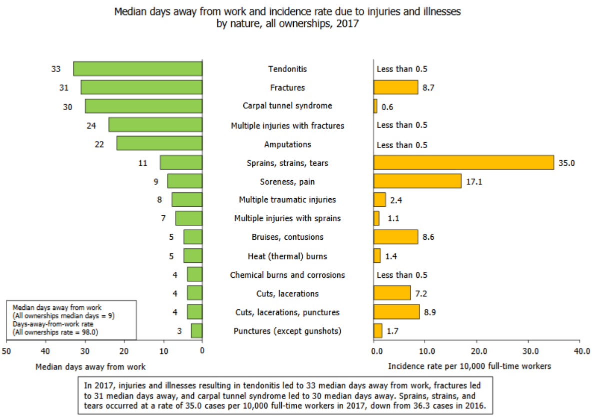



*Fig. 2.*

Work related MSDs are among the most frequently reported causes of lost or restricted work time. According to the Bureau of Labor Statistics (BLS) in 2013, MSD cases accounted for 33 percent of all worker injury and illness cases.

## Risk factors

Ergonomists have examined a number of jobs with a high incidence of MSDs and have found some common elements present in each that are associated with these injuries. These elements are called **risk factors** because exposure to them increases the chance that a worker will become injured. The following are examples of risk factors that are found in office work, some or all of which may be present at the same time.

**Repetition**, performing the same or similar motions repeatedly, can result in trauma to the joints and surrounding tissues. Without time for rest and recovery, repetition can lead to injury. Examples include computer work, like typing at a keyboard with the attendant odd wrist postures (see picture below), or office work, like flipping through files, numerical entry, or any long-term continuous task involving a given segment of the body. Even long-term cell phone texting can put a person's thumbs at risk of MSDs from excessive repetition.

*Photo by Pongsawat Pasom.*

One of the risk factors that has increased in the computerized office is **static loading**, where the muscles must hold the body in a single positionfor a long period of time. This lack of movement reduces circulation and causes muscle tension, which can contribute to or aggravate an injury. **Sustained exertions** are a type of static loading where force is applied continuously for long periods of time, like holding hands over the keyboard or sitting still for long periods of time.

Postures that bend the joints into positions where they are more likely to become injured are termed **awkward postures**. Examples are typing with bent wrists or slouching in the chair.

A hard or sharp surface or object pressing into the soft tissues can cause damage that over time can result in serious injury. This damage is termed **mechanical contact stress**. Examples include resting wrists on desk edges while typing.

*Photo by Luis Villafranca.*

Many office tasks require a moderate amount of **force** to be applied by very small muscles, which may cause fatigue, swelling, and muscle and ligament strains.

Such activities can include dragging and dropping with the mouse and stapling or stamping by hand.

## Controls

Implementing an ergonomic process is effective in reducing the risk of developing MSDs in high-risk industries as diverse as construction, food processing, firefighting, office jobs, healthcare, transportation, and warehousing. The following are important elements of an ergonomic process.

1. A strong commitment by management is critical to the overall success of an ergonomic process.
2. Management should define clear goals and objectives for the ergonomic process, discuss them with their workers, assign responsibilities to designated staff members, and communicate clearly with the workforce.
3. A participatory ergonomic approach, where workers are directly involved in worksite assessments, solution development, and implementation, is the essence of a successful ergonomic process.
4. Training is an important element in the ergonomic process. It ensures that workers are aware of ergonomics and its benefits, become informed about ergonomics-related concerns in the workplace, and understand the importance of reporting early symptoms of MSDs.
5. An important step in the ergonomic process is to identify and assess ergonomic problems in the workplace before they result in MSDs.

## Questions and problems

1. What does the word "ergonomic" mean, both based on its Latin roots as well as in the modern-day context?

a. Ergonomic diseases include all of following EXCEPT:

b. Repetitive stress diseases

c. Cumulative trauma disorders

d. Carpal tunnel syndrome

e. Pneumoconiosis

2. That part of ergonomics which studies the statistics of human sizes, in terms of diversity, percentiles, differences by gender, averages, etc. is termed:

a. Anthropometry

b. Postures

c. Dynamic forces study

d. None of the above

3. The immediate cause of carpal tunnel syndrome is:

a. Excessive wear of the tendons in the wrist

b. Excessive use of the ligaments in the wrist

c. Compression of the median nerve in the wrist

d. A rip or tear in the muscle of the wrist

4. Which of these industries experience ergonomic hazards?

a. Computer intensive keyboarding endeavors, like form entry and data entry

b. Automobile assembly

c. Meat and poultry processing

d. All of the above

5. List three synonyms for ergonomics.

## Bibliography and resources

**Figures 1 and 2:** 2017 Survey of Occupational Injuries & Illnesses Charts Package (2018). Retrieved from https://www.bls.gov/iif/osch0062.pdf.

State of Washington ergonomics guide

US Federal Aviation Administration Airman's Manual

US Bureau of Labor Statistics

*Photos are individually linked to their sources when possible.*

# 8. Thermal Stressors

## Learning objectives and terms

Understand effects of both hot and cold temperature stress and how each can be prevented.

Recognize the most common forms of heat and cold stress outcomes, both acute and chronic.

**Terms**

- Heat exhaustion
- Heat stroke
- Acclimatization
- Raynaud's phenomenon
- Frostbite
- Frostnip
- Hypothermia

# Introduction

The proportion of unsafe work situations is directly related to temperature extremes in that environment. Both extreme hot and cold temperatures negatively affect a worker's physical functioning.

*via Tim Ryan.*

## Heat stress

There are several types of heat stress the body can experience when not properly adjusted to hot temperatures.

One type is **fainting**, also called heat syncope, which occurs when an acclimated worker is standing in heat for extended periods of time. Symptoms include vertigo and exhaustion. **Heat exhaustion** results from a loss of fluids and salts, and the worker will continue to sweat but experience fatigue or weakness, nausea, or a headache. **Heat stroke** is when the body fails to regulate its core temperature. This happens at a temperature of 106 degrees Fahrenheit or higher. Symptoms include lack of sweat, mental confusion, loss of consciousness, or even coma. The skin is hot and dry and colored red, mottled, or bluish. As heat stroke is potentially fatal, it must be treated promptly. Workers can also experience dehydration, cramps, or heat rash.

**Environmental Factors**

Conditions that workers cannot control are called **environmental factors**. These include temperature, humidity, radiant heat, and air velocity.

**Heat Stress Assessment**

When evaluating a worker's possible heat stress, consider heat gain and loss, worker's heat production, and environmental factors, including solar load, temperature, and humidity.

Different work activities generate more heat in workers. For example, a worker would produce more heat while digging trenches than while seated at a keyboard. Environmental factors can be monitored by equipment. Wet Bulb Globe Temperature (WBGT) is used to determine the effects of environmental factors on workers.

$$WBGTin = 0.7\,Twb + 0.3\,Tg$$

$$WBGTout = 0.7\,Twb + 0.2\,Tg + 0.1\,Tdb$$

The WBGT index indicates precautions needed for certain temperatures.

*Wet Globe Bulb Thermometer, via Tim Ryan.*

# Preventing heat stress

Four practices can be used to prevent heat stress—acclimatization, engineering controls, work practices, and employee education.

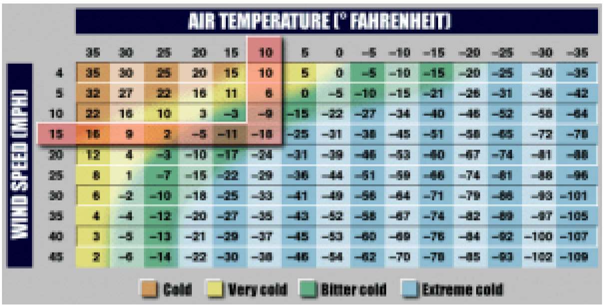
1. **Acclimatization**, which means enhancing workers' heat tolerance, can be done in eight to ten days. This process allows workers to adjust by allowing them to sweat faster. Most at risk for heat stress are new employees and transfers, who have not yet become acclimated to the heat.
2. **Engineering controls**, such as supplied air islands, phase change vests, air cooling vests, and liquid cooling systems, can be added to supplement the other three practices.
3. **Work Practices** including work and rest cycles may be additionally be adjusted to give workers time out of the heat. Technology can be used to determine body core temperature, like a thermometer sender that a worker can swallow and then read the results.
4. **Employee Education** can be very effective in mitigating some of the heat stress risks. Persons trained to be vigilant, replace fluids and salts, and to recognize signs of heat disorders are less likely to encounter the more severe hazards of heat stress.

# Cold stress

Effects of cold stress include loss of motor skills, vision effects, Raynaud's phenomenon, frostnip, frostbite, and hypothermia.

**Raynaud's phenomenon** is when blood vessels in the extremities, usually finger and toes, constrict in response to cold and cut off blood flow. The affected area turns white or blue, and then red and hot when the blood vessels allow to blood to resume flowing. Dressing warmer and limiting time in cold usually stops this problem. **Frostnip** is when the top layers of the skin freeze, making skin look waxy and white. The tissue underneath will feel soft. Frostnip can be treated with warming the affected area, but it can progress to **frostbite**. Frostbite is when all layers of skin freeze. Muscle and tissue may freeze, and this may reach the bone. The skin is white, hard, and numb through all layers, and nerves are frozen. Mild cases of frostbite can be reversed. **Hypothermia** is when the body temperature drops below 93 degrees Fahrenheit. The person can exhibit all signs of being clinically dead, including blue skin, fixed and dilated pupils, rigid muscles, and no noticeable breathing.

Cold stress is a greater risk when wind velocity is higher. This well recognized situation is known as wind chill, and it can be deadly. Wind chill can be thought of semi-quantitatively as the rate at which a heated object such as the human body loses heat owing to wind speed. The faster the wind, the greater the loss rate. This is illustrated in the chart below. To prevent cold stress, consider similar factors as for heat stress, and keep wind chill in mind.



| Wind speed (mph) \ Air temperature (° Fahrenheit) | 35 | 30 | 25 | 20 | 15 | 10 | 5 | 0 | –5 | –10 | –15 | –20 | –25 | –30 | –35 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 4 | 35 | 30 | 25 | 20 | 15 | 10 | 5 | 0 | –5 | –10 | –15 | –20 | –25 | –30 | –35 |
| 5 | 32 | 27 | 22 | 16 | 11 | 6 | 0 | –5 | –10 | –15 | –21 | –26 | –31 | –36 | –42 |
| 10 | 22 | 16 | 10 | 3 | –3 | –9 | –15 | –22 | –27 | –34 | –40 | –46 | –52 | –58 | –64 |
| 15 | 16 | 9 | 2 | –5 | –11 | –18 | –25 | –31 | –38 | –45 | –51 | –58 | –65 | –72 | –78 |
| 20 | 12 | 4 | –3 | –10 | –17 | –24 | –31 | –39 | –46 | –53 | –60 | –67 | –74 | –81 | –88 |
| 25 | 8 | 1 | –7 | –15 | –22 | –29 | –36 | –44 | –51 | –59 | –66 | –74 | –81 | –88 | –96 |
| 30 | 6 | –2 | –10 | –18 | –25 | –33 | –41 | –49 | –56 | –64 | –71 | –79 | –86 | –93 | –101 |
| 35 | 4 | –4 | –12 | –20 | –27 | –35 | –43 | –52 | –58 | –67 | –74 | –82 | –89 | –97 | –105 |
| 40 | 3 | –5 | –13 | –21 | –29 | –37 | –45 | –53 | –60 | –69 | –76 | –84 | –92 | –100 | –107 |
| 45 | 2 | –6 | –14 | –22 | –30 | –38 | –46 | –54 | –62 | –70 | –78 | –85 | –93 | –102 | –109 |

Cold / Very cold / Bitter cold / Extreme cold

*via Tim Ryan.*

## Questions and problems

1. Acclimatization is an administrative control used in the practice area of:

   a. Noise

   b. Indoor air quality

   c. Ventilation

   d. Heat stress

2. This is the instrument of choice by the industrial hygienist when tasked with assessing environmental heat stress conditions:

   a. Dry bulb thermometer

   b. Wet bulb thermometer

   c. Globe thermometer

   d. WBGT device

3. Excessively high or low ambient work temperatures cause higher proportions of unsafe work behaviors.

a. True

b. False

4. The most easily distinguished (most important) difference between heat stroke and heat stress symptomology is that in heat stroke:

a. The victim can no longer stand unassisted

b. The victim's skin is dry and red or bluish or mottled in color

c. The victim's skin is clammy and moist

d. The victim complains of a headache and nausea

5. This condition can be caused by both pregnancy as well as occupational exposure to excessive vibration (especially when work is performed in cold temperatures).

a. Trigger finger

b. Tennis Elbow (epicondylitis)

c. Schweinfurter's Syndrome

d. Raynaud's phenomenon

6. A man is working indoors in front of a steel blast furnace, presenting a considerable radiant heat load. An IH uses three separate thermometers to assess the heat risk to him. They read: wet bulb=75 F; dry bulb=90 F; and globe temp=95 F. The WBGT for this situation is:

a. 80 F

b. 85 F

c. 90 F

d. 95 F

## Bibliography and resources

U.S. National Oceanic and Atmospheric Administration

*Graphs and images from Dr. Tim Ryan.*

# Appendix

**Sampling of airborne contaminants.**

OSHA Calibration Procedures for Sampling: beginning at Appendix D.

OSHA Technical Manual: Personal Sampling for Air Contaminants. (n.d.). Retrieved from https://www.osha.gov/dts/osta/otm/otm_ii/otm_ii_1.html