PROCESS SAFETY ENGINEERING (0905477)

05- QUANTITATIVE TOXICOLOGY

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The superior man, when resting in safety, does not forget that danger may come.... When all is orderly, he does not forget that disorder may come. Confucius (551 BC – 479 BC)

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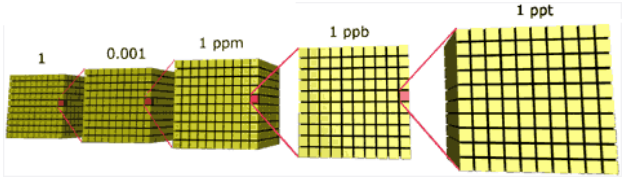
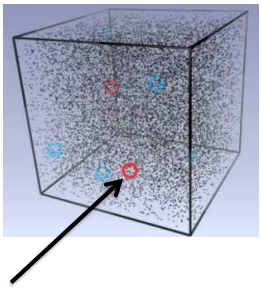
Outline

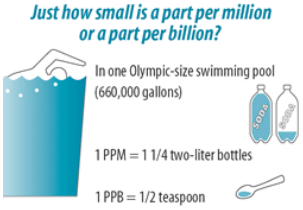
- Measurement of Toxicity
- Parts Per Million, Billion and Trillion
- Lethal Dose - LD_{50}
- Lethal Concentration – LC_{50}
- Threshold Limit Value (TLV)
- Effect of Exposure to Various Concentrations of Common Gases
- National Fire Protection Association (NFPA) Diamond.

Parts Per Million (ppm), Billion (ppb) and Trillion (ppt)

- One part in one million (10^6) parts **ppm**.
- One part in on billion (10^9) parts **ppb**.
- One part in on trillion (10^{12}) parts **ppt**.





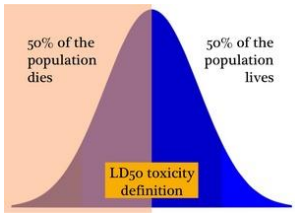


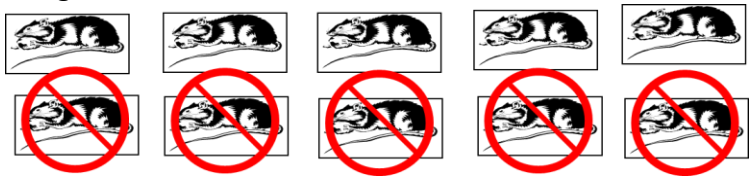
$$C_{ppm} = \frac{22.4}{M}\left(\frac{T}{273}\right)\left(\frac{1}{P}\right)C\,(\text{mg/ m}^3)$$

M is molecular weight (g/mol)
T is temperature (Kelvin)
P is pressure (atm)

Lethal Dose - LD_{50}

- The LD_{50} is the dosage, when administrated to laboratory animals **all at once**, results in 50% fatalities.
  - The expression is made in milligrams of the substance administered per body weight of the animal expressed in kilograms (mg/kg).
  - LD_{50} typically refers to dermal dosages.
  - Can also, be used for radiation or pathogens.

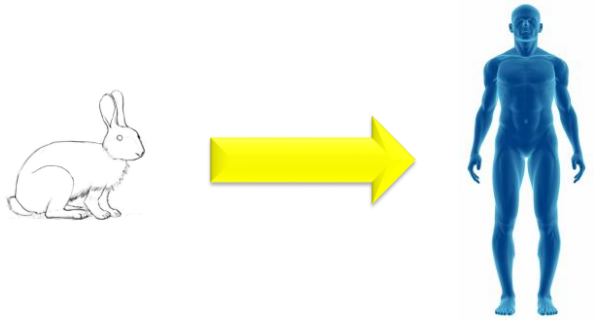




Extrapolation to Humans

- When extrapolated to humans, the lethal dose of an average person who weighs *w* kilograms is

$$\mathrm{LD} = \mathrm{LD}_{50} \times w$$



LD_{50} Severity Classification

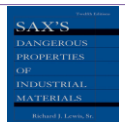
Toxicity Increases

Method of administration	Category 1	Category 2	Category 3	Category 4	Category 5
Oral: LD_{50} measured in mg/kg of bodyweight	5	50	300	2 000	5 000
Dermal: LD_{50} measured in mg/kg of bodyweight	50	200	1 000	2 000	5 000
Gas Inhalation: LC_{50} measured in ppmV	100	500	2 500	20 000	Undefined
Vapour Inhalation: LC_{50} measured in mg/L	0.5	2.0	10	20	Undefined
Dust and Mist Inhalation: LC_{50} measured in mg/L	0.05	0.5	1.0	5.0	Undefined

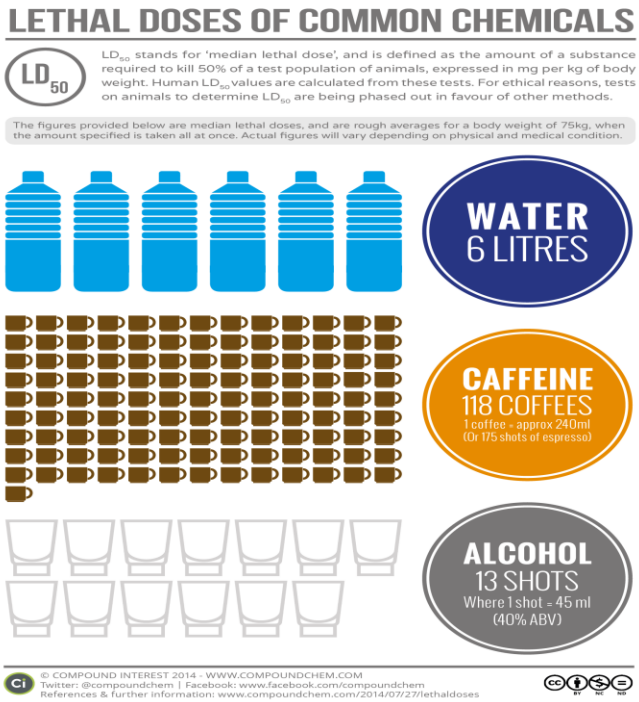
The undefined values are expected to be roughly equivalent to the category 5 values for oral and dermal administration

Hodge-Sterner Degree of Toxicity

Toxicity Category	LD50 (mg/kg)	Probable LD for 70 kg adult (g)	Example compounds
Super-toxic	<5	< 0.35 Taste	Botulin Aflatoxin
Extremely toxic	5-50	0.35-3.5 Teaspoonful	Cyanide Vitamin D (Calciferol)
Very toxic	50-500	3.5-35 Ounce	Nicotine Caffeine
Moderately toxic	500-5000	35-350 Pint	Aspirin (acetasalicyclic acid) Salt (NaCl)
Slightly toxic	5000-15000	350-1050 Quart	Ethanol Trichloroethylene
Practically nontoxic	>15000	>1050 More than a quart	Sugar (Sucrose)

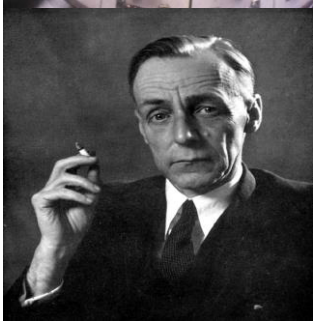


Sax's Dangerous Properties of Industrial Materials



Who Created the LD_{50}?

- In 1927, J.W. Trevan attempted to find a way to estimate the relative poisoning potency of drugs and medicines used at that time. He developed the LD50 test because the use of death as a "target" allows for comparisons between chemicals that poison the body in very different ways. Since Trevan's early work, other scientists have developed different approaches for more direct, faster methods of obtaining the LD50.



Lethal Concentration - LC_{50}

- The **LC_{50}** is the concentration of a material that, normally expressed as parts per million (ppm) by volume, that when administrated to laboratory animals, kill half of them during the period of exposure.
  - LC_{50} typically refers to airborne dosages.

Threshold Limit Value - TLV

- The TLV is the upper limit of a toxin concentration to which an average healthy person may be repeatedly exposed on an all-day, everyday basis (8 hr./ 5 days) without suffering adverse health effects.
- Typically used for workplace exposure determinations.
  - Gaseous substances in air, are usually expressed in ppm.
  - Fumes or mists in air, are expressed in (mg/m^3).
  - TLV values are set by the American Conference of Governmental Industrial Hygienist (ACGIH).
  - For flammables, TLV is ¼ of lower flammable limit (LFL/LEL).
  - Some toxicants have zero thresholds.

TLV Types

TLV

TWA: **Time Weighted Average** concentration for a normal eight-hour work day.

Maximum allowed exposure in normal work day.

STEL: **Short Term Exposure Limit** 15 minute time weighted average exposure.

Repeated exposure no more than four times per 8 hour work shift.

Minimum duration between exposures 60 minutes.

Maximum allowed exposure for 15 minutes.

C: Ceiling Concentration that should not be exceeded, even instantaneously.

Maximum allowed exposure instantaneously.

Chemical substances with equivalent TLVs (i.e. same numerical values) cannot be assumed to have similar toxicological effects or similar biologic potency.

Hygiene standards are quoted for pure substances. The 8 hr TWA is best assessed by personal dosimetry in which exposure is continuously monitored throughout the work day wherever the operator goes. When data are available on the individual fluctuations in exposure, e.g. from a variety of tasks, the 8 hr TWA exposure can be calculated as in the following example:

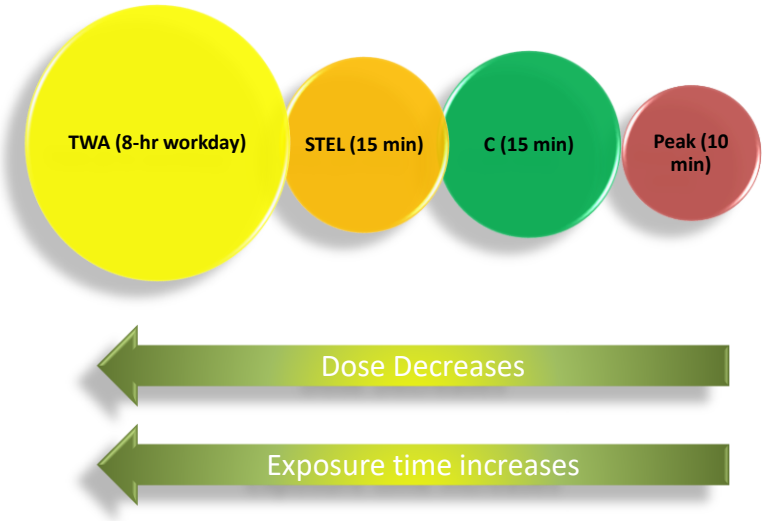
Working period	*Exposure* (mg/m^3)
8.00–10.30	0.16
10.30–10.45	0.00
10.45–12.45	0.07
12.45–13.30	0.00
13.30–15.30	0.42
15.30–15.45	0.00
15.45–17.15	0.21

$$\text{8 hr TWA exposure} = \frac{0.16 \times 2.5 + 0.07 \times 2 + 0.42 \times 2 + 0.21 \times 1.5 + 0 \times 1.25}{8}$$

$$= \frac{0.40 + 0.14 + 0.84 + 0.32}{8}$$

$$= 0.21 \text{ mg/m}^3$$

Exposure Limits



Threshold Limit Values (R) from ACGIH (R) 2008 TLVs and BEIs

Chemical Substance	TWA (8-hour Average)	STEL (15-Minute Average)
Ammonia	25 ppm	35 ppm
Benzeze	0.5 ppm	2.5 ppm
Carbon Dioxide	5,000 ppm	30,000 ppm
Carbon Monoxide	25 ppm	---
Chlorine	0.5 ppm	1 ppm
Diesel Fumes	15 ppm	---
Gasoline	300 ppm	500 ppm
Hydrogen Sulfide	10 ppm	15 ppm
Nitrogen	Simple Asphyxiant	
Nitrous Oxide	50 ppm	---
Nitrogen Dioxide	3 ppm	5 ppm

Pollutant	ASHRAE	OSHA	ACGIH	WHO
Carbon Monoxide	PPM 8hr	--------	25 PPM	10 PPM 8hr 25PPM 1hr
PM10 Fine Dust Particulates	50 µg/m³ 150 µg/m³	--------	--------	--------
Formaldehyde	0.05 PPM 8hr	0.75 PPM 8hr 2.00 PPm hr	0.3 PPM	0.8 PPm 8hr
Styrene	--------	--------	20 PPM	--------

ACGIH : American Conference of Governmental Industrial Hygienist

ASHIRAE : American Society of Heating Refrigerating and Air-Conditioning Engineers

OSHA : Occupational Safety and Health Administration

WHO : World Health Organization

Table 5.18 Common sources of toxic atmospheres

Source	*Examples*
Improper storage, handling, use or disposal of specific chemicals	Leakages(1) Improper venting or draining(1) Open handling(1) Incorrect notification on disposal Use of wrong material
Accidental release, spillage	Transport incidents Overfilling of containers Equipment failure Unexpected reactions Runaway reactions
Admixture of chemicals	By mistake, e.g. wrongly identified In wrong proportions In wrong circumstances(1) In wrong sequence
Fires	Pyrolysis products Combustion products(1) Vaporization Through domino effects
Operation in confined spaces	Improper isolation From residues Oxygen deficiency (inherent, from purging or from rust
Maintenance or cleaning of equipment	Residues Loss of containment (breaking lines) Stripping insulation Burning-off paint, flame heating components Reaction or vaporization of cleaning products
Wastes	Anaerobic breakdown Admixture of effluents Open handling of effluents or 'wastes' Atmospheric venting Solid wastes Uncontrolled incineration
Fabrication, manufacturing or machining operations etc.	Welding fumes(1) Spray painting, curing of paints(1) Use of adhesives, curing of adhesives(1) Cutting/grinding/fettling/shotblasting(1) Electroplating(1) Degreasing/cleaning/etching/pickling(1) Plastics forming or overheating(1)

(1) May result in long-term exposure (throughout operation or in workplace).

Oxygen Concentration in Air Effects

Vol. (%)	Effect (s) for a person at rest
19	Some adverse physiological effects occur, but they may not be noticeable.
15-19	Impaired thinking and attention. Increased pulse and breathing rate. Reduced coordination. Decreased ability to work strenuously. Reduced physical and intellectual performance without awareness.
12-15	Poor judgment. Faulty coordination. Abnormal fatigue upon exertion. Emotional upset.
10-12	Very poor judgment and coordination. Impaired respiration that may cause permanent heart damage. Possibility of fainting within a few minutes without warning. Nausea and vomiting.
< 10	Inability to move. Fainting almost immediate. Loss of consciousness. Convulsions. Death.

Typical Reactions of Persons to Carbon Dioxide in Air

CO_2		Effect (s)
ppm	**%**	
5000	**0.5**	TLV/OEL-TWA: can be tolerated for 8 hr exposure with no symptoms and no permanent damage
15000	**1.5**	OEL-STEL: 10 min
20000	**2.0**	Breathing rate increased by 50%
30000	**3.0**	TLV-STEL: breathing rate increased by 100%
50000	**5.0**	Vomiting, dizziness, disorientation, breathing difficulties after 30 min
80000	**8.0**	Headache, vomiting, dizziness, disorientation, breathing difficulties after short exposure
100000	**10.0**	Headache, vomiting, dizziness, disorientation, unconsciousness, death after a few minutes

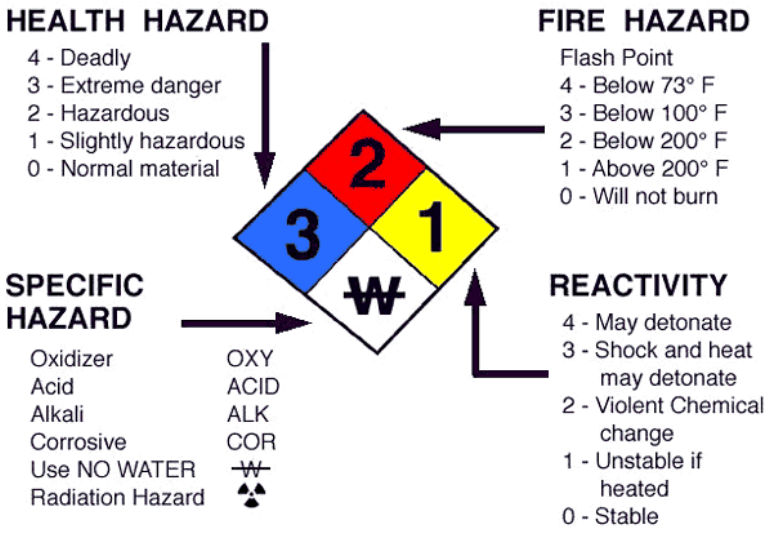
Typical Reactions of Persons to Carbon Monoxide in Air

CO (ppm)	Effect (s)
30	Recommended exposure limit (8 hr time-weighted average concentration)
200	Headache after about 7 hr if resting or after 2 hr exertion
400	Headache with discomfort with possibility of collapse after 2 hr at rest or 45 min exertion
1200	Palpitation after 30 min at rest or 10 min exertion
2000	Unconscious after 30 min at rest or 10 min exertion

Typical Effects of Hydrogen Sulphide Concentrations in Air

H_2S (ppm)	Effect (s)
0.2	Detectable odor
20–150	Conjunctivitis
150	Olfactory nerve paralysis
250	Prolonged exposure may cause pulmonary oedema
500	Systemic symptoms may occur in 0.5 to 1 hr
1000	Rapid collapse, respiratory paralysis imminent
5000	Immediately fatal

National Fire Protection Association (NFPA) Diamond



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