The Safety Company

# Gas Detection Handbook

## Key Concepts & Reference Material for Installed Gas Monitoring Systems

NINTH EDITION

MSA**safety**.com

The MSA Gas Detection Handbook is designed to introduce users to key terms and concepts in gas detection and to serve as a quick reference manual for information such as specific gas properties, exposure limits, and other data.

## The Handbook contains:

- A glossary of essential gas detection terms and abbreviations.
- A summary of key principles in combustible and toxic gas monitoring.
- Reference data – including physical properties and exposure limits – for the most commonly monitored gases, in industrial and various other environments.
- A comparison of the most widely-used gas detection technologies.
- A table indicating the gas hazards common to specific applications within major industries.
- A summary of key gas detection instrumentation approvals information, including hazardous locations classification.
- MSA's exclusive Sensor Placement Guide, detailing important factors to take into consideration when determining optimum gas sensor placement.

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# Section 1

## Gas Detection Terms & Abbreviations

# Gas Detection Terms & Abbreviations

**ACGIH** - American Conference of Governmental Industrial Hygienists.

**Alarm Set Point** - The selected gas concentration level at which an alarm is activated.

**Ambient Air** - Surrounding air to which the sensing element is normally exposed in its installed position.

**Asphyxiant** - A substance that impairs normal breathing by displacing oxygen.

**ATEX** - From the French ATmosphère EXplosible (Explosive Atmospheres); refers to the European Union (EU) directives regulating explosion protection.

**Atmosphere** - The total gases, vapors, mists, and fumes present in a specific location.

**Autoignition Temperature [also "Spontaneous Ignition Temperature" (SIT)]** - The minimum temperature at which a combustible substance (gas, vapor, liquid, or solid) will ignite and sustain combustion under its own heat energy.

**Bump Check (Functional Test)** - Procedure used to verify the response of an instrument which does not include actual adjustment. (Also known as "Span Check".)

**Calibration** - Procedure by which the performance of a detector is verified to maximize the accuracy of its readings. A calibration is performed by: (1) comparing the instrument with a known standard, and (2) adjusting the instrument reading to match the standard.

**Calibration Gas (also "Span Gas" or "Cal gas")** - A known concentration of gas that is used to set instrument accuracy.

**Ceiling Limit (C)** - The maximum gas concentration to which a worker may be exposed. (See "TLV - C".)

**Combustible Gas*** - A gas that is capable of igniting and burning.

**Combustion** - The rapid oxidation of a substance involving heat and light.

**Confined Space** - An area that is large enough for an employee to bodily enter and perform work, has limited or restricted areas of entry or exit, and is not designed for continuous human occupancy.

* *Any material that will burn at any temperature is considered to be "combustible", so this term covers all such materials, regardless of how easily they ignite. The term "flammable" specifically refers to those combustible gases that ignite easily and burn rapidly.*

# Gas Detection Terms & Abbreviations

**Controller** - The part of a gas detector that provides centralized processing of the gas signal. The controller receives and responds to the electrical signal from the sensor to output an indication, alarm or other function.

**Cross Sensitivity** - The predictable response of a detector to compounds other than the target gas.

**Dew Point** - The temperature at which a gas (air) is saturated with a condensable component.

**Diffusion** - Process by which particles spread from regions of higher concentration to regions of lesser concentration as a result of random molecular movement. Also used to describe the process by which the atmosphere being monitored is transported to the gas-sensing element by natural random molecular movement.

**Electrochemical Sensor** - A sensor that uses an electrochemical reaction to provide an electrical output proportional to the measured gas concentration.

**Explosion** - Rapid uncontrolled combustion process which generates a high temperature, a large volume of gas, and a pressure or shock wave.

**Explosion-proof (XP)** - Method of protection in which an explosion in a hazardous location is prevented by containing any combustion within the device, and thereby, is prevented from spreading into the atmosphere surrounding the enclosure.

**Explosive (or "Flammable") Limits** - Though a flammable liquid can support combustion at its flash point temperature, to sustain it requires the vapor concentration to be between two specific levels, or "flammable limits" – the lower flammable limit and the upper flammable limit *(see below)*. Any gas or vapor concentration that falls between these two limits is in the flammable range.

- **Lower Explosive** (or "Flammable") Limit (LEL) - the minimum concentration of a vapor (usually expressed as the percentage of material in air) required to sustain a fire.
- **Upper Explosive** (or "Flammable") Limit (UEL) - the maximum concentration of a vapor (usually expressed as the percentage of material in air) beyond which a fire cannot be sustained, as the amount of oxygen would be insufficient to continue the fire.

## Gas Detection Terms & Abbreviations

**Explosive (or "Flammable") Range** - The range that encompasses any gas or vapor concentration between the substance's lower explosive limit and upper explosive limit, and is therefore capable of sustaining combustion.

**Flameproof** - Method of protection in which an internal ignition within a flammable atmosphere will not transmit outside of a protective enclosure, and thereby, will prevent the ignition of surrounding flammables in the hazardous area.

**Flammable Gas*** - This term applies to a special group of combustible gases that ignites easily and burns rapidly.

**Flash Point** - The minimum temperature at which a liquid gives off enough vapor to form an ignitable mixture with air (reaching 100% LEL).

**Gas** - A state of matter characterized by very low density and viscosity (relative to liquids and solids), comparatively great expansion and contraction with changes in pressure and temperature, ability to diffuse readily into other gases, and ability to occupy with almost complete uniformity the whole of any container. (Often used interchangeably with "vapor".)

**Gas Detection Instrument** - A device composed of electrical, optical, mechanical, or chemical components that senses and responds to the presence of gas mixtures.

**General Purpose (GP) Enclosure** - An enclosure intended for indoor use in non-hazardous rated areas, primarily to prevent accidental contact of personnel with the enclosed equipment in areas where unusual service conditions do not exist.

**Hazardous Atmosphere** - (As defined by OSHA 29 CFR 1910.146.) An atmosphere in which workers are exposed to the risk of death, injury, incapacitation, or illness.

**Humidity** - The amount of water vapor present in the atmosphere.

**IDLH (Immediately Dangerous to Life and Health)**** – The maximum concentration level of a substance (gas) from which a worker could escape within 30 minutes without developing immediate, severe or irreversible health effects, or other escape-impairing symptoms. IDLH levels are measured in ppm (parts per million).

*wible gases that ignite easily and burn rapidly.*

*** As defined by NIOSH (National Institute for Occupational Safety and Health).*

## Gas Detection Terms & Abbreviations

**IECEx** - International Electrotechnical Commission system for certification to standards relating to equipment for use in Explosive Atmospheres.

**Interferent** - Any gas other than the target gas that will cause a response from a gas sensor.

**Intrinsic Safety (IS)** - A method of protection in which an explosion is prevented through an electrical design using energy storage devices in which the possibility of ignition is eliminated.

**LEL (Lower Explosive Limit)** - (See "Explosive Limits".)

**LEL.m (Lower Explosive Limit per Meter)** - A gas measurement for Open Path Gas Detectors.

**Monitor** - An instrument used to continuously measure a condition that must be kept within specific limits.

**NIOSH** - National Institute for Occupational Safety and Health.

**OSHA** - United States Department of Labor Occupational Safety and Health Administration.

**Oxygen Deficient Atmosphere** - An atmosphere containing less than 19.5% oxygen by volume. (Possesses a risk of insufficient oxygen for breathing.)

**Oxygen Enriched Atmosphere** - An atmosphere containing more than 20.8% oxygen by volume. (Possesses an increased risk of explosion.)

**PEL (Permissible Exposure Limit)** - An airborne concentration of contaminant that most workers can be exposed to repeatedly in a normal 8-hour day, in a 40-hour week, without adverse health effects. PEL levels are measured in ppm (parts per million) and are established by OSHA.

**Permanent (or Fixed) Gas Monitor** - A gas monitor that is permanently installed in a location.

**PPB (Parts Per Billion)** - A term that expresses the number of units (parts) of a given substance that exist as a portion of a greater substance comprised of one billion parts.

**PPM (Parts Per Million)** - The most common unit of measurement for toxic gases. A "10,000 parts per million" gas concentration level equals a 1% by volume exposure.

**PPM.m (Parts Per Million per Meter)** - A gas measurement for Open Path Gas Detectors.

**Relative Density** - The density of a gas as compared to that of another gas (i.e. typically air). In gas detection, relative density is used to assist in determining optimum sensor placement. If the relative density of the monitored gas is less than 1, then it will tend to rise in air; if the relative density is greater than 1, then it will tend to sink in air and accumulate at ground level.

# Gas Detection Terms & Abbreviations

**Sensor** - The part of a gas detector that converts the presence of a gas or vapor into a measurable signal.

**Smart Sensor** - Sensor that contains a microprocessor, allowing it to record data, communicate with other devices or control devices such as relays.

**Span Check** - (See “Bump Check”.)

**STEL** - Short-term exposure limit. (See “TLV - STEL”.)

**Spontaneous Ignition Temperature (SIT)** - (See “Autoignition Temperature”.)

**TLV® (Threshold Limit Value)*** - Refers to the airborne concentration of substances and represents conditions under which it is believed that nearly all workers may be repeatedly exposed day after day without adverse health effects.

**There are three categories of TLVs:**

- **TLV – TWA (Time Weighted Average)** - This is the average amount of gas that a worker can be repeatedly exposed to in a normal 8-hour day, in a 40-hour week, without adverse health effects.
- **TLV – STEL (Short Term Exposure Limit)** - The gas concentration that most workers can be continuously exposed to for a 15-minute time period without suffering adverse health affects that would impair self-rescue or worker safety. This limit should not be repeated more than 4 times per day and there should be at least 60 minutes between individual STEL exposure periods.
- **TLV – C (Ceiling)** - The highest gas concentration to which workers may be exposed. Ceiling TLVs should never be exceeded and they take precedence over all TWAs and STELs.

**Toxic Atmosphere** - An atmosphere in which the concentration of gases, dusts, vapors, or mists exceeds the permissible exposure limit (PEL).

**Toxic Gas or Vapor** - Substance that causes illness or death when inhaled or absorbed by the body in relatively small quantities.

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* *As defined by the ACGIH® (American Conference of Governmental Industrial Hygienists).*

# Gas Detection Terms & Abbreviations

**True Zero** - A reading indicating that no amount of target gas is present in the sample. (Also known as "baseline".)

**TWA** - Time-weighted average (See "TLV-TWA".)

**UEL (Upper Explosive Limit)** - (See "Explosive Limits".)

**Vapor** - Often used interchangeably with "gas"; vapor is generally used to refer to the gaseous phase of a substance that generally exists as a liquid or solid at room temperature, while "gas" is more commonly used to refer to a substance that generally exists in the gaseous phase at room temperature.

**Vapor Density** - The weight of a volume of pure gas or vapor compared to that of an equal volume of air at the same temperature and pressure. A vapor density of less than 1 indicates that the gas or vapor is lighter than air and will tend to rise. A vapor density of greater than 1 indicates that the vapor is heavier than air and will tend to accumulate closer to the ground. It may also move a significant distance at these low levels to a source of ignition and then flash back to the original location once ignited. When using vapor density to determine optimum sensor placement, other factors such as air flow patterns and temperature gradients should also be considered.

**Vapor Pressure** - The pressure exerted when a solid or liquid is in equilibrium with its own vapor. Vapor pressure is directly related to temperature. In gas detection, this is significant because the higher the vapor pressure of a substance, the greater the amount of it that will be present in vapor phase at a given temperature, and thus a greater degree of gas hazard exists.

**Zero Check** - Check performed to verify that the instrument reads true zero.

**Zero Gas** - A cylinder of gas that is free of the gas of interest and interferents. It is used to properly zero an instrument's base line.

# Section 2

Gas Monitoring Categories

Combustible Atmospheres

Toxic Atmospheres

Oxygen Deficiency Enrichment Atmospheres

Gas Detection Technologies

Gas Sampling

## The Four Main Types of Gas Hazards

The following table summarizes the four main reasons why gas monitoring is performed:

| Type of Monitoring | The Purpose | The Hazard | Possible Source of Hazard |
|---|---|---|---|
| Personal protection | Worker safety | Toxic gases | Leaks, fugitives emissions, industrial process defects |
| Explosive | Worker and facility safety | Explosions | Presence of combustible gases/vapors due to leaks, industrial process defects |
| Environmental | Environmental safety | Environmental degradation | Oil leaks into sewers or lakes, acid gas emissions |
| Industrial process | Process control | Malfunction of the process | Possible fault or other process error |

# Gas Monitoring Categories

**Gas Monitoring Categories:**

### 1. Combustible/Flammable Gas

- Explosive hazard.
- To avoid an explosion, atmospheric levels must be maintained below the lower explosive limit (LEL) for each gas, or purged of oxygen.
- Generally measured as 0-100% of the lower explosive limit or in parts per million range.
- Combustible gas monitors are designed to alarm before a potential explosive condition occurs.

### 2. Toxic/Irritant Gases

- Hazardous to human health; worker exposure must be monitored.
- Typically measured in the parts per million (ppm) range.
- Toxic gas monitors are designed to alert workers before the gas level reaches a harmful concentration.
- Some toxic gas monitors can calculate the average exposure over time, providing short-term exposure limit (STEL) and time-weighted average (TWA) readings.

### 3. Oxygen

- Atmospheres containing too little oxygen (less than 19.5% oxygen by volume) are considered “oxygen deficient” and interfere with normal human respiration.
- Atmospheres containing too much oxygen (more than 25% oxygen by volume) are considered “oxygen enriched” and possess an increased risk of explosion.
- Measured in the percent volume range (normal oxygen percentage in air is 20.8% by volume at sea level).
- Oxygen monitors are generally set to alarm if the atmosphere contains either too little or too much oxygen.

# Combustible Atmospheres

### Combustible Atmospheres

In order for a flame to exist, three conditions must be met.

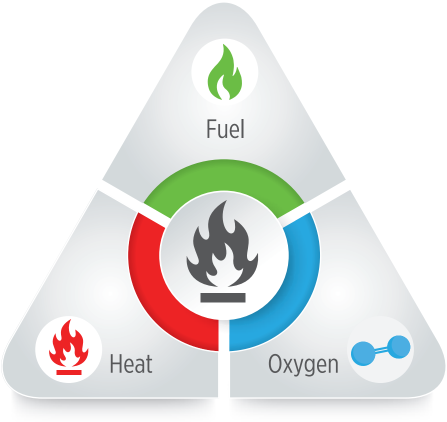
**There must be:**

- A source of fuel (e.g. methane or gasoline vapors).
- Enough oxygen (greater than 10-15%) to oxidize or burn the fuel.
- A source of heat (ignition) to start the process.

### Examples of Heat and Ignition Sources

- Open flames such as those from lighters, burners, matches, and welding torches are the most common sources of ignition.
- Radiation in the form of sunlight or coming from hot surfaces.
- Sparks from various sources such as the switching on or off of electric appliances, removing plugs, static electricity, or switching relays.

## Fire Triangle



Combustion

# Combustible Atmospheres

## Combustible Atmosphere Factors

### Vapor vs. Gas

Though often used interchangeably, the terms “vapor” and “gas” are not identical. The term “vapor” is used to refer to a substance that, though present in the gaseous phase, generally exists as a liquid or solid at room temperature. When we say that a liquid or solid substance is burning, it is actually its vapors that burn. “Gas” refers to a substance that generally exists in the gaseous phase at room temperature.

### Vapor Pressure and Boiling Point

Vapor pressure is the pressure exerted when a solid or liquid is in equilibrium with its own vapor. It is directly related to temperature.
An example of vapor pressure is the pressure developed by the vapor of a liquid in a partially-filled closed container. Depending on temperature, the vapor pressure will increase up to a certain threshold. When this threshold is reached, the space is considered to be saturated.

The vapor pressure and boiling point of a chemical determine how much of it is likely to become airborne. Low vapor pressure means there are fewer molecules of the substance to ignite, so there is generally less of a hazard present. This also means that there are fewer molecules to sense, which may make detection more challenging and require higher-sensitivity instrumentation. With higher vapor pressure and a lower boiling point, there is a greater likelihood of evaporation. If containers of chemicals with such properties are left open, or if they’re allowed to spread over large surfaces, they are likely to cause greater hazards.

### Flashpoint

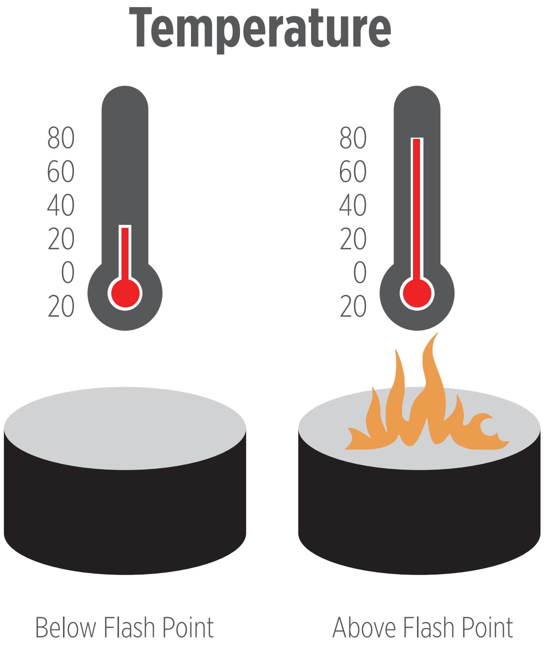
A flammable material will not give off an amount of gas or vapor sufficient to start a fire until it is heated to its flashpoint. Flashpoint is defined as the lowest temperature at which a liquid produces sufficient vapor to produce a flame. If the temperature is below this point, the liquid will not produce enough vapor to ignite. If the flashpoint is reached and an external source of ignition such as a spark is provided, the material will catch fire. The National Fire Protection Agency’s (NFPA) document NFPA-325M, *Fire Hazard Properties of Flammable Liquids, Gases and Volatile Solvents,* lists the flashpoints of many common substances. See www.nfpa.org.

### Combustible Atmospheres

Flash points are significant because they give an indication of the degree of hazard presented by a flammable liquid. Generally, the lower the flash point, the easier it is for flammable fuel-air mixtures to form; thus, the greater the hazard.

### Autoignition Temperature

If heated to a certain point—the spontaneous ignition (or "autoignition") temperature—most flammable chemicals can spontaneously ignite under its own heat energy, without an external source of ignition.



# Combustible Atmospheres

## Vapor Density

Vapor density is the weight ratio of a volume of flammable vapor compared to an equal volume of air. Most flammable vapors are heavier than air so they gravitate toward the ground, settling in low areas. A gas or vapor with a vapor density greater than 1 may travel at low levels to find a source of ignition (e.g. hexane, which has a 3.0 vapor density); a gas or vapor with a vapor density less than 1 will tend to rise (e.g. methane, which has a 0.6 vapor density). Vapor density is important to consider when determining optimum sensor placement because it helps predict where the gas or vapor is most likely to accumulate in a room or area.

## Explosive Limits

To produce a flame, a sufficient amount of gas or vapor must exist. But too much gas can displace the oxygen in an area and fail to support combustion. Because of this, there are limits at both low-end and high-end gas concentrations where combustion can occur. These limits are known as the Lower Explosive Limit (LEL) and the Upper Explosive Limit (UEL). They are also referred to as the Lower Flammability Limit (LFL) and the Upper Flammability Limit (UFL).

To sustain combustion, the atmosphere must contain the correct mix of fuel and oxygen (air). The LEL indicates the lowest quantity of gas which must be present for combustion and the UEL indicates the maximum quantity of gas. The actual LEL level for different gases may vary widely and is measured as a percent by volume in air. Gas LELs and UELs can be found in NFPA 325.

LELs are typically 1.4% to 5% by volume. As temperature increases, less energy is required to ignite a fire and the percent gas by volume required to reach 100% LEL decreases, increasing the hazard. An environment containing enriched oxygen levels raises the UEL of a gas, as well as its rate and intensity of propagation. Since mixtures of multiple gases add complexity, their exact LEL must be determined by testing.

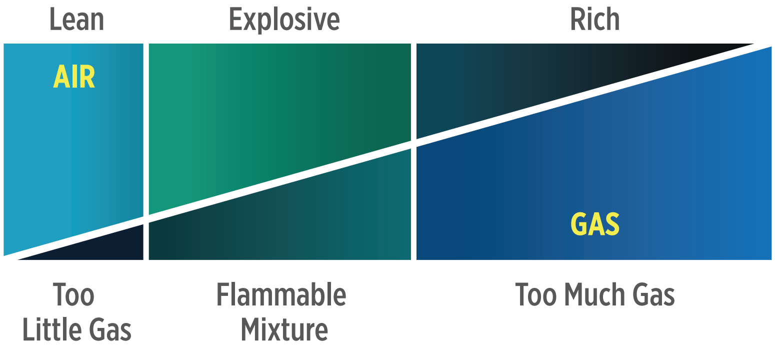
Most combustible gas instruments measure in the LEL range and display gas readings as a percentage of the LEL. For example: a 50% LEL reading means the sampled gas mixture contains one-half of the amount of gas necessary to support combustion.

## Combustible Atmospheres

Any gas or vapor concentration that falls between these two limits is in the flammable (explosive) range. Different substances have different flammable range widths — some are very wide and some are narrower. Those with a wider range are generally more hazardous since a larger amount of concentration levels can be ignited.

Atmospheres in which the gas concentration level is below the LEL (insufficient fuel to ignite) are referred to as too "lean" to burn; those in which the gas level is above the UEL (insufficient oxygen to ignite) are too "rich" to burn.

Gas-to-Air Mixture



# Toxic Atmospheres

## Toxic Gas Monitoring

A toxic gas is one which is capable of causing damage to living tissue, impairment of the central nervous system, severe illness or—in extreme cases—death, when ingested, inhaled or absorbed by the skin or eyes. The amounts required to produce these results vary widely with the nature of the substance and exposure time. "Acute" toxicity refers to exposure of short duration, such as a single brief exposure. "Chronic" toxicity refers to exposure of long duration, such as repeated or prolonged exposures.

Toxic gas monitoring is important because some substances can't be seen or smelled and have no immediate effects. Thus, the recognition of a gas hazard via a worker's senses often comes too late, after concentrations have reached harmful levels.

The toxic effects of gases range from generally harmless to highly toxic. Some are life-threatening at even short, low-level exposures, while others are hazardous only upon multiple exposures at higher concentrations. The degree of hazard that a substance poses to a worker depends upon several factors which include the gas concentration level and the duration of exposure.

## Exposure Limits

The American Conference of Governmental Industrial Hygienists (ACGIH) publishes an annually revised list of recommended exposure limits for common industrial compounds, titled "TLVs and BEIs Based on the Documentation of the Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices". (To order a copy, visit www.acgih.org). ACGIH developed the concept of Threshold Limit Value (TLV), which is defined as the airborne concentration of a contaminant to which it is believed that almost all workers may be repeatedly exposed, day after day, over a working lifetime without developing adverse effects. These values are based on a combination of industrial experience and human and animal research.

## Time-Weighted Averages (TWAs)

TLVs are generally formulated as 8-hour time-weighted averages. The averaging aspect enables excursions above the prescribed limit as long as they are offset by periods of exposure below the TLV.

## Toxic Atmospheres

### Short-Term Exposure Limits (STELs)

Short-term exposure limits are concentrations above the 8-hour average to which workers may be exposed for short periods of time without harmful effects. (If the concentration is high enough, even a one-time exposure can produce harmful health effects.) STELs are used to govern situations in which a worker is exposed to a high gas concentration, but only for a short period of time. They are defined as 15-minute time-weighted averages that are not to be exceeded even if the 8-hour TWA is below the TLV.

### Ceiling Concentrations

For some toxic gases, a single exposure exceeding the TLV may be hazardous to worker health. In these cases, ceiling concentrations are used to indicate levels that are never to be exceeded.

### Permissible Exposure Limits (PELs)

PELs are enforced by OSHA. Part 29 of the Code of Federal Regulations (CFR) Section 1910.1000 contains these standards, which are similar to ACGIH TLVs except that they are legally enforceable rather than simply recommendations. However, the most accurate PELs are listed in the associated Safety Data Sheets (SDS).

### Immediately Dangerous to Life and Health (IDLH)

NIOSH defines an IDLH exposure condition atmosphere as one that poses a threat of exposure to airborne contaminants when that exposure is likely to cause death or immediate or delayed permanent adverse health effects or prevent escape from such an environment. Since IDLH values exist to ensure that a worker can escape from a hazardous environment in the event of failure of respiratory protection equipment, they are primarily used to determine appropriate respiratory selection in compliance with OSHA standards.

# Toxic Atmospheres

**Web resources:**

ACGIH: **www.acgih.org/TLV**

OSHA: **www.osha.gov**

NIOSH: **www.cdc.gov/niosh/homepage.html**

**Gas detection systems are used to monitor toxic gases in primarily two types of monitoring applications:**

**1. Ambient air monitoring (includes leak monitoring)**

- low-level gas detection for worker safety
- to reduce leakage of expensive compounds (e.g. refrigerants)

**2. Process monitoring**

- to monitor levels of compounds used in chemical synthesis processes (e.g. plastics, rubber, leather, and food industries)
- from low ppm levels to high % by volume levels

For toxic gas monitoring, electrochemical, metal oxide semiconductor (solid state), infrared, and photoionization are the sensing technologies most commonly used.

## Oxygen Deficiency/Enrichment

### Oxygen Deficiency

Normal ambient air contains an oxygen concentration of 20.8% by volume. When the oxygen level dips below 19.5% of the total atmosphere, the area is considered oxygen deficient. In oxygen-deficient atmospheres, life-supporting oxygen may be displaced by other gases, such as carbon dioxide. This results in an atmosphere that can be dangerous or fatal when inhaled. Oxygen deficiency may also be caused by rust, corrosion, fermentation, or other forms of oxidation that consume oxygen. As materials decompose, oxygen is drawn from the atmosphere to fuel the oxidation process.

The impact of oxygen deficiency can be gradual or sudden, depending on the overall oxygen concentration and the concentration levels of other gases in the atmosphere. Typically, decreasing levels of atmospheric oxygen cause the following physiological symptoms *(see chart on right).*

### Oxygen Enrichment

When the oxygen concentration rises above 20.8% by volume, the atmosphere is considered oxygen-enriched and is prone to becoming unstable. As a result of the higher oxygen level, the likelihood and severity of a flash fire or explosion is significantly increased.

| % OXYGEN | PHYSIOLOGICAL EFFECT |
|---|---|
| **19.5 - 16** | No visible effect. |
| **16 - 14** | Increased breathing rate. Accelerated heartbeat. Impaired attention, thinking and coordination. |
| **14 - 10** | Faulty judgment and poor muscular coordination. Muscular exertion causing rapid fatigue. Intermittent respiration. |
| **10 - 6** | Nausea and vomiting. Inability to perform vigorous movement, or loss of the ability to move. Unconsciousness, followed by death. |
| **BELOW 6** | Difficulty breathing. Convulsive movements. Death in minutes. |

# Gas Detection Technologies

## Gas Detection Technologies

There are a variety of gas detection technologies in use today. Among the most commonly employed are:

- Catalytic Bead
- Metal Oxide Semiconductor (also known as “solid state”)
- Non-Dispersive Infrared
  - Point
  - Open Path
- Tuneable Laser Diode Absorption Spectroscopy
- Photoacoustic Infrared
- Electrochemical
  - Toxic Gas
  - Oxygen
- Ultrasonic (Acoustic)

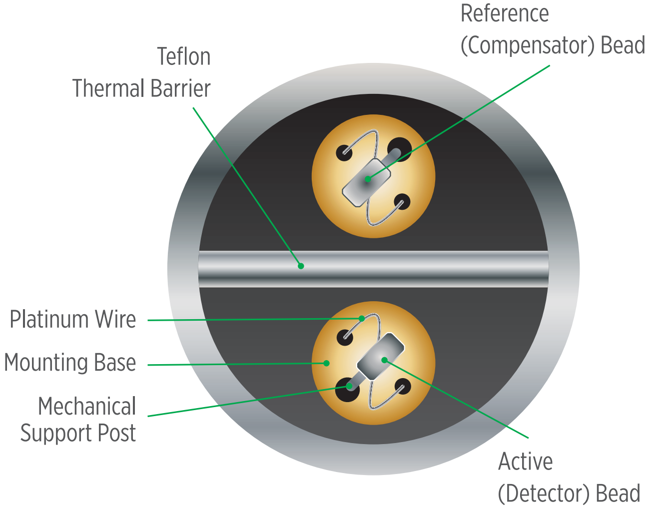
The tables and diagrams on the following pages summarize the operation of each technology.

## Gas Detection Technologies

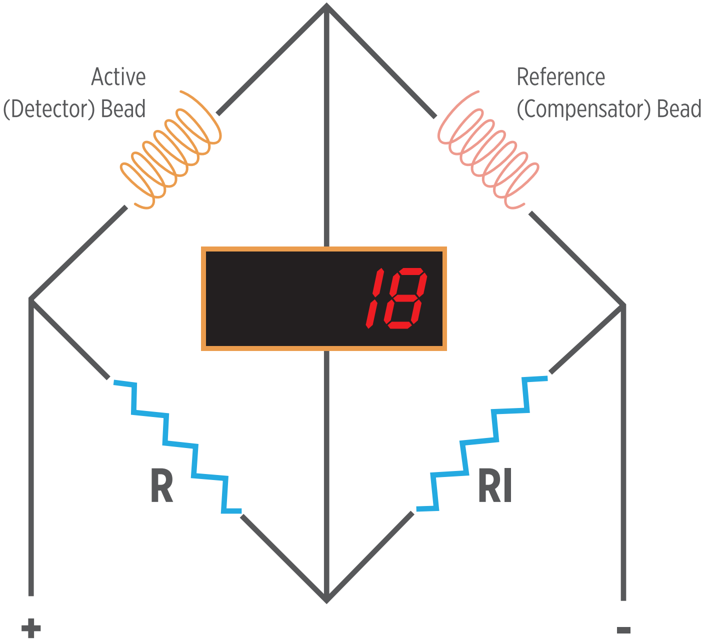
| | |
|---|---|
| **TECHNOLOGY** | Catalytic bead |
| **GAS TYPE DETECTED** | Combustible gas |
| **PRINCIPLE OF OPERATION** | Uses a catalytic bead that changes resistance in response to the presence of a combustible gas; the resulting change is measured and translated into a sensor reading. |
| **DESCRIPTION - DETAILED** | A wire coil is coated with a catalyst-coated glass or ceramic material, and is electrically heated to a temperature that allows it to burn (catalyze) the gas being monitored, releasing heat and increasing the temperature of the wire in direct proportion to the concentration of the gas. As the temperature of the wire increases, so does its electrical resistance. This resistance is measured by a Wheatstone Bridge circuit and the resulting measurement is converted to an electrical signal used by gas detectors.<br>A second sensor, the compensator, is used to compensate for temperature, pressure, and humidity. |
| **READINGS** | % LEL |
| **PROS** | Long life, less sensitive to temperature, humidity, condensation, and pressure changes; high accuracy; fast response; monitors a wide range of combustible gases and vapors in air (e.g. hydrogen, heptane). |
| **CONS** | Subject to sensor poisoning from silicates or hydrogen sulfide ($H_2S$); requires air or oxygen; shortened life with frequent or continuous exposure to high LEL levels. |

# Gas Detection Technologies

## Typical Catalytic Bead Sensor Operation



The active bead oxidizes (burns) combustible gas molecules.
The inert reference bead remains permanently non-responsive to gas.

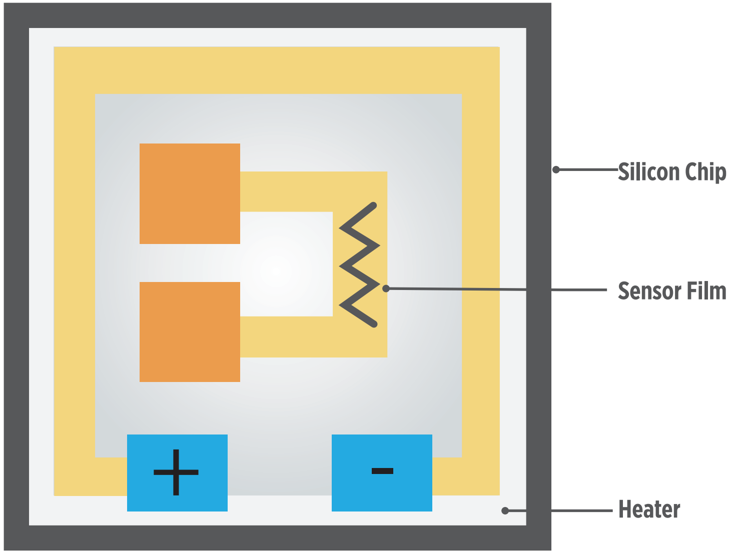


As gas oxidizes on the active bead, the bead temperature rise increases the resistance of the active bead, and when compared with the reference bead resistance, results in a measurable voltage differential.

## Gas Detection Technologies

| | |
|---|---|
| **TECHNOLOGY** | Metal Oxide Semiconductor |
| **GAS TYPE DETECTED** | Combustible gas; toxic gas |
| **PRINCIPLE OF OPERATION** | Made of a metal oxide that changes resistance in response to the presence of a gas; this change is measured and translated into a concentration reading. |
| **DESCRIPTION - DETAILED** | A semiconducting material (metal oxide) is applied to a non-conducting substance (substrate) between two electrodes. The substrate is heated to a temperature at which the presence of the gas can cause a reversible change in the conductivity of the semi-conducting material. When no gas is present, oxygen is ionized onto the surface and the sensor becomes semi-conductive; when molecules of the gas of interest are present, they replace the oxygen ions, decreasing the resistance between the electrodes. This change is measured electrically and is proportional to the concentration of the gas being measured. |
| **READINGS** | ppm |
| **PROS** | High sensitivity (detects low concentrations); wide operating temperature range; long life. |
| **CONS** | Non-specific (cross-sensitive to other compounds); nonlinear output; sensitive to changes in humidity; subject to poisoning. |

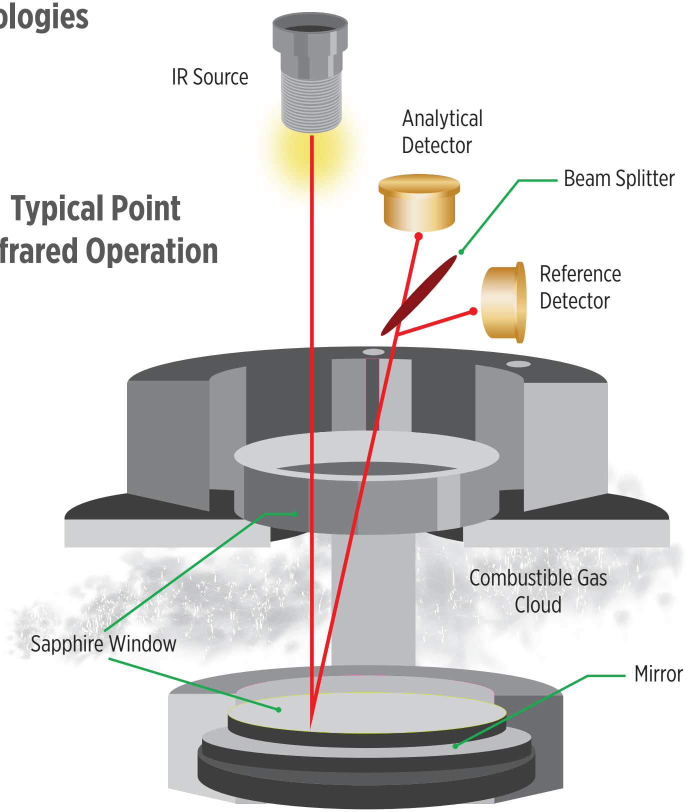
## Typical Metal Oxide Semiconductor (Solid State) Sensor Operation



## Gas Detection Technologies

| | |
|---|---|
| **TECHNOLOGY** | Non-Dispersive Infrared (NDIR) - Point |
| **GAS TYPE DETECTED** | Combustible gas |
| **PRINCIPLE OF OPERATION** | Absorptive IR uses a gas's ability to absorb IR radiation. Two gas samples – the gas of interest, and an inert reference gas – are exposed to infrared light. The amount of light transmitted through each sample is compared to determine the concentration of the gas of interest. |
| **DESCRIPTION - DETAILED** | Uses an electrically modulated source of infrared energy and two detectors that convert the infrared energy into electrical signals. Each detector is sensitive to a different range of wavelengths in the infrared portion of the spectrum. The source emission is directed through a window in the main enclosure into an open volume. A mirror may be used at the end of this volume to direct the energy back through the window and onto the detectors.<br>The presence of a combustible gas will reduce the intensity of the source emission reaching the analytical detector, but not the intensity of emission reaching the reference detector. The microprocessor monitors the ratio of these two signals and correlates this to a % LEL reading. |
| **READINGS** | % LEL |
| **PROS** | High accuracy and selectivity; large measurement range; low maintenance; highly resistant to chemical poisons; does not require oxygen or air; span drift potential virtually eliminated (no routine calibration required); fail-safe. Compared to open-path IR, provides exact gas level (at point of detection only). |
| **CONS** | Not suitable for measuring gases that do not absorb infrared light: diatomic molecules like oxygen, nitrogen, and hydrogen. |

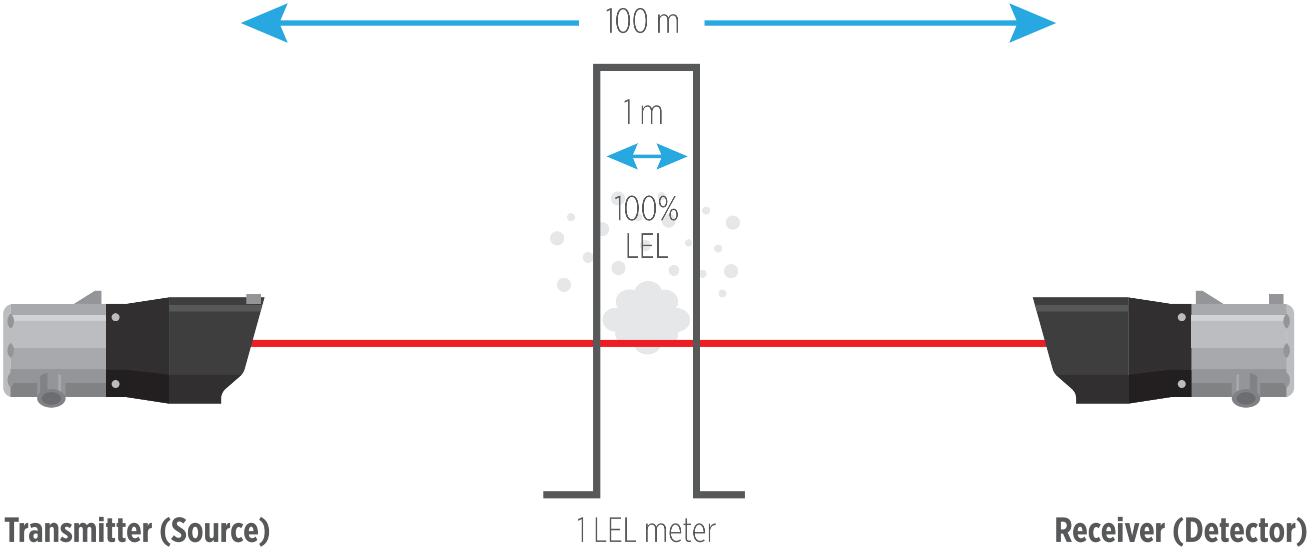
## Typical Point Infrared Operation



# Gas Detection Technologies

| | |
|---|---|
| **TECHNOLOGY** | Non-Dispersive Infrared (NDIR) - Open Path |
| **GAS TYPE DETECTED** | Combustible gas |
| **PRINCIPLE OF OPERATION** | Operates similarly to point infrared detectors, except that the IR source is separated from the detector. |
| **DESCRIPTION - DETAILED** | Open-path IR monitors expand the concepts of point IR detection to a gas sampling path of up to 150 meters.<br>Like point IR monitors, they utilize a dual beam concept. The "sample" beam is in the infrared wavelength which absorbs hydrocarbons, while the second "reference" beam is outside this gas absorbing wavelength. The ratio of the two beams is continuously compared. When no gas is present, the signal ratio is constant; when a gas cloud crosses the beam, the sample signal is absorbed or reduced in proportion to the amount of gas present while the reference beam is not. System calculates the product of the average gas concentration and the gas cloud width, and readings are given in % LEL per meter. |
| **READINGS** | LEL per meter (LEL.m) |
| **PROS** | High accuracy and selectivity; large measurement range; low maintenance; highly resistant to chemical poisons; does not require oxygen or air; span drift potential virtually eliminated (no routine calibration required); fail-safe. |
| **CONS** | Not suitable for hydrogen detection.<br>Compared with point IR detection, is not capable of isolating the leak source.<br>Requires unobstructed path between source and detector.<br>Longer path lengths can be more difficult to align and may be susceptible to beam block (loss of IR signal by the detector) in heavy fog or rain. |

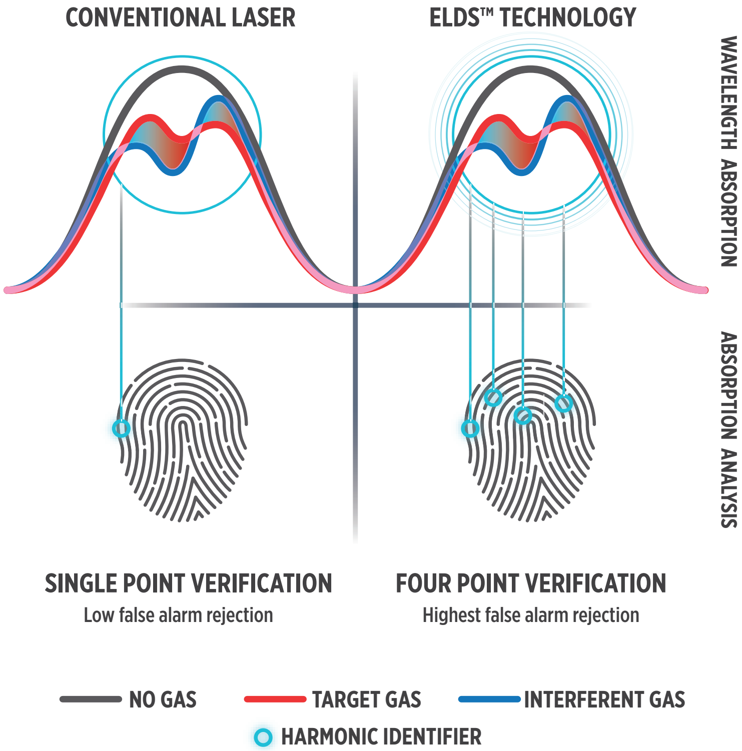
## Typical NDIR (Open Path) Operation



# Gas Detection Technologies

| | |
|---|---|
| **TECHNOLOGY** | Tuneable Laser Diode Absorption Spectroscopy (TLDAS) - Open Path |
| **GAS TYPE DETECTED** | Combustible gas; toxic gas |
| **PRINCIPLE OF OPERATION** | A separate transmitter (source) - which emits an infrared beam - is optically aligned to a receiver - which detects (receives) the beam. A detection signal is produced when a gaseous mixture crosses the IR beam at any point along its path. |
| **DESCRIPTION - DETAILED** | Gas concentrations are detected and measured at specific target gas absorption wavelengths over distances of up to 200 meters (gas dependant).<br>The transmitter generates a specific wavelength of IR radiation that will only be absorbed exclusively by the target gas in question. Control of the generated wavelength is via a retained sample of the target gas in the transmitter. Absorption of the detection wavelength by the target gas in the open path results in a modified light signal. The 2nd harmonic of this modified signal is analyzed to confirm the presence and quantity of the target gas.<br>Enhanced Laser Diode Spectroscopy (ELDS) uses the same technique with 4 levels of harmonic verification which maximizes false alarm rejection to the highest degree. |
| **READINGS** | LEL per meter (LEL.m); ppm per meter (ppm.m) |
| **PROS** | Target gas specific – no false alarms from interferent gases.<br>Not subject to poisoning; detects large/low concentration and small/high concentration gas escapes.<br>Greater area of coverage compared to point detection.<br>Better uptime availability in heavy fog and rain conditions (i.e., the laser is not absorbed by moisture) and higher sensitivity than differential IR combustible open path gas detectors.<br>Able to detect toxic gases; no consumable sensing elements. |
| **CONS** | Not all gases can be detected by TLDAS technology; requires a clear line of site. |

# Gas Detection Technologies

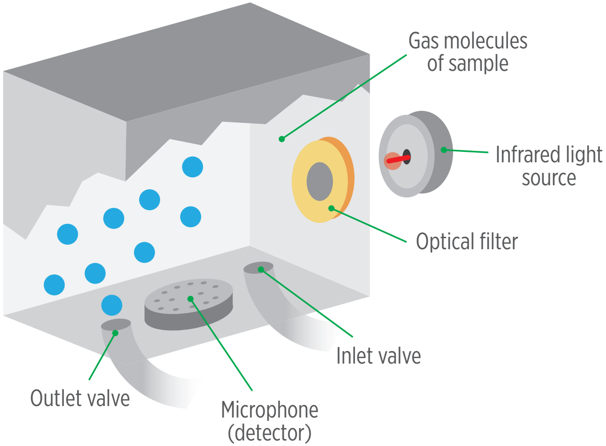


## Gas Detection Technologies

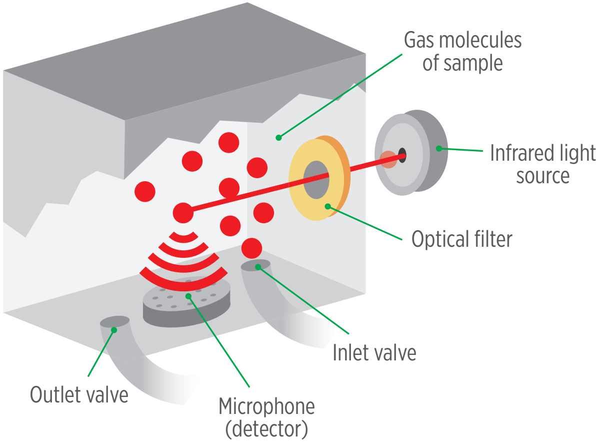
| | |
|---|---|
| **TECHNOLOGY** | Photoacoustic Infrared |
| **GAS TYPE DETECTED** | Combustible gas; toxic gas |
| **PRINCIPLE OF OPERATION** | Uses a gas's ability to absorb IR radiation and the resulting change in pressure. |
| **DESCRIPTION - DETAILED** | The gas sample is exposed to infrared light; as it absorbs light, its molecules generate a pressure pulse. The magnitude of the pressure pulse indicates the gas concentration present. |
| **READINGS** | % LEL; % by volume; ppm; ppb |
| **PROS** | High sensitivity; linear output; easy to handle; not subject to poisoning; long-term stability. |
| **CONS** | Not suitable for hydrogen detection. |

## Pumped Photoacoustic Infrared Operation

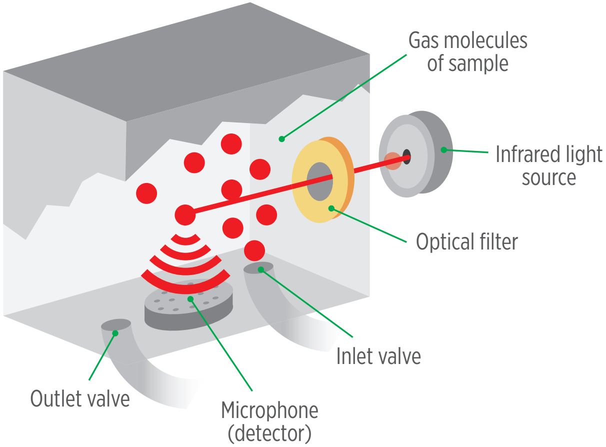
(Diffusion method also available)



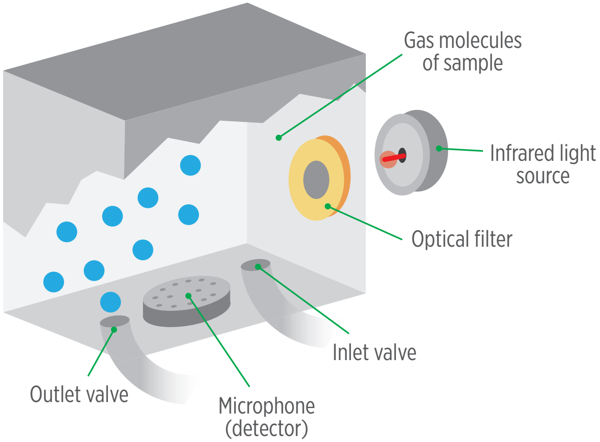
Sample gas enters the measuring cell.



The gas is irradiated with pulsed infrared energy.



The gas molecules heat and cool as they absorb the infrared energy. The pressure changes as a result of the heating and cooling of the molecules measured by the detector. This pressure change is converted into a gas reading.



The gas is exhausted and a fresh sample enters the cell. This sampling process is continuously repeated.

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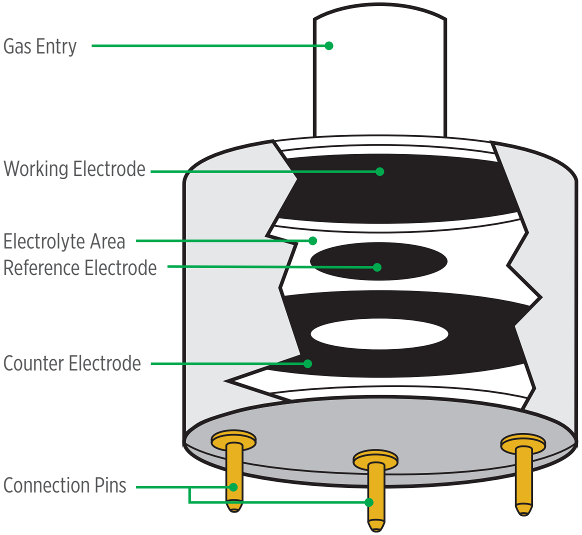
# Gas Detection Technologies

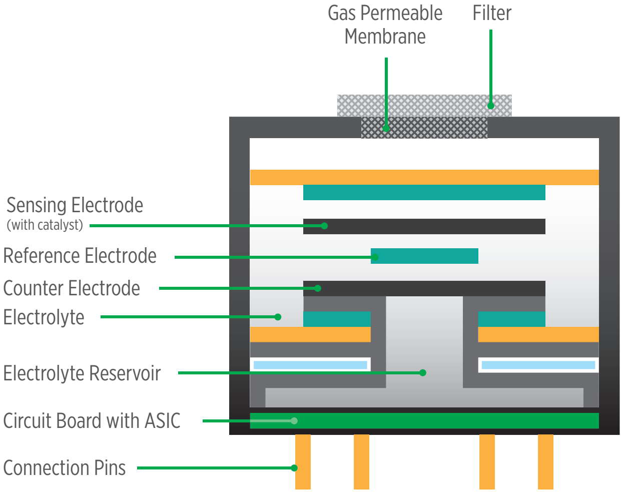
| | |
|---|---|
| **TECHNOLOGY** | Electrochemical - Toxic Gas |
| **GAS TYPE DETECTED** | Toxic gas |
| **PRINCIPLE OF OPERATION** | Uses an electrochemical reaction to generate a current proportional to the gas concentration. |
| **DESCRIPTION - DETAILED** | The sensor is a chamber containing a gel or electrolyte and two active electrodes – the measuring (sensing/working) electrode (anode), and the counter electrode (cathode). A third electrode (reference) is used to build up a constant voltage between the anode and the cathode. The gas sample enters the casing through a membrane; oxidation occurs at the anode and reduction takes place at the cathode. When the positive ions flow to the cathode and the negative ions flow to the anode, a current proportional to the gas concentration is generated.<br>In comparison, MSA's XCell® sensors utilize identical electrochemical principles but employ a number of significant physical design advancements (pictured on the following page). |
| **READINGS** | ppm |
| **PROS** | High sensitivity; linear output; easy to handle. |
| **CONS** | Limited shelf life; subject to interferents; sensor lifetime shortened in very dry and very hot environments; performance impacted by extreme humidity environments. |

# Gas Detection Technologies

## Typical Electrochemical Toxic Sensor



## XCell® Electrochemical Toxic Sensor



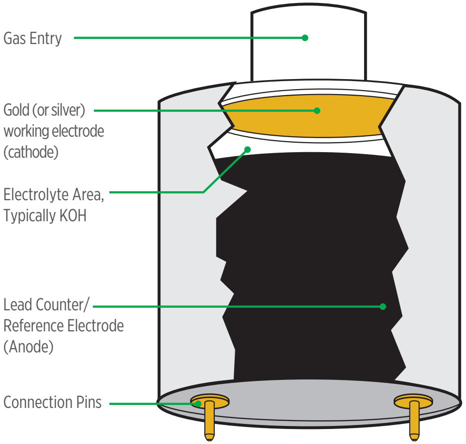
The mechanical design of the XCell sensor is optimized for the most effective interaction between the electrolyte, electrode catalyst, and target gas regardless of environmental conditions to overcome.

# Gas Detection Technologies

| | |
|---|---|
| **TECHNOLOGY** | Electrochemical - Oxygen ($O_2$) |
| **GAS TYPE DETECTED** | Oxygen deficiency/enrichment |
| **PRINCIPLE OF OPERATION** | Uses an electrochemical reaction to generate a current proportional to the gas concentration. |
| **DESCRIPTION - DETAILED** | The sensor is a chamber containing a gel or electrolyte and two electrodes – the measuring (sensing/working) electrode, and the (usually lead) counter/reference electrode. The gas sample enters the casing through a membrane; oxidation occurs at the anode and reduction takes place at the cathode. When the positive ions flow to the cathode and the negative ions flow to the anode, a current proportional to the gas concentration is generated.<br>By contrast, the electrocatalytic system in an XCell® Oxygen Sensor is lead-free and uses a non-consuming chemical reaction, thus eliminating susceptibility to shelf life limitations related to lead. |
| **READINGS** | % by volume of oxygen |
| **PROS** | High sensitivity; linear output; easy to handle; not subject to poisoning. |
| **CONS** | Limited shelf life; subject to interferents; sensor life shortened in very dry and hot environments.*<br>Sensor life negatively affected in enriched oxygen applications. |

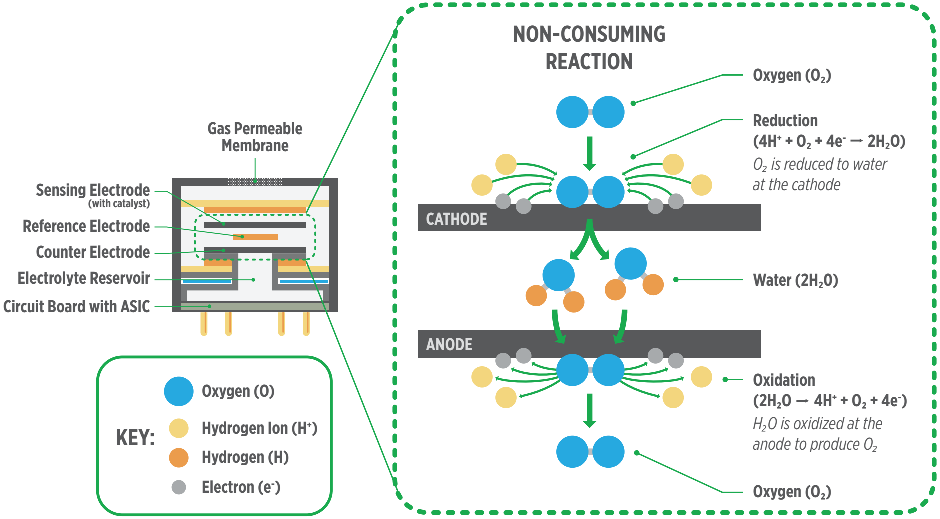
** Applicable only to lead-based sensors, not XCell $O_2$ sensors.*

## Typical Electrochemical Oxygen Sensor



Sensor lifetime is determined by the amount of lead on-board.

## XCell® Electrochemical Oxygen Sensor

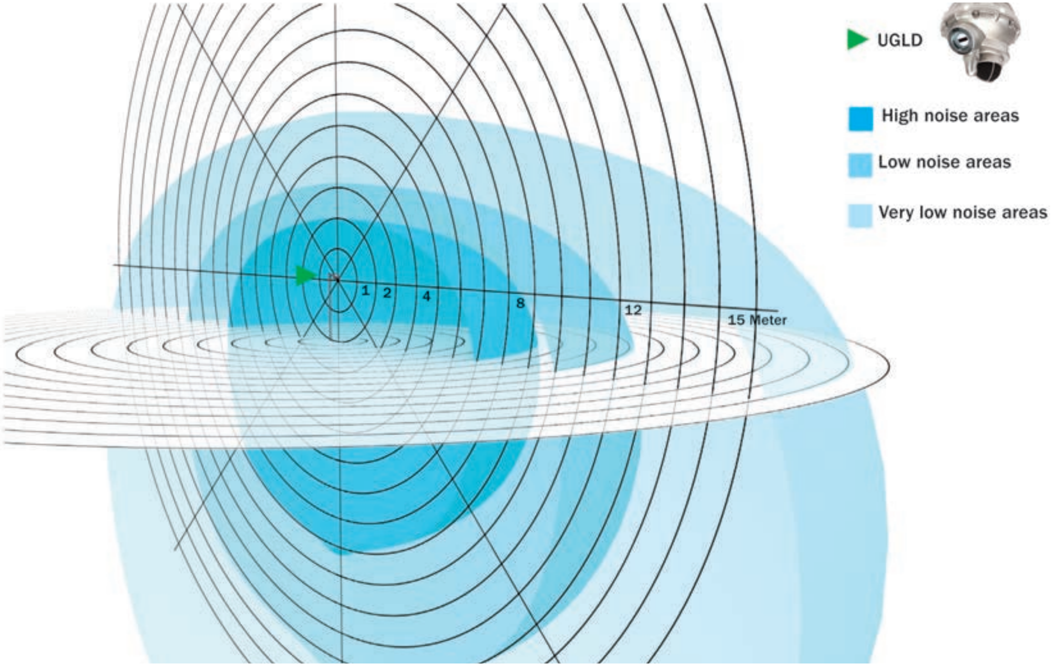


The diagram above illustrates that for every oxygen molecule that is reduced at the working electrode (cathode), a complimentary oxygen molecule is produced by the oxidation of water (from the electrolyte) at the counter electrode (anode). This non-consuming process eliminates sensor life limitations exclusively associated with lead-based designs.

# Gas Detection Technologies

| | |
|---|---|
| **TECHNOLOGY** | Ultrasonic Gas Leak Detection (UGLD) |
| **GAS TYPE DETECTED** | Pressurized gas leaks |
| **PRINCIPLE OF OPERATION** | Ultrasonic gas leak detectors do not measure gas concentration, but rather leaks from high pressure systems. |
| **DESCRIPTION - DETAILED** | UGLD detects leaks from pressurized gas systems by sensing the airborne acoustic ultrasound produced by the escaping gas. When a gas leak occurs, the ultrasound generated by the leak travels at the speed of sound, through the air, from the source to the detector. The response of the UGLD is not dependent on the gas to accumulate into potentially dangerous levels and travel to the detector, which means that it reacts much faster to a gas leak. These devices are therefore often used to supplement traditional gas detection devices and can serve as early warning systems. |
| **READINGS** | Decibels (dB) |
| **PROS** | Rapid response speed.<br>Immune to the effects of weather conditions that cause gas dispersal (e.g. wind).<br>Unaffected by audible noise.<br>Coverage area can be confirmed using an inert gas.<br>No routine calibration is necessary. |
| **CONS** | The target element must be in the gas phase and cannot be a liquid; any object in the sensor path will return an echo; sensor reach is limited to shape and size of sound wave emissions. |

## Gas Detection Technologies



The graphic shows the detection coverage characteristics for UGLD. The distances are based on the detection of methane-based gas leaks using a leak rate of 0.1 kg/s as the performance standard. The response of the UGLD is not dependent on the gas to travel to the detector, which means that it reacts much faster to a dangerous gas leak.

# Gas Sampling

### Gas Sampling

**There are three methods of gas sampling:**

- Diffusion Sampling
- Pumped Sampling
- Aspirated Sampling

### Diffusion Sampling

Diffusion is the natural movement of molecules away from an area of high concentration to an area of lower concentration. The term “diffusion” denotes the process by which molecules or other particles intermingle as a result of their random thermal motion. Ambient conditions such as temperature, air currents, and other characteristics affect diffusion.

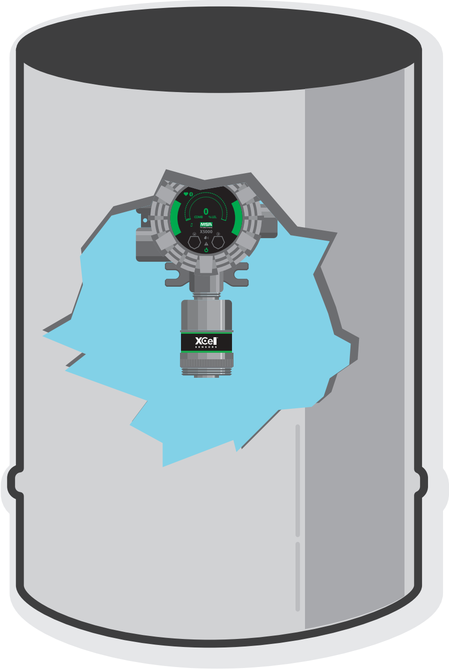
### Advantages:

- Most effective placement is at desired sampling point.
- Fast response because no sample transport is required.
- No pumps and/or filters to maintain.

### Pumped Sampling

Pumped sampling uses a pump to pull the sample from a remote location into or through the sensor. With pumped sampling, samples can be gathered simultaneously from two or more locations.

## Sensor Mounted Inside Gas Tank



# Gas Sampling

**Conditions Favoring Pumped Sampling:**

- Sampling point is too hot/cold.
- Sampling point is difficult to access.
- Heavy vapor present that does not diffuse well by natural forces.
- An application can be converted from an explosion-proof (XP) rating to a general purpose (GP) rating through pumped operation. (Flashback arrestors may be necessary between the sample port and the sensor.)
- Confined Spaces.

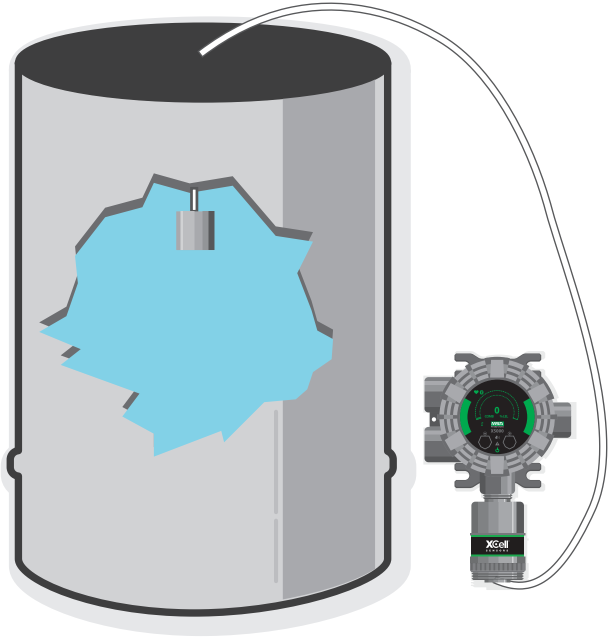
**Aspirated Sampling**

Aspirated sampling uses suction to draw the sample from a remote location into or through the sensor.

**Advantages of Aspirated Sampling Versus Pumped:**

- Lower cost.
- Reduced maintenance because there are no moving parts.

**Sensor Mounted Outside Tank with Tube Running into Tank**



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# Section 3

## Flame Detection

# Technology — UV/IR Flame Detection

**Flames Detected**

Hydrocarbon or hydrogen flames

**Principle of Operation**

Uses separate ultraviolet and infrared sensors to detect electromagnetic radiation indicative of a flame. The detector will indicate that a fire exists when both sensors determine that a fire is present.

**Description Detailed**

Uses a ultraviolet phototube and an infrared pyrometer to discern a flames spectral signature from other background radiation.
The UV phototube *(Figure 1)* is sensitive to ultraviolet radiation given off by a flame in the UV spectral region *(Figure 2).*
The infrared detector is constantly monitoring for infrared radiation given off by a hydrocarbon flame *(Figure 3)* or a hydrogen flame *(Figure 4)*.

**Reading**

UV present. IR present. Flame detected.

**Pros**

Good false alarm immunity – immune to most background irradiation

Fast response

Wide field of view

**Cons**

Limited distance

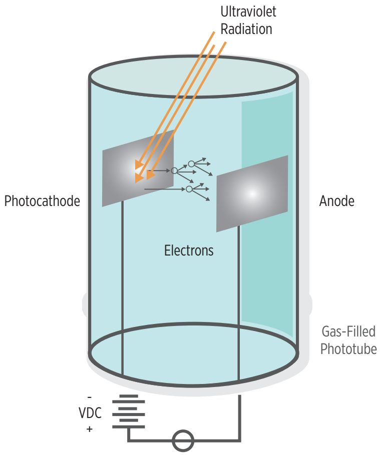

*Figure 1*

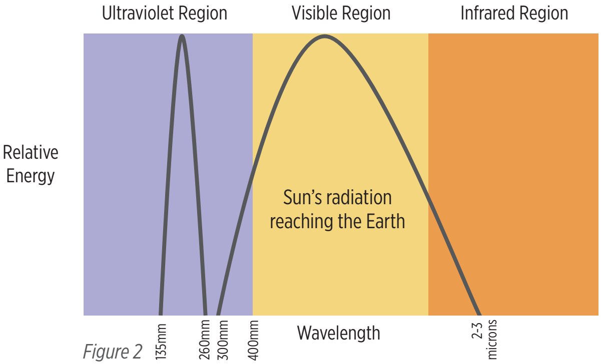

*Figure 2*

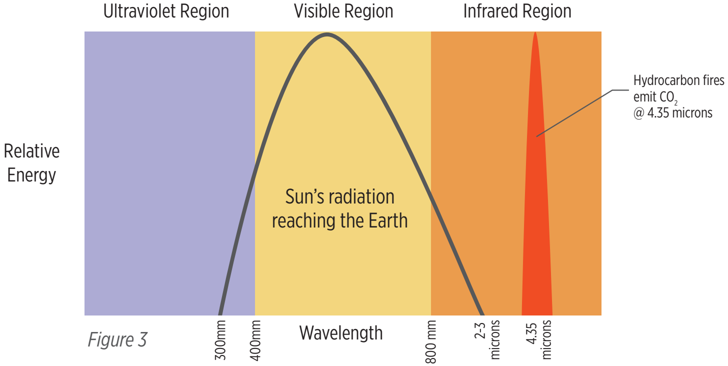

*Figure 3*

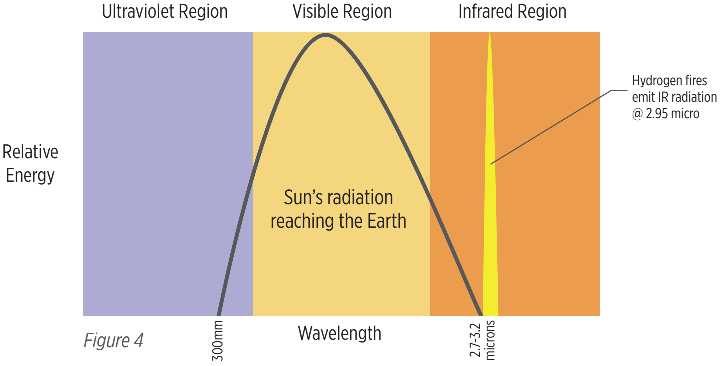

*Figure 4*

## Technology – Multi-Spectral IR Flame Detection

**Flames Detected**

Hydrocarbon flames

**Principle of Operation**

Uses multiple infrared sensors to monitor for flames while eliminating false alarms associated with UV sources.

**Description Detailed**

Uses multiple infrared sensors radiation at wavelengths indicative of a flame to determine the presence of a flame. Additional infrared sensors are used to monitor for radiation at other infrared wavelengths to prevent false alarms. The combination of multiple sensors and complex algorithms are used to determine that a fire is present.

**Reading**

Flame detected

**Pros**

Superior false alarm immunity – immune to background irradiation including arc welding at close distances.

Longest distance protection *(see Figure 5).*

**Cons**

Slower response than UV/IR

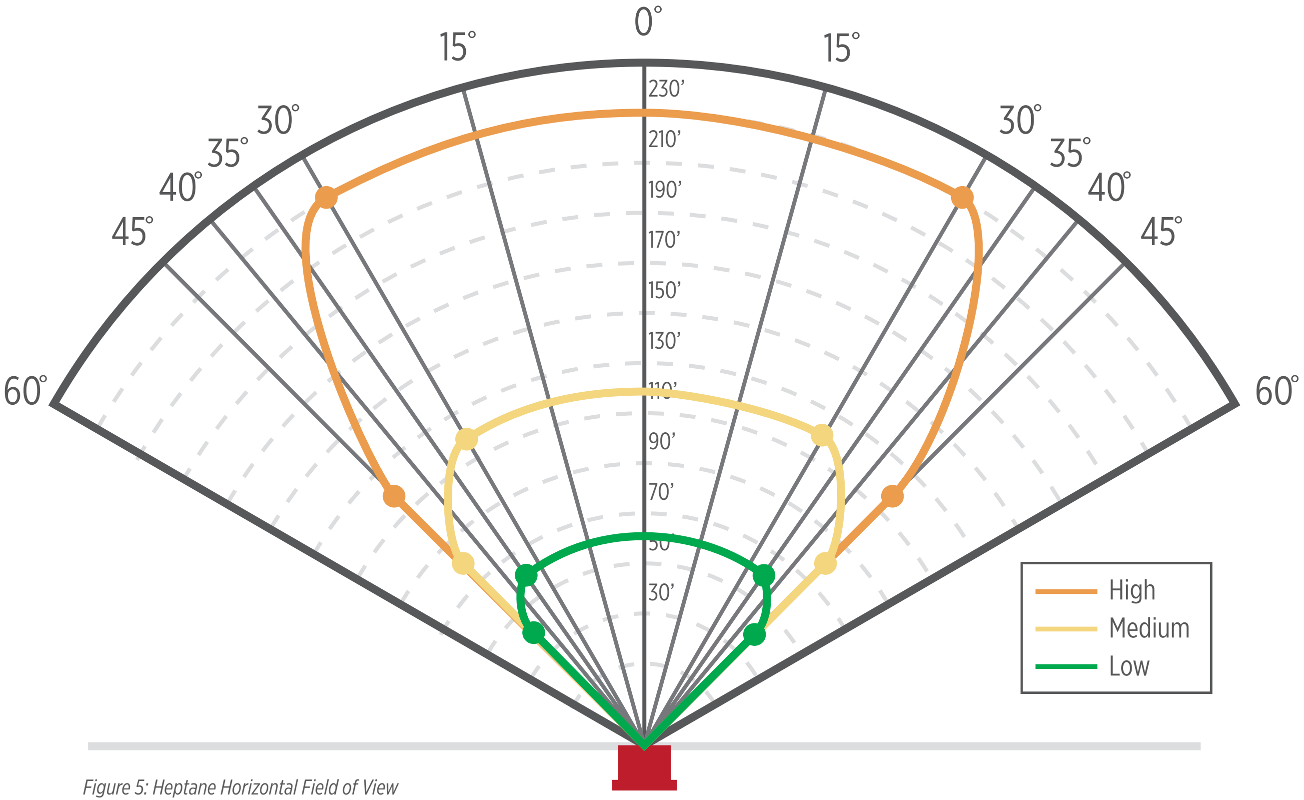

*Figure 5: Heptane Horizontal Field of View*

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# Section 4

## Gas Information Tables

# Gas Information Table

| | | | | | | | | | | Detection Technologies | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Gas or Vapor** | **Synonym** | **Chemical Formula** | **Relative Density (vs. Air)+** | **Combustible** | **Flash Point (°C)[1]*** | **LEL (% by vol)[1]** | **UEL (% by vol)[1]** | **OSHA PEL (PPM)[2]** | **NIOSH IDLH (PPM)[3]** | **Electrochemical** | **Catalytic** | **Photoacoustic IR** | **Absorptive IR** | **Semiconductor** | **Ignition Temp (°C)*** | **Boiling Point (°C)[1]** | **Vapor Pressure (mm Hg at 20°C) [1,4]** |
| Acetaldehyde | Acetic aldehyde | $C_2H_4O$ | Heavier | ✓ | -38 | 4.0 | 60 | 200 | 2,000 | | ✓ | ✓ | | ✓ | 175 | 21 | 740 |
| Acetic acid | | $C_2H_4O_2$ | Heavier | ✓ | 39 | 4.0 | 19.9 | 10 | 50 | | ✓ | ✓ | ✓ | ✓ | 463 | 118 | 11 |
| Acetic aldehyde | Acetaldehyde | $C_2H_4O$ | Heavier | ✓ | -38 | 4.0 | 60 | 200 | 2,000 | | ✓ | ✓ | | ✓ | 175 | 180 | 740 |
| Acetone | | $C_3H_6O$ | Heavier | ✓ | -18 | 2.5 | 12.8 | 1,000 | 2,500 | | ✓ | ✓ | ✓ | ✓ | 465 | 56 | 180 |
| Acetonitrile | | $C_2H_3N$ | Heavier | ✓ | 6 | 3.0 | 16 | 40 | 137 | | ✓ | ✓ | ✓ | ✓ | 524 | 44 | 73 |
| Acetylene | Ethine, Ethyne | $C_2H_2$ | Lighter | ✓ | Gas | 2.5 | 100 | - | - | | ✓ | ✓ | ✓ | ✓ | 305 | -83 | Gas |
| Acrylic acid | Acroleic acid | $C_2H_4O_2$ | Heavier | ✓ | 50 | 2.0 | 8 | - | - | | ✓ | | ✓ | ✓ | 438 | 142 | 3 |
| Acrolein | Acrylaldehyde | $C_3H_4O$ | Heavier | ✓ | -26 | 2.8 | 31 | 0.1 | 2 | | ✓ | ✓ | ✓ | ✓ | 220 | 52 | 210 |
| Acrylaldehyde | Acrolein | $C_3H_4O$ | Heavier | ✓ | -26 | 2.8 | 31 | 0.1 | 2 | | ✓ | ✓ | ✓ | ✓ | 220 | 52 | 210 |
| Acrylic acid | Acroleic acid | $C_2H_4O_2$ | Heavier | ✓ | 50 | 2.0 | 8 | - | - | | ✓ | | ✓ | ✓ | 438 | 142 | 3 |
| Acrylonitrile | | $C_2H_3N$ | Heavier | ✓ | -1 | 3.0 | 17 | 2 | 60 | | ✓ | | ✓ | ✓ | 481 | 77 | 83 |

**Key:** **[C]** = Ceiling Limit (never exceed) **A** = Asphyxiant **Ca** = Carcinogen **–** = Data not currently available **n/a** = Data not applicable

# Gas Information Table

| Gas or Vapor | Synonym | Chemical Formula | Relative Density (vs. Air)+ | Combustible | Flash Point (°C)$^{1*}$ | LEL (% by vol)$^{1}$ | UEL (% by vol)$^{1}$ | OSHA PEL (PPM)$^{2}$ | NIOSH IDLH (PPM)$^{3}$ | Detection Technologies<br>Electrochemical | Catalytic | Photoacoustic IR | Absorptive IR | Semiconductor | Ignition Temp (°C)* | Boiling Point (°C)$^{1}$ | Vapor Pressure (mm Hg at 20°C)$^{1,4}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Allyl alcohol | 2-propenyl | $C_3H_6O$ | Heavier | ✓ | 21 | 2.5 | 18 | 2 | 20 |  | ✓ | ✓ | ✓ | ✓ | 378 | 97 | 17 |
| Allyl chloride |  | $C_3H_5Cl$ | Heavier | ✓ | -31 | 2.9 | 11.1 | 1 | 250 |  | ✓ |  |  | ✓ | 392 | 45 | 295 |
| Ammonia |  | $NH_3$ | Lighter | ✓ | Gas | 15 | 28 | 50 | 300 | ✓ | ✓ | ✓ | ✓ |  | 651 | -33 | Gas |
| Amyl acetate, n- |  | $C_7H_{14}O_2$ | Heavier | ✓ | 25 | 1.1 | 7.5 | 100 | 1,000 |  | ✓ |  | ✓ | ✓ | 360 | 149 | 4 |
| Arsine |  | $AsH_3$ | Heavier | ✓ | Gas | 5.1 | 78 | 0.05 | 3 | ✓ |  |  |  |  |  | -62 | Gas |
| Benzene |  | $C_6H_6$ | Heavier | ✓ | -11 | 1.3 | 7.8 | 10 | 500 |  | ✓ | ✓ | ✓ | ✓ | 498 | 80 | 75 |
| Benzene chloride | Chlorobenzene | $C_6H_5Cl$ | Heavier | ✓ | 28 | 1.3 | 9.6 | 75 | 10 |  | ✓ | ✓ | ✓ | ✓ | 638 | 132 | 9 |
| Bromine |  | $Br_2$ | Heavier |  | n/a | n/a | n/a | 0.1 | 3 | ✓ |  |  |  |  |  | 59 | 172 |
| Bromochlorodi fluoromethane | Halon 1211 | $CF_2ClBr$ | Heavier |  | n/a | n/a | n/a | – | – |  |  | ✓ | ✓ | ✓ | – | 3.3 | Gas |
| Bromomethane | Methyl bromide | $CH_3Br$ | Heavier | ✓ | n/a | 10.0 | 16 | 20 [C] | 250 [Ca] |  | ✓ | ✓ | ✓ | ✓ | 537 | 4 | Gas |
| Bromotrifluoro methane | Halon 1301 ®,<br>Trifluorobromo-methane | $CBrF_3$ | Heavier |  | n/a | n/a | n/a | 1,000 | 40,000 |  |  | ✓ | ✓ | ✓ | – | -58 | Gas |

**Key:** **[C]** = Ceiling Limit (never exceed) **A** = Asphyxiant **Ca** = Carcinogen **–** = Data not currently available **n/a** = Data not applicable

# Gas Information Table

| Gas or Vapor | Synonym | Chemical Formula | Relative Density (vs. Air)+ | Combustible | Flash Point (°C)[1]* | LEL (% by vol)[1] | UEL (% by vol)[1] | OSHA PEL (PPM)[2] | NIOSH IDLH (PPM)[3] | Detection Technologies |  |  |  |  | Ignition Temp (°C)* | Boiling Point (°C)[1] | Vapor Pressure (mm Hg at 20°C) [1,4] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  |  |  |  |  |  |  |  |  | Electrochemical | Catalytic | Photoacoustic IR | Absorptive IR | Semiconductor |  |  |  |
| Butadiene |  | $C_4H_{10}$ | Heavier | ✓ | -76 | 2.0 | 11.5 | 1 | 2,000 [Ca] |  | ✓ | ✓ |  | ✓ | 420 | -4 | Gas |
| Butane, n- |  | $C_4H_{10}$ | Heavier | ✓ | Gas | 1.5 | 8.5 | – | 1,600 |  | ✓ | ✓ | ✓ | ✓ | 287 | -1 | Gas |
| Butanol, n- | Butyl alcohol, n- | $C_4H_{10}O$ | Heavier | ✓ | 29 | 1.4 | 11.2 | 100 | 1,400 |  | ✓ | ✓ |  | ✓ | 343 | 117 | 6 |
| Butanol, sec- | Butyl alcohol, sec- | $C_4H_{10}O$ | Heavier | ✓ | 24 | 1.7 | 9.8 | 150 | 2,000 |  | ✓ | ✓ | ✓ | ✓ | 405 | 94 | 12 |
| Butanone, 2- | Methylethylketone | $C_4H_8O$ | Heavier | ✓ | -9 | 1.4 | 11.4 | 200 | 3,000 |  | ✓ | ✓ | ✓ | ✓ | 404 | 80 | 78 |
| Butyl acetate, n- |  | $C_6H_{12}O_2$ | Heavier | ✓ | 22 | 1.7 | 7.6 | 150 | 1,700 |  | ✓ | ✓ | ✓ | ✓ | 420 | 127 | 10 |
| Butyl acetate, sec- |  | $C_6H_{12}O_2$ | Heavier | ✓ | 17 | 1.7 | 9.8 | 200 | 1,700 |  | ✓ | ✓ | ✓ | ✓ | – | 112 | 10 |
| Butyl acetate, tert- |  | $C_6H_{12}O_2$ | Heavier | ✓ | 22 | 1.5 | – | 200 | 1,500 |  | ✓ | ✓ | ✓ | ✓ | – | 97 | 34 |
| Butyl acrylate, n- |  | $C_6H_{12}O_2$ | Heavier | ✓ | 29 | 1.5 | 9.9 | – | 113 |  | ✓ | ✓ | ✓ | ✓ | 267 | 127 | 4 |
| Butyl alcohol, n- | Butanol, n- | $C_4H_{10}$ | Heavier | ✓ | 29 | 1.4 | 11.2 | 100 | 1,400 |  | ✓ | ✓ | ✓ | ✓ | 343 | 117 | 6 |
| Butyl ethylene hexylene | Hexene, 1- | $C_6H_{12}$ | Heavier | ✓ | -26 | 1.2 | 6.9 | – | – |  | ✓ | ✓ | ✓ |  | 253 | 63 | 308 @ 38 °C |

**Key:** **[C]** = Ceiling Limit (never exceed) **A** = Asphyxiant **Ca** = Carcinogen **–** = Data not currently available **n/a** = Data not applicable

# Gas Information Table

| Gas or Vapor | Synonym | Chemical Formula | Relative Density (vs. Air)+ | Combustible | Flash Point (°C)[1]* | LEL (% by vol)[1] | UEL (% by vol)[1] | OSHA PEL (PPM)[2] | NIOSH IDLH (PPM)[3] | Detection Technologies | | | | | Ignition Temp (°C)* | Boiling Point (°C)[1] | Vapor Pressure (mm Hg at 20°C) [1,4] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | Electrochemical | Catalytic | Photoacoustic IR | Absorptive IR | Semiconductor | | | |
| Butyraldehyde | Butylaldehyde: butanal | $C_4H_8O$ | Heavier | ✓ | -22 | 1.9 | 12.5 | 1 | – | | ✓ | ✓ | ✓ | ✓ | 218 | 76 | 2 |
| Carbon dioxide | | $CO_2$ | Heavier | | n/a | n/a | n/a | 5,000 | 40,000 | ✓ | | ✓ | ✓ | | – | | Gas |
| Carbon disulfide | | $CS_2$ | Heavier | ✓ | -30 | 1.3 | 50 | 20 | 500 | | | | ✓ | | 90 | 46 | 300 |
| Carbon monoxide | | $CO$ | Slightly lighter | ✓ | Gas | 12.0 | 75 | 50 | 1,200 | ✓ | ✓ | ✓ | ✓ | ✓ | 609 | -192 | Gas |
| Carbon tetrachloride | Tetrachloromethane | $CCl_4$ | Heavier | | n/a | n/a | n/a | 10 | 200 | | | ✓ | ✓ | | – | 77 | 91 |
| Carbonyl chloride | Phosgene | $COCl_2$ | Heavier | | n/a | n/a | n/a | 0 | 2 | | | ✓ | ✓ | | – | 8 | Gas |
| Chlorine | | $Cl_2$ | Heavier | | Gas | – | n/a | 1 [C] | 10 | ✓ | | | | | – | -34 | Gas |
| Chlorine dioxide | | $ClO_2$ | Heavier | | n/a | n/a | n/a | 0.1 | 5 | ✓ | | | | | – | | Gas |
| Chlorobenzene | Benzene chloride | $C_6H_5Cl$ | Heavier | ✓ | 28 | 1.3 | 9.6 | 75 | 1,000 | | ✓ | ✓ | ✓ | | 638 | 132 | 12 |
| Chloroethane | Ethyl chloride | $C_2H_5Cl$ | Heavier | ✓ | -50 | 3.8 | 15.4 | 1,000 | 3,800 | | ✓ | ✓ | ✓ | | 519 | 12 | Gas |

**Key:** **[C]** = Ceiling Limit (never exceed) **A** = Asphyxiant **Ca** = Carcinogen **–** = Data not currently available **n/a** = Data not applicable

# Gas Information Table

| | | | | | | | | | | Detection Technologies | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Gas or Vapor** | **Synonym** | **Chemical Formula** | **Relative Density (vs. Air)+** | **Combustible** | **Flash Point (°C)[1]*** | **LEL (% by vol)[1]** | **UEL (% by vol)[1]** | **OSHA PEL (PPM)[2]** | **NIOSH IDLH (PPM)[3]** | **Electrochemical** | **Catalytic** | **Photoacoustic IR** | **Absorptive IR** | **Semiconductor** | **Ignition Temp (°C)*** | **Boiling Point (°C)[1]** | **Vapor Pressure (mm Hg at 20°C) [1,4]** |
| Chloroform | Trichloromethane | $CHCl_3$ | Heavier | | n/a | n/a | n/a | 50 [C] | 500 | | | ✓ | ✓ | | - | 62 | 160 |
| Chloromethane | Methyl chloride | $CH_3Cl$ | Heavier | ✓ | Gas | 8.1 | 17.4 | 100 | 2,000 | | ✓ | ✓ | ✓ | | 632 | -24 | Gas |
| Cumene | Isopropylenzene | $C_9H_{12}$ | Heavier | ✓ | 36 | 0.9 | 6.5 | 50 | 900 | | ✓ | ✓ | ✓ | ✓ | 425 | 152 | 8 |
| Cyclohexane | | $C_6H_{12}$ | Heavier | ✓ | -20 | 1.3 | 8 | 300 | 1,300 | | ✓ | ✓ | ✓ | ✓ | 245 | 82 | 78 |
| Cyclohexanone | | $C_6H_{10}O$ | Heavier | ✓ | 44 | 1.1 | 9.4 | 50 | 700 | | ✓ | ✓ | ✓ | ✓ | 420 | 156 | 5 |
| Cyclopetane | | $C_5H_{10}$ | Heavier | ✓ | -37 | 1.1 | 8.7 | - | - | | ✓ | ✓ | ✓ | ✓ | 361 | 49 | 400 |
| Diacetone alcohol | Diacetone | $C_6H_{12}O_2$ | Heavier | ✓ | 58 | 1.8 | 6.9 | 50 | 1,800 | | ✓ | ✓ | ✓ | ✓ | 603 | 164 | 1 |
| Diborane | Boroethane | $B_2H_6$ | Slightly heavier | ✓ | -90 | 0.8 | 88 | 0.1 | 15 | ✓ | | | | | 38-52 | -93 | 224 @ 112°C |
| Dichlorobenzene 0 | | $C_6H_4Cl_2$ | Heavier | ✓ | 66 | 2.2 | 9.2 | 50 [C] | 200 | | ✓ | ✓ | ✓ | ✓ | 648 | 180 | 1.2 |
| Dichloroethane, 1,1- | Ethylidene dichloride | $C_2H_4Cl_2$ | Heavier | ✓ | -17 | 5.4 | 11.4 | 100 | 3,000 | | ✓ | ✓ | ✓ | ✓ | 458 | 57-59 | 182 |
| Dichloroethane, 1,2- | Ethylene dichloride | $C_2H_4Cl_2$ | Heavier | ✓ | 13 | 6.2 | 15.9 | 50 | 50 [Ca] | | ✓ | ✓ | ✓ | ✓ | 413 | 84 | 65 |
| Diethyl ether | Ethyl ether | $C_4H_{10}O$ | Heavier | ✓ | -45 | 1.9 | 36 | 400 | 1,900 | | ✓ | ✓ | ✓ | ✓ | 160 | 35 | 440 |

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# Gas Information Table

| Gas or Vapor | Synonym | Chemical Formula | Relative Density (vs. Air)+ | Combustible | Flash Point (°C)[1]* | LEL (% by vol)[1] | UEL (% by vol)[1] | OSHA PEL (PPM)[2] | NIOSH IDLH (PPM)[3] | Detection Technologies: Electrochemical | Catalytic | Photoacoustic IR | Absorptive IR | Semiconductor | Ignition Temp (°C)* | Boiling Point (°C)[1] | Vapor Pressure (mm Hg at 20°C) [1,4] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Diethyl ketone | DEK | $C_5H_{10}O$ | Heavier | ✓ | 13 | 1.6 | 6.4 | - | - |  | ✓ | ✓ | ✓ | ✓ | 450 | 103 | 35 |
| Diethylamine | Diethamine | $C_4H_{11}N$ | Heavier | ✓ | -26 | 1.8 | 10.1 | 25 | 200 |  | ✓ | ✓ | ✓ | ✓ | 312 | 56 | 194 |
| Diethylbenzene | Dowtherm | $C_{10}H_{14}$ | Heavier | ✓ | 55 | – | – | - | - |  |  | ✓ | ✓ |  | 380 | 181 | 0.75 |
| Diisopropylamine |  | $C_6H_{15}N$ | Heavier | ✓ | -6 | 0.8 | 7.1 | 5 | 200 |  | ✓ | ✓ | ✓ | ✓ | 316 | 84 | 60 |
| Difluoromethane | HFC-32 | $CH_2F_2$ | Heavier | ✓ | n/a | 12.7 | 33.4 | - | - |  |  | ✓ | ✓ | ✓ | 647 | -52 | 11,377<br>@ 21˚C |
| Dimethyl acetamide |  | $C_4H_9NO$ | Heavier | ✓ | 70 | 1.8 | 11.5 | 10 | 300 |  | ✓ | ✓ | ✓ | ✓ | 490 | 165 | 2 |
| Dimethyl ether | DME | $C_2H_6O$ | Heavier | ✓ | Gas | 3.4 | 27 | - | - |  | ✓ | ✓ | ✓ | ✓ | 350 | -24 | 1, 4 |
| Dimethylamine | DMA | $C_2H_7N$ | Heavier | ✓ | Gas | 2.8 | 14.4 | 10 | 500 |  | ✓ | ✓ |  | ✓ | 430 | 7 | 1500 @<br>@ 25˚C |
| Dimethylethylamine |  | $C_2H_{11}N$ | Heavier | ✓ | -45 | 0.9 | 11.2 | - | - |  | ✓ | ✓ | ✓ |  | 190 | 36 | – |
| Dimethylformamide | DMF | $C_3H_7NO$ | Heavier | ✓ | 57 | 2.2 | 15.2 | 10 | 500 |  |  | ✓ | ✓ | ✓ | 445 | 153 | 3 |

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# Gas Information Table

| | | | | | | | | | | Detection Technologies | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Gas or Vapor** | **Synonym** | **Chemical Formula** | **Relative Density (vs. Air)+** | **Combustible** | **Flash Point (°C)[1]*** | **LEL (% by vol)[1]** | **UEL (% by vol)[1]** | **OSHA PEL (PPM)[2]** | **NIOSH IDLH (PPM)[3]** | **Electrochemical** | **Catalytic** | **Photoacoustic IR** | **Absorptive IR** | **Semiconductor** | **Ignition Temp (°C)*** | **Boiling Point (°C)[1]** | **Vapor Pressure (mm Hg at 20°C) [1,4]** |
| Dimethylsulfoxide | | $C_2H_6SO$ | | | 95 | 2.6 | 42 | - | - | | | ✓ | ✓ | ✓ | 215 | 189 | <1 |
| Dioxane | Diethylene dioxide | $C_4H_8O_2$ | Heavier | ✓ | 13 | 2.0 | 22 | 100 | 500 | | ✓ | ✓ | ✓ | ✓ | 180 | 101 | 29 |
| Dowtherm J | Diethylbenzene | $C_{10}H_{14}$ | Heavier | ✓ | 55 | 3.8 | - | - | - | | | ✓ | ✓ | | 380 | 181 | 0.75 |
| Epichlorohydrin | Ethylene | $C_3H_5OCl$ | Heavier | ✓ | 34 | 3.0 | 21 | 5 | 75 | | ✓ | ✓ | ✓ | ✓ | 411 | 116 | 13 |
| Ethane | | $C_2H_6$ | Slightly heavier | ✓ | Gas | 2.7 | 12.5 | - | - | | ✓ | ✓ | ✓ | ✓ | 472 | - | Gas |
| Ethene | Ethylene | $C_2H_4$ | Slightly lighter | ✓ | Gas | 1.7 | 15.5) | - | - | | ✓ | ✓ | ✓ | ✓ | 490 | -104 | Gas |
| Ethoxyethanol, 2- | Cellosolve® | $C_4H_{10}O_2$ | Heavier | ✓ | 43 | 2.0 | 3.6 | 200 | 500 | | ✓ | ✓ | ✓ | ✓ | 235 | 135 | 4 |
| Ethyl acetate | | $C_4H_8O_2$ | Heavier | ✓ | -4 | 1.4 | 15.6 | 400 | 2,000 | | ✓ | ✓ | ✓ | ✓ | 427 | 77 | 73 |
| Ethyl acrylate | | $C_5H_8O_2$ | Heavier | ✓ | 9 | 3.3 | 11.5 | 25 | 300 [Ca] | | ✓ | ✓ | ✓ | ✓ | 372 | 100 | 31 |
| Ethyl alcohol | Ethanol | $C_2H_6O$ | Heavier | ✓ | 13 | 0.8 | 14 | 1,000 | 3,300 | | ✓ | ✓ | ✓ | ✓ | 363 | 78 | 44 |
| Ethylbenzene | | $C_8H_{10}$ | Heavier | ✓ | 13 | 6.2 | 19 | 100 | 800 | | ✓ | ✓ | ✓ | ✓ | 432 | 136 | 7 |

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# Gas Information Table

| Gas or Vapor | Synonym | Chemical Formula | Relative Density (vs. Air)+ | Combustible | Flash Point (°C)[1]* | LEL (% by vol)[1] | UEL (% by vol)[1] | OSHA PEL (PPM)[2] | NIOSH IDLH (PPM)[3] | Detection Technologies | | | | | Ignition Temp (°C)* | Boiling Point (°C)[1] | Vapor Pressure (mm Hg at 20°C) [1,4] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | Electrochemical | Catalytic | Photoacoustic IR | Absorptive IR | Semiconductor | | | |
| Ethyl chloride | Chloroethane | $C_2H_5Cl$ | Heavier | ✓ | -50 | 3.8 | 15.4 | 1,000 | 3,800 | | ✓ | ✓ | ✓ | ✓ | 519 | 12 | Gas |
| Ethyl ether | Diethyl ether | $C_4H_{10}O$ | Heavier | ✓ | -45 | 1.9 | 36 | 400 | 1,900 | | ✓ | ✓ | ✓ | ✓ | 160 | 35 | 442 |
| Ethylene | Ethene | $C_2H_4$ | Slightly lighter | ✓ | Gas | 2.7 | 3.6 | - | - | | ✓ | ✓ | ✓ | ✓ | 490 | 104 | Gas |
| Ethylene dichloride | Dichloroethylene, 1,2- | $C_2H4Cl_2$ | Heavier | ✓ | 13 | 6.2 | 15.9 | 50 | 50 [Ca] | | ✓ | ✓ | ✓ | ✓ | 413 | 84 | 100 @ 29 ˚ C |
| Ethylene glycol | | $C_2H_6O_2$ | Heavier | ✓ | 111 | 3.2 | 15.3 | - | - | | | | | ✓ | 398 | 197 | <1 |
| Ethylene oxide | EtO, ED | $C_2H_4O$ | Heavier | ✓ | -20 | 3.0 | 100 | 1 | 800 [Ca] | ✓ | ✓ | ✓ | ✓ | | 429 | 11 | Gas |
| Ethylidene dichloride | Dichloroethane, 1,1- | $C_2H_3Cl_2$ | Heavier | ✓ | -17 | 5.4 | 11.4 | 100 | 3,000 | | ✓ | ✓ | ✓ | ✓ | 458 | 57-59 | 64 |
| Fluorine | | $F_2$ | Heavier | | n/a | n/a | n/a | 0.1 | 25 | ✓ | | | | ✓ | 429 | 188 | Gas |
| Furfural | Furfurol | $C_5H_4O_2$ | Heavier | ✓ | 60 | 2.1 | 19.3 | 5 | 100 | | | ✓ | ✓ | ✓ | 316 | 162 | 2 |
| Gasoline | Heptane, Hexane | | | ✓ | -42 | 1.4 | 7.6 | - | [Ca] | | ✓ | ✓ | ✓ | ✓ | | | 30-300 |

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# Gas Information Table

| Gas or Vapor | Synonym | Chemical Formula | Relative Density (vs. Air)+ | Combustible | Flash Point (°C)[1]* | LEL (% by vol)[1] | UEL (% by vol)[1] | OSHA PEL (PPM)[2] | NIOSH IDLH (PPM)[3] | Detection Technologies | | | | | Ignition Temp (°C)* | Boiling Point (°C)[1] | Vapor Pressure (mm Hg at 20°C) [1,4] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | Electrochemical | Catalytic | Photoacoustic IR | Absorptive IR | Semiconductor | | | |
| Halon 1211 | Bromochlorodifluoromethane | $CF_2ClBr$ | Heavier | | n/a | n/a | n/a | | | | | ✓ | ✓ | ✓ | | -3.3 | Gas |
| Halon 1301 | Bromotrifluoromethane | $CBrF_3$ | Heavier | | n/a | n/a | n/a | 1,000 | | | | ✓ | ✓ | ✓ | | -58 | Gas |
| Heptane, n- | | $C_7H_{16}$ | Heavier | ✓ | -4 | 1.1 | 6.7 | 500 | 750 | | ✓ | ✓ | ✓ | ✓ | 204 | 98 | Gas |
| Hexafluoro-1, 3-butadiene | | $C4F_6$ | Heavier | ✓ | | 7 | 73 | | | | | ✓ | ✓ | ✓ | | 6 | Gas |
| Hexafluoropropene | Hexafluoropropylene | $C_3F_6$ | Heavier | | n/a | n/a | n/a | | | | | ✓ | ✓ | ✓ | | -30 | Gas |
| Hesafluoropropylene | Hexafluoropropene | $C_3F_6$ | Heavier | | n/a | n/a | n/a | | | | | ✓ | ✓ | ✓ | | -30 | Gas |
| Hexanone, 2- | Methyl butyl ketone | $C_6H_{12}O$ | Heavier | ✓ | 25 | 1.2 | 8 | 100 | 1,600 | | ✓ | ✓ | ✓ | | 423 | 128 | 11 |
| Hexene, 1- | Butyl ethylene hexylene | $C_6H_{12}$ | Heavier | ✓ | <-7 | 1.2 | 6.9 | | | | ✓ | ✓ | ✓ | | 253 | 63 | 308 @ 38˚C |

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# Gas Information Table

| Gas or Vapor | Synonym | Chemical Formula | Relative Density (vs. Air)+ | Combustible | Flash Point (°C)[1]* | LEL (% by vol)[1] | UEL (% by vol)[1] | OSHA PEL (PPM)[2] | NIOSH IDLH (PPM)[3] | Detection Technologies | | | | | Ignition Temp (°C)* | Boiling Point (°C)[1] | Vapor Pressure (mm Hg at 20°C) [1,4] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | Electrochemical | Catalytic | Photoacoustic IR | Absorptive IR | Semiconductor | | | |
| Hexane, 2- | | $C_6H_{12}$ | Heavier | ✓ | <-7 | | | | | | ✓ | ✓ | ✓ | | 245 | 67 | 310 @ 38˚C |
| HFC - 32 | Difluoromethane | $CH_2F_2$ | | ✓ | n/a | 12.7 | 33.4 | | | | | ✓ | ✓ | ✓ | 647 | -52 | Gas |
| HFE 347E | | $C_4F_7OH_3$ | Heavier | | | n/a | n/a | | | | | ✓ | ✓ | ✓ | n/a | 36 | 500 @ 22˚C |
| HFE 7100 | | | Heavier | | | | | | | | | ✓ | ✓ | ✓ | 405 | 61 | 202 @ 25˚C |
| Hydrobromic acid | Hydrogen bromide | HBr | Heavier | | n/a | n/a | n/a | 3 | 30 | ✓ | | | | | | 74 | |
| Hydrocarbons (see specific) | | | | | | | | | | | | | | | -252 | | |
| Hydrogen | | $H_2$ | Lighter | ✓ | Gas | 4.0 | 75 | | | ✓ | ✓ | | | ✓ | 500 | | Gas |
| Hydrogen bromide | Hydrobromic acid | HBr | Heavier | | n/a | n/a | n/a | 3 | 30 | ✓ | | | | | n/a | | Gas |

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# Gas Information Table

| | | | | | | | | | | Detection Technologies | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Gas or Vapor | Synonym | Chemical Formula | Relative Density (vs. Air)+ | Combustible | Flash Point (°C)[1]* | LEL (% by vol)[1] | UEL (% by vol)[1] | OSHA PEL (PPM)[2] | NIOSH IDLH (PPM)[3] | Electrochemical | Catalytic | Photoacoustic IR | Absorptive IR | Semiconductor | Ignition Temp (°C)* | Boiling Point (°C)[1] | Vapor Pressure (mm Hg at 20°C) [1,4] |
| Hydrogen chloride | Hydrochloric acid | HCl | Heavier | | n/a | n/ | n/a | 5 [C] | 50 | ✓ | | | | | | | Gas |
| Hydrogen cyanide | | HCN | Lighter | ✓ | -18 | 5.6 | 40 | 10 | 50 | ✓ | | | ✓ | | 540 | 26 | 620 |
| Hydrogen fluoride | | HF | Lighter | | n/a | n/ | n/a | 3 | 30 | ✓ | | | | | - | 19 | Gas |
| Hydrogen sulfide | | $H_2S$ | Heavier | ✓ | Gas | 4.0 | 44 | 20 [C] | 100 | ✓ | | | | ✓ | 260 | -61 | Gas |
| Isoamyl alcohol | | $C_5H_{12}O$ | Heavier | ✓ | 43 | 1.2 | 9 | 100 | 500 | | | | ✓ | ✓ | 350 | 132 | 28 |
| Isobutane | | $C_4H_{10}$ | Heavier | ✓ | Gas | 1.6 | 8.4 | | | | ✓ | ✓ | ✓ | ✓ | 460 | 13 | Gas |
| Isobutyl acetate | | $C_6H_{12}O_2$ | Heavier | | 18 | 1.3 | 10.5 | 150 | 1,300 | | ✓ | ✓ | ✓ | ✓ | 421 | 118 | 13 |
| Isophorone | | $C_9H_{14}O$ | Heavier | ✓ | 84 | 0.8 | 3.8 | 25 | 200 | | ✓ | ✓ | ✓ | ✓ | 460 | 215 | <1 |
| Isoprene | | $C_5H_8$ | Heavier | ✓ | -54 | 2.0 | 9 | | | | ✓ | ✓ | ✓ | ✓ | 220 | 34 | 400 @ 15˚C |

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# Gas Information Table

| Gas or Vapor | Synonym | Chemical Formula | Relative Density (vs. Air)+ | Combustible | Flash Point (°C)[1]* | LEL (% by vol)[1] | UEL (% by vol)[1] | OSHA PEL (PPM)[2] | NIOSH IDLH (PPM)[3] | Detection Technologies | | | | | Ignition Temp (°C)* | Boiling Point (°C)[1] | Vapor Pressure (mm Hg at 20°C) [1,4] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | Electrochemical | Catalytic | Photoacoustic IR | Absorptive IR | Semiconductor | | | |
| Isopropanol | Isoropyl alcohol | $C_3H_8O$ | Heavier | ✓ | 12 | 2.0 | 12.7 | 400 | 2,000 | | ✓ | ✓ | ✓ | ✓ | 399 | 83 | 33 |
| Isopropyl acetate | | $C_5H_{10}O_2$ | Heavier | ✓ | 2 | 1.8 | 8 | 250 | 1,800 | | ✓ | ✓ | ✓ | ✓ | 460 | 90 | 42 |
| Isoproryl alcohol | Isopropanol | $C_3H_8O$ | Heavier | ✓ | 11 | 2.0 | 12.7 | 400 | 2,000 | | ✓ | ✓ | ✓ | ✓ | 399 | 83 | 33 |
| Isopropyl benzene | Cumene | $C_9H_{12}$ | Heavier | ✓ | 36 | 0.9 | 6.5 | 50 | 900 | | ✓ | ✓ | ✓ | ✓ | 425 | 152 | 8 |
| Isopropyl ether | Diisopropyl ether | $C_6H_{14}O$ | Heavier | ✓ | -28 | 1.4 | 7.9 | 500 | 1,400 | | ✓ | ✓ | ✓ | ✓ | 443 | 69 | 119 |
| Kerosene/JP-1 Jet fuel | Fuel oil no. 1 | | Heavier | ✓ | 37- | 0.7 | 5 | | | | | ✓ | ✓ | ✓ | 210 | 151-301 | 5 |
| Methane | | $CH_4$ | Lighter | ✓ | Gas | 5.0 | 15 | | A | | ✓ | ✓ | ✓ | ✓ | 537 | -162 | Gas |
| Methanol | Methyl alcohol | $CH_4O$ | Heavier | ✓ | 11 | 6.0 | 36 | 200 | 6,000 | | | ✓ | ✓ | ✓ | 464 | 64 | 96 |
| Methoxyethanol, 2- | Methyl cellosolve | $C_3H_8O_2$ | Heavier | ✓ | 39 | 1.8 | 14 | 25 | 200 | | | ✓ | ✓ | ✓ | 285 | 124 | 6 |
| Methyl acetate | | $C_3H_6O_2$ | Heavier | ✓ | -10 | 3.1 | 16 | 200 | 3,100 | | ✓ | ✓ | ✓ | ✓ | 454 | 60 | 173 |

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# Gas Information Table

| Gas or Vapor | Synonym | Chemical Formula | Relative Density (vs. Air)+ | Combustible | Flash Point (°C)[1]* | LEL (% by vol)[1] | UEL (% by vol)[1] | OSHA PEL (PPM)[2] | NIOSH IDLH (PPM)[3] | Detection Technologies | | | | | Ignition Temp (°C)* | Boiling Point (°C)[1] | Vapor Pressure (mm Hg at 20°C)[1,4] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | Electrochemical | Catalytic | Photoacoustic IR | Absorptive IR | Semiconductor | | | |
| Methyl alcohol | Methanol | $CH_4O$ | Heavier | ✓ | 11 | 6.0 | 36 | 200 | 6,000 | | ✓ | ✓ | ✓ | ✓ | 464 | 64 | 96 |
| Methyl bromide | Bromomethane | $CH_3Br$ | Heavier | ✓ | n/a | 10.0 | 16 | 20 [C] | 250 [Ca] | | ✓ | ✓ | ✓ | ✓ | 537 | 4 | Gas |
| Methyl butyl ketone | Hexanone, 2- | $C_6H_{12}O$ | Heavier | ✓ | 25 | 1.2 | 8 | 100 | 1,600 | | ✓ | ✓ | ✓ | ✓ | 423 | 128 | 11 |
| Methyl cellosolve | Methoxyethanol, 2- | $C_3H_8O_2$ | Heavier | ✓ | 39 | 1.8 | 14 | 25 | 200 | | | ✓ | ✓ | ✓ | 285 | 124 | 6 |
| Methyl chloride | Chloromethane | $CH_3Cl$ | Heavier | ✓ | -50 | 8.1 | 17.4 | 100 | 2,000 | | ✓ | ✓ | ✓ | ✓ | 632 | 24 | Gas |
| Methylchloroform | Trichloroethane, 1,1,1- | $C_2H_3Cl_3$ | Heavier | ✓ | | 7.5 | 12.5 | 350 | 700 | | ✓ | ✓ | ✓ | ✓ | 500 | 74 | 100 |
| Methyl ethyl ketone (MEK) | Butanone, 2- | $C_4H_8O$ | Heavier | ✓ | -9 | 1.4 | 11.4 | 100 | 3,000 | | ✓ | ✓ | ✓ | ✓ | 404 | 80 | 78 |
| Methyl fluoride | | $CH_3F$ | Heavier | ✓ | | | | | | | | ✓ | ✓ | ✓ | | 78 | Gas |
| Methylformate | | $C_2H_4O_2$ | Heavier | ✓ | -19 | 4.5 | 23 | 100 | 4,500 | | ✓ | ✓ | ✓ | ✓ | 456 | 32 | 476 |

**Key:** **[C]** = Ceiling Limit (never exceed) **A** = Asphyxiant **Ca** = Carcinogen **–** = Data not currently available **n/a** = Data not applicable

# Gas Information Table

| Gas or Vapor | Synonym | Chemical Formula | Relative Density (vs. Air)+ | Combustible | Flash Point (°C)[1]* | LEL (% by vol)[1] | UEL (% by vol)[1] | OSHA PEL (PPM)[2] | NIOSH IDLH (PPM)[3] | Detection Technologies | | | | | Ignition Temp (°C)* | Boiling Point (°C)[1] | Vapor Pressure (mm Hg at 20°C) [1,4] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | Electrochemical | Catalytic | Photoacoustic IR | Absorptive IR | Semiconductor | | | |
| Methyl iodide | | $CH_3I$ | Heavier | | n/a | n/a | n/ | 5 | 100 [Ca] | | ✓ | ✓ | ✓ | ✓ | | 43 | 400 |
| Methyl isoamyl ketone | | $C_7H_{14}O$ | Heavier | ✓ | 36 | 1.0 | 8.2 | 100 | | | ✓ | ✓ | ✓ | ✓ | 191 | 146 | 5 |
| Methyl isobutyl carbinol | Methylamyl alcohol | $C_6H_{14}O$ | Heavier | ✓ | 48 | 1.0 | 5.5 | 25 | 400 | | ✓ | ✓ | ✓ | ✓ | 460 | 132 | 3 |
| Methyl isobutyl ketone (MIBK) | | $C_6H_{12}O$ | | ✓ | 18 | 1.2 | 8.2 | 0.2 | 500 | | ✓ | ✓ | ✓ | ✓ | 448 | 117 | 16 |
| Methyl methacrylate | | $C_5H_8O_2$ | Heavier | ✓ | 10 | 1.7 | 20.7 | 100 | 1,000 | | ✓ | ✓ | ✓ | ✓ | 435 | 100 | 29 |
| Methylamine | Monomethylamine | $CH_5N$ | Slightly heavier | ✓ | Gas | 4.9 | 23 | 10 | 100 | | ✓ | ✓ | ✓ | ✓ | 430 | -6 | Gas |
| Methylene chloride | Dichloromethane | $CH_2Cl_2$ | Heavier | ✓ | - | 13.0 | 9.6 | 25 | 2300 | | ✓ | ✓ | ✓ | ✓ | 556 | 40 | 350 |
| Monochloro-benzene | (Benezene chloride) | $C_6H_5Cl$ | Heavier | ✓ | 28 | 1.3 | 20.7 | 75 | [Ca] | | ✓ | ✓ | ✓ | ✓ | 638 | 132 | 9 |
| Monomethlamine | Methylamine | $CH_5N$ | Slightly heavier | ✓ | Gas | 4.9 | 23 | 10 | 1,000 | | ✓ | ✓ | ✓ | ✓ | 430 | -6 | Gas |

**Key:** **[C]** = Ceiling Limit (never exceed) **A** = Asphyxiant **Ca** = Carcinogen **–** = Data not currently available **n/a** = Data not applicable

# Gas Information Table

| Gas or Vapor | Synonym | Chemical Formula | Relative Density (vs. Air)+ | Combustible | Flash Point (°C)[1]* | LEL (% by vol)[1] | UEL (% by vol)[1] | OSHA PEL (PPM)[2] | NIOSH IDLH (PPM)[3] | Detection Technologies | | | | | Ignition Temp (°C)* | Boiling Point ( °C)[1] | Vapor Pressure (mm Hg at 20°C) [1,4] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | Electrochemical | Catalytic | Photoacoustic IR | Absorptive IR | Semiconductor | | | |
| Naphtha | Coal Tar | | Heavier | ✓ | 100 | 0.9 | 6 | 100 | 1,000 | | ✓ | ✓ | ✓ | ✓ | | | <5 |
| Napthalene | | $C_{10}H_8$ | Heavier | ✓ | 79 | 0.9 | 5.9 | 10 | 250 | | ✓ | ✓ | ✓ | ✓ | 526 | 218 | @ 53 C |
| Nitric oxide | | NO | Same | | n/a | n/a | n/a | 25 | 100 | ✓ | | | ✓ | | | -52 | Gas |
| Nitrobenzene | | $C_6H_5NO_2$ | Heavier | ✓ | 88 | 1.8 | | 1 | 200 | | ✓ | ✓ | ✓ | ✓ | 480 | 211 | 0.3 |
| Nitrogen dioxide | | $NO_2$ | Heavier | | Gas | | n/a | 5 [C] | 20 | ✓ | | | ✓ | | | 15 | Gas |
| Nitrogen trifluoride | | $NF_3$ | | | | n/a | n/a | 10 | 1,000 | | | ✓ | ✓ | | | | Gas |
| Nitropropane, 1- | | $C_3H_7NO_2$ | Heavier | ✓ | 36 | 2.2 | - | 25 | 1,000 | | ✓ | ✓ | ✓ | ✓ | 421 | 120-132 | 8 |
| Nitropropane, 2- | | $C_3H_7NO_2$ | Heavier | ✓ | 24 | 2.6 | 11 | 25 | 100 [Ca] | | ✓ | ✓ | ✓ | ✓ | 428 | 120-132 | 13 |
| Nitrous oxide | | $N_2O$ | Heavier | | | n/a | n/a | | | | | ✓ | ✓ | | | | Gas |
| Octafluorocyclobutane | | $C_4F_8$ | Heavier | | | | | | | | | ✓ | ✓ | ✓ | | -6 | Gas |
| Octafluorocyclopropene | | | | | | | | | | | | ✓ | ✓ | ✓ | | | Gas |

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# Gas Information Table

| Gas or Vapor | Synonym | Chemical Formula | Relative Density (vs. Air)+ | Combustible | Flash Point (°C)[1]* | LEL (% by vol)[1] | UEL (% by vol)[1] | OSHA PEL (PPM)[2] | NIOSH IDLH (PPM)[3] | Detection Technologies | | | | | Ignition Temp (°C)* | Boiling Point (°C)[1] | Vapor Pressure (mm Hg at 20°C) [1,4] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | Electrochemical | Catalytic | Photoacoustic IR | Absorptive IR | Semiconductor | | | |
| Octane, n- | | $CH_8H_{18}$ | Heavier | ✓ | 13 | 1.0 | 6.5 | 500 | 1,000 | | ✓ | ✓ | ✓ | | 206 | 126 | 10 |
| Oxygen | | $O_2$ | Same | | Gas | - | n/a | n/a | n/a | ✓ | | | | | | 183 | Gas |
| Pentane | | $C_5H_{12}$ | Heavier | ✓ | -49 | 1.5 | 7.8 | 1,000 | 1,500 | | ✓ | ✓ | ✓ | ✓ | 260 | 36 | 420 |
| Perchloroethlyene | Tetrachloroethylene | $C_2Cl_4$ | Heavier | | n/a | n/a | n/a | 0.1 | 150 [Ca] | | | ✓ | ✓ | ✓ | | 121 | 14 |
| Perfluorohexane | | | | | | n/a | n/a | | | | | ✓ | ✓ | ✓ | | >58 | |
| Perfluoromethyl vinyl ether | PMVE | | | | | 7.5 | 50 | | | | | ✓ | ✓ | | 135 | -25 | Gas |
| Phosgene | Carbony chloride | $COCl_2$ | Heavier | | n/a | n/a | n/a | 0.1 | 2 | | | ✓ | ✓ | | | 8 | 568 @ 0˚C |
| Phosphine | | $PH_3$ | Heavier | ✓ | Gas | 1.8 | 98 | 0.3 | 50 | ✓ | | | | | 38 | -88 | Gas |
| Propane | | $C_3H_8$ | Heavier | ✓ | Gas | 2.1 | 9.5 | 1,000 | 2,100 | | ✓ | ✓ | ✓ | ✓ | 450 | -42 | Gas |
| Propanol, 2- | Isopropyl Alcohol | $C_3H_6O$ | Heavier | ✓ | 12 | 2.0 | 12.7 | 400 | 2000 | | ✓ | ✓ | ✓ | ✓ | 378 | 97 | 33 |

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# Gas Information Table

| Gas or Vapor | Synonym | Chemical Formula | Relative Density (vs. Air)+ | Combustible | Flash Point (°C)[1]* | LEL (% by vol)[1] | UEL (% by vol)[1] | OSHA PEL (PPM)[2] | NIOSH IDLH (PPM)[3] | Detection Technologies | | | | | Ignition Temp (°C)* | Boiling Point (°C)[1] | Vapor Pressure (mm Hg at 20°C)[1,4] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | Electrochemical | Catalytic | Photoacoustic IR | Absorptive IR | Semiconductor | | | |
| Propanol, n- | Propyl alcohol, n- | $C_3H_8O$ | Heavier | ✓ | 22 | 2.2 | 13.7 | 100 | 800 | | ✓ | ✓ | ✓ | ✓ | 371 | 97 | 15 |
| Propyl acetate, n- | | $C_5H_{10}O_2$ | Heavier | ✓ | 13 | 1.7 | 8 | 200 | 1,700 | | ✓ | ✓ | ✓ | ✓ | 450 | 102 | 25 |
| Propyl alcohol, n- | Propanol, n | $C_3H_8O$ | Heavier | ✓ | 22 | 2.2 | 13.7 | 200 | 800 | | ✓ | ✓ | ✓ | ✓ | 371 | 97 | 15 |
| Propylene | | $C_3H_6$ | Heavier | ✓ | Gas | 2.0 | 11.1 | - | - | | ✓ | ✓ | ✓ | ✓ | 455 | -47 | Gas |
| Propylene dichloride | | $C_3H_6Cl_2$ | Heavier | ✓ | 16 | 3.4 | 14.5 | 75 | 400 [Ca] | | ✓ | ✓ | ✓ | ✓ | 557 | 96 | 40 |
| Propylene oxide | | $C3H_6O$ | Heavier | ✓ | -37 | 2.3 | 36 | 100 | 400 [Ca] | | ✓ | ✓ | ✓ | | 465 | 34 | 445 |
| Propyleneglycol dimethyl acetate | | | Heavier | | 43 | | | | 1,000 | | | | | | 670 | 145 | 3.7 |
| Silane | | $SiH_4$ | Heavier | ✓ | - | 1.4 | 96 | | | ✓ | | | | | - | 112 | Gas |
| Stoddard solvent | | $C_8H_{15}BrO_2$ | Heavier | ✓ | 21 | 0.9 | 6 | 500 | 2,000 mg/m3 | | ✓ | ✓ | ✓ | | 229 | 149-204 | 2 |
| Styrene | | $C_8H_8$ | Heavier | ✓ | 31 | 1.1 | 7 | | 700 | | ✓ | | | ✓ | 490 | 145 | 5 |

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# Gas Information Table

| | | | | | | | | | | Detection Technologies | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Gas or Vapor | Synonym | Chemical Formula | Relative Density (vs. Air)+ | Combustible | Flash Point (°C)$^{1*}$ | LEL (% by vol)$^{1}$ | UEL (% by vol)$^{1}$ | OSHA PEL (PPM)$^{2}$ | NIOSH IDLH (PPM)$^{3}$ | Electrochemical | Catalytic | Photoacoustic IR | Absorptive IR | Semiconductor | Ignition Temp (°C)* | Boiling Point (°C)$^{1}$ | Vapor Pressure (mm Hg at 20°C)$^{1,4}$ |
| Sulfur dioxide | | $SO_2$ | Heavier | | Gas | n/a | n/a | 5 | 100 | ✓ | | | ✓ | | | -10 | Gas |
| Sulfur hexafluoride | | $SF_6$ | Heavier | | n/a | n/a | n/a | 1,000 | - | | | ✓ | ✓ | | | | Gas |
| Tetrachloroethylene | Perchloroethylene | $C_2Cl_4$ | Heavier | | n/a | n/a | n/a | 0.1 | 150 [Ca] | | | ✓ | ✓ | ✓ | | 121 | 13 |
| Tetrachloromethane | Carbon Tetrachloride | $CCl_4$ | Heavier | | n/a | n/a | n/a | 10 | 200 | | | ✓ | ✓ | | | 77 | 91 |
| Tetrafluoroethylene | | $C_2F_4$ | Heavier | ✓ | <0 | 11.0 | 60 | | | | | ✓ | ✓ | ✓ | 188 | -78 | Gas |
| Tetrahydrofuran | | $C_4H_8O$ | Heavier | ✓ | -14 | 2.0 | 11.8 | 200 | 2,000 | | ✓ | ✓ | | ✓ | 321 | 66 | 145 |
| Toluene | | $C_7H_8$ | Heavier | ✓ | 4 | 1.1 | 7.1 | 200 | 500 | | ✓ | ✓ | ✓ | ✓ | 480 | 111 | 22 |
| Trichloroethane, 1, 1, 1- | Methyl chloroform | $C_2H_3Cl_3$ | Heavier | ✓ | 4 | 7.5 | 12.5 | 350 | 700 | | ✓ | ✓ | ✓ | ✓ | 500 | 74 | 100 |
| Trichloroethane, 1, 2, 2- | | $C_2H_3Cl_3$ | Heavier | ✓ | - | 6.0 | 15.5 | 10 | 100 [Ca] | | ✓ | ✓ | ✓ | ✓ | | 113 | 19 |
| Trichloroethylene | | $C_2HCl_3$ | Heavier | ✓ | 31 | 8.0 | 10.5 | 100 | 1,000 [Ca] | | ✓ | ✓ | ✓ | ✓ | 420 | 87 | 58 |

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# Gas Information Table

| Gas or Vapor | Synonym | Chemical Formula | Relative Density (vs. Air)+ | Combustible | Flash Point (°C)[1]* | LEL (% by vol)[1] | UEL (% by vol)[1] | OSHA PEL (PPM)[2] | NIOSH IDLH (PPM)[3] | Detection Technologies |  |  |  |  | Ignition Temp (°C)* | Boiling Point (°C)[1] | Vapor Pressure (mm Hg at 20°C) [1,4] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  |  |  |  |  |  |  |  |  | Electrochemical | Catalytic | Photoacoustic IR | Absorptive IR | Semiconductor |  |  |  |
| Trichloromethane | Chloroform | $CHCl_3$ | Heavier |  | n/a | n/a | n/ | 50 [C] | 500 |  |  | ✓ | ✓ |  |  | 62 | 160 |
| Triethylamine |  | $C_6H_{15}N$ | Heavier | ✓ | -7 | 1.2 | 8 | 25 | 200 |  | ✓ | ✓ |  | ✓ | 249 | 89 | 54 |
| Turpentine |  | $C_{10}H_{16}$ |  | ✓ | 35 | 0.8 |  | 100 | 800 |  |  | ✓ | ✓ | ✓ | 220 | 149 | 4 |
| Vinyl acetate |  | $C_4H_6O_2$ | Heavier | ✓ | -8 | 2.6 | 13.4 |  |  |  | ✓ | ✓ | ✓ | ✓ | 402 | 73 | 83 |
| Vinyl chloride |  | $C_2H_3Cl$ | Heavier | ✓ | -78 | 3.6 | 33 | 1 | Ca |  | ✓ | ✓ | ✓ | ✓ | 472 | 14 | 2,524 |
| Vinyl fluoride |  | $C_2H_3F$ | Heavier | ✓ | Gas | 2.6 | 21.7 |  |  |  |  | ✓ | ✓ | ✓ | 385 | 72 | 25.2 atm |
| Vinylidene chloride |  | $C_2H_2Cl_2$ | Heavier | ✓ | -19 | 6.5 | 15.5 |  | Ca |  | ✓ | ✓ | ✓ | ✓ | 570 | 32 | 500 |
| Xylenes |  | $C_8H_{10}$ | Heavier | ✓ | 27-30 | 1.1 | 6.7 | 100 | 900 |  | ✓ | ✓ | ✓ | ✓ | 463-528 | 137-144 | 6 |

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# Gas Information Table

[1] Data obtained from the National Fire Protection Association (NFPA) Fire Protection Guide to Hazardous Materials, 14th ed., 2010; National Institute for Occupational Safety and Health (NIOSH) Pocket Guide to Chemical Hazards, and material safety data sheets.

[2] The PELs are the maximum 8-hour time weighted average concentrations to which a worker may be exposed, per 29 CFR 1910.1000 Table Z-1; [C] denotes a ceiling limit, the maximum concentration to which a worker may be exposed. They are to be determined from breathing-zone air samples. Data obtained from National Institute for Occupational Safety and Health (NIOSH) Documentation for Immediately Dangerous to Life or Health Concentrations, 1995, and material safety data sheets.

[3] Data obtained from U.S. Department of Labor Occupational Safety and Health Administration (OSHA) 29 CFR 1910.1000 Table Z-1 Limits for Air Contaminants, and material safety data sheets.

^ See 29 CFR 1910.1028 for specific circumstantial exceptions.

+ Density of gas at 1 atmosphere.

* ‘Gas’ indicates substance is a gas at normal ambient temperature.

# Section 5

## A Selection of Gases Typically Associated with Various Industries

# A Selection of Gases Typically Associated with Various Industries

| **Industry** | **Aerospace/Defense** | | | |
|---|---|---|---|---|
| | **Test Chambers/Labs** | **Plant Facilities** | **Heat Treating** | **Launch Pads** |
| Combustible gases | ✓ | ✓ | ✓ | ✓ |
| Ammonia | | | | ✓ |
| Carbon dioxide | ✓ | | ✓ | |
| Carbon monoxide | | | | |
| Chlorine | | | | |
| Chlorine dioxide | | | | |
| Ethylene | | | | |
| Ethylene oxide | | | | |
| Hydrogen chloride | | | | |
| Hydrogen cyanide | | | | |
| Hydrogen sulfide | | | | |
| Nitric oxide | ✓ | | | |
| Nitrogen dioxide | | | | |
| $O_2$ deficiency/enrichment | ✓ | ✓ | ✓ | ✓ |
| Phosphine | | | | |
| Refrigerants | ✓ | ✓ | | ✓ |
| Toluene | ✓ | | | |
| VOCs | | | | |

# A Selection of Gases Typically Associated with Various Industries

| Industry | Agriculture | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Chillers | Fruit Storage Areas | Greenhouses, Silos, & Storage Areas | Forklift Operation | Confined Spaces (Silos) | Grain Storage & Processing | Poultry Houses | Fumigation | Livestock, Oil Extraction Process | Soil Fertilization |
| Combustible gases | | | | ✓ | ✓ | | | | ✓ | |
| Ammonia | ✓ | ✓ | | | | | ✓ | | ✓ | ✓ |
| Carbon dioxide | ✓ | ✓ | ✓ | | ✓ | | ✓ | ✓ | | |
| Carbon monoxide | | | | | | | | | | |
| Chlorine | | | | | | | | | | |
| Chlorine dioxide | | | | | | | | | | |
| Ethylene | | ✓ | ✓ | | ✓ | | | | | |
| Ethylene oxide | | | | | | | | ✓ | | |
| Hydrogen chloride | | | | | | | | | | |
| Hydrogen cyanide | | | | | | | | ✓ | | |
| Hydrogen sulfide | | | | | | | | ✓ | | |
| Nitric oxide | | | | ✓ | ✓ | | | | | |
| Nitrogen dioxide | | | | ✓ | ✓ | | | | | |
| $O_2$ deficiency/enrichment | | ✓ | ✓ | | ✓ | | | | | |
| Phosphine | | | | | | ✓ | | ✓ | | |
| Refrigerants | ✓ | ✓ | | | | | | | | |
| Sulfur dioxide | | | | | | | ✓ | ✓ | | |
| VOCs | | ✓ | | | | | | | | |

# A Selection of Gases Typically Associated with Various Industries

| Industry | Automotive | | |
|---|---|---|---|
| | Research & Development | Engine Testing | Environmental Chambers |
| Combustible Gases | ✓ | ✓ | ✓ |
| Ammonia | | | |
| Carbon dioxide | ✓ | ✓ | ✓ |
| Carbon monoxide | ✓ | ✓ | ✓ |
| Chlorine | | | |
| Chlorine dioxide | | | |
| Ethylene | | | |
| Ethylene oxide | | | ✓ |
| Hydrogen chloride | | | |
| Hydrogen cyanide | | | |
| Hydrogen sulfide | | | |
| Nitric oxide | ✓ | ✓ | |
| Nitrogen dioxide | ✓ | ✓ | |
| $O_2$ deficiency/enrichment | ✓ | ✓ | ✓ |
| Phosphine | | | |
| Refrigerants | ✓ | ✓ | ✓ |
| Sulfur dioxide | ✓ | | |
| VOCs | ✓ | | |

# A Selection of Gases Typically Associated with Various Industries

| **Industry** | **Aviation** | | | | |
|---|---|---|---|---|---|
| | **Body & Engine Repair & Maintenance** | **Aircraft hanger facilities, fuel & hydraulic fluid storage & pumping facilities** | **Confined space (wing) tank maintenance** | **Jet fuel vapors, solvents** | **Aircraft parts manufacturing** |
| Combustible Gases | ✓ | ✓ | ✓ | ✓ | |
| Ammonia | | | | ✓ | |
| Carbon dioxide | | | ✓ | | |
| Carbon monoxide | ✓ | | ✓ | | |
| Chlorine | | | | | |
| Chlorine dioxide | | | | | |
| Ethylene | | | | | |
| Ethylene oxide | | | | | |
| Hydrogen chloride | | | | | |
| Hydrogen cyanide | ✓ | | | | ✓ |
| Hydrogen sulfide | | | | | |
| Nitric oxide | ✓ | | | | |
| Nitrogen dioxide | ✓ | | | ✓ | |
| $O_2$ deficiency/enrichment | | | ✓ | | ✓ |
| Phosphine | | | | | |
| Refrigerants | | | | | |
| Sulfur dioxide | | | | | |
| VOCs | ✓ | ✓ | | ✓ | ✓ |

# A Selection of Gases Typically Associated with Various Industries

| **Industry** | **Chemical** | | | | | | |
|---|---|---|---|---|---|---|---|
| | General leak detection process manufacturing | Confined space (liquid nitrogen carriers/ storage tank maintenance, reactor work, tunnels) | Labs, fine chemical manufacturing | Manufacturing, polymers plastics, process manufacturing for leaks | Organic synthesis operations, liquid-solid separation, cleaning agents | General leak detection, organic synthesis | Textiles |
| Combustible Gases | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | |
| Ammonia | ✓ | | ✓ | ✓ | ✓ | ✓ | ✓ |
| Carbon dioxide | ✓ | ✓ | | | | | |
| Carbon monoxide | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | |
| Chlorine | ✓ | | ✓ | | ✓ | ✓ | ✓ |
| Chlorine dioxide | ✓ | | ✓ | | ✓ | ✓ | |
| Ethylene | ✓ | | ✓ | ✓ | ✓ | ✓ | ✓ |
| Ethylene oxide | ✓ | | ✓ | ✓ | ✓ | ✓ | |
| Hydrogen chloride | ✓ | | | | ✓ | | |
| Hydrogen cyanide | ✓ | | ✓ | ✓ | | ✓ | ✓ |
| Hydrogen sulfide | ✓ | ✓ | | | ✓ | | ✓ |
| Nitric oxide | ✓ | | ✓ | | | ✓ | ✓ |
| Nitrogen dioxide | ✓ | | ✓ | ✓ | | ✓ | |
| $O_2$ deficiency/enrichment | ✓ | ✓ | | ✓ | | | ✓ |
| Phosphine | ✓ | | ✓ | ✓ | | | |
| Refrigerants | | | ✓ | | | | |
| Sulfur dioxide | ✓ | | | | | | ✓ |
| VOCs | ✓ | | ✓ | ✓ | ✓ | ✓ | |

# A Selection of Gases Typically Associated with Various Industries

| Industry | Chemical | | | |
|---|---|---|---|---|
| | Rubber | Storage warehouses | Solvent recovery | Holding tanks, transfer areas, loading & unloading areas |
| Combustible gases | ✓ | ✓ | ✓ | ✓ |
| Ammonia | ✓ | ✓ | | ✓ |
| Carbon dioxide | | ✓ | | ✓ |
| Carbon monoxide | | ✓ | | ✓ |
| Chlorine | | ✓ | | ✓ |
| Chlorine dioxide | | ✓ | | ✓ |
| Ethylene | | ✓ | | ✓ |
| Ethylene oxide | | ✓ | | |
| Hydrogen chloride | | ✓ | | |
| Hydrogen cyanide | ✓ | ✓ | | |
| Hydrogen sulfide | ✓ | ✓ | | |
| Nitric oxide | | ✓ | | |
| Nitrogen dioxide | | ✓ | | |
| $O_2$ deficiency/enrichment | | ✓ | | ✓ |
| Phosphine | | ✓ | | |
| Refrigerants | | ✓ | | |
| Sulfur dioxide | | ✓ | | |
| VOCs | ✓ | | ✓ | ✓ |

## A Selection of Gases Typically Associated with Various Industries

| Industry | Coatings & Printing Adhesives | |
|---|---|---|
| | Manufacturing floor outside of press | Press processes |
| Combustible Gases | ✓ | ✓ |
| Ammonia | | |
| Carbon dioxide | | |
| Carbon monoxide | | |
| Chlorine | | |
| Chlorine dioxide | | |
| Ethylene | | |
| Ethylene oxide | | |
| Hydrogen chloride | | |
| Hydrogen cyanide | | |
| Hydrogen sulfide | | |
| Nitric oxide | | |
| Nitrogen dioxide | | |
| $O_2$ deficiency/enrichment | ✓ | ✓ |
| Phosphine | | |
| Refrigerants | | |
| Sulfur dioxide | | |
| VOCs | ✓ | ✓ |

# A Selection of Gases Typically Associated with Various Industries

| Industry | Food & Beverage | | | | | | |
|---|---|---|---|---|---|---|---|
| | Refrigeration facilities & cold storage | Fruit storage areas | Grain processing | Edible oil processing | Breweries & wineries, beverage bottling, fermentation tanks, refrigeration facilities, meat packing, food processing | Heaters & boilers, gasoline powered equipment, vehicles & forklifts baking facilities | Coolers, confined spaces |
| Combustible Gases | | | ✓ | ✓ | | ✓ | ✓ |
| Ammonia | ✓ | ✓ | | | ✓ | | ✓ |
| Carbon dioxide | ✓ | ✓ | | | ✓ | | |
| Carbon monoxide | | | ✓ | | | ✓ | ✓ |
| Chlorine | | | | | | | |
| Chlorine dioxide | | | | | | | |
| Ethylene | ✓ | ✓ | | | | | |
| Ethylene oxide | | | | | | | |
| Hydrogen chloride | | | | | | | |
| Hydrogen cyanide | | | | | | | |
| Hydrogen sulfide | | | | | | | |
| Nitric oxide | | | | | | ✓ | |
| Nitrogen dioxide | | | | | | ✓ | |
| $O_2$ deficiency/enrichment | ✓ | ✓ | | | | | ✓ |
| Phosphine | | | | | | | |
| Refrigerants | ✓ | ✓ | | | ✓ | | ✓ |
| Sulfur dioxide | ✓ | | ✓ | | ✓ | | |
| VOCs | | | | | | | |

# A Selection of Gases Typically Associated with Various Industries

| Industry | Food & Beverage | | | | |
|---|---|---|---|---|---|
| | Wastewater tanks, drainage and sewage areas | Drainage & sewage areas, boilers & heaters, food packaging | Fermentation process, packaging or gassing foods, confined space | Fumigation of yeast & mold spores, sterilization | Disinfecting equipment & utensils |
| Combustible Gases | ✓ | ✓ | | | |
| Ammonia | | | ✓ | | |
| Carbon dioxide | | | ✓ | ✓ | |
| Carbon monoxide | | ✓ | ✓ | | |
| Chlorine | | | | ✓ | ✓ |
| Chlorine dioxide | | | | ✓ | ✓ |
| Ethylene | | | ✓ | | |
| Ethylene oxide | | | | ✓ | ✓ |
| Hydrogen chloride | | | | | |
| Hydrogen cyanide | | | | | |
| Hydrogen sulfide | ✓ | ✓ | | | |
| Nitric oxide | | | | | |
| Nitrogen dioxide | | | | | |
| $O_2$ deficiency/enrichment | ✓ | | ✓ | | |
| Phosphine | | | | | |
| Refrigerants | | | | | |
| Sulfur dioxide | | | ✓ | ✓ | |
| VOCs | ✓ | ✓ | | | |

# A Selection of Gases Typically Associated with Various Industries

| Industry | Food & Beverage | |
|---|---|---|
| | Cold storage & transport facilities, meat packing plants, supermarkets, refrigerator & storage locations, food storage systems monitoring | Food packaging (solvent vapor process monitoring) |
| Combustible Gases | | ✓ |
| Ammonia | ✓ | |
| Carbon dioxide | ✓ | ✓ |
| Carbon monoxide | | ✓ |
| Chlorine | | |
| Chlorine dioxide | | |
| Ethylene | | |
| Ethylene oxide | | |
| Hydrogen chloride | | |
| Hydrogen cyanide | | |
| Hydrogen sulfide | | |
| Nitric oxide | | |
| Nitrogen dioxide | | |
| $O_2$ deficiency/enrichment | ✓ | ✓ |
| Phosphine | | |
| Refrigerants | ✓ | |
| Sulfur dioxide | ✓ | |
| VOCs | | ✓ |

# A Selection of Gases Typically Associated with Various Industries

| Industry | Foundries | | | | | Fuel Cell Manufacturing |
|---|---|---|---|---|---|---|
| | Furnace operation, coremaking, metal preparation & pouring | Metal-mining, finishing work | Coremaking | Heat-treating processes | Confined space | Manufacturing floor, fuel cells |
| Combustible Gases | | ✓ | ✓ | ✓ | ✓ | ✓ |
| Ammonia | | | | | | |
| Carbon dioxide | | | | ✓ | ✓ | ✓ |
| Carbon monoxide | ✓ | | ✓ | ✓ | ✓ | ✓ |
| Chlorine | | | | | | |
| Chlorine dioxide | | | | | | |
| Ethylene | | | | | | |
| Ethylene oxide | | | | | | |
| Hydrogen chloride | | | | | | |
| Hydrogen cyanide | | ✓ | | | | |
| Hydrogen sulfide | | ✓ | ✓ | | | ✓ |
| Nitric oxide | | | ✓ | | | |
| Nitrogen dioxide | | | ✓ | | | |
| $O_2$ deficiency/enrichment | | | | | | ✓ |
| Phosphine | | | | | | |
| Refrigerants | | | | | | |
| Sulfur dioxide | | | ✓ | | | |
| VOCs | | | | | | |

# A Selection of Gases Typically Associated with Various Industries

| Industry | HAZMAT | | | | |
|---|---|---|---|---|---|
| | HazMat applications | Flammable liquid/gas storage & pumping facilities | Confined space | Underground construction | Storage, transfer and treatment |
| Combustible Gases | ✓ | ✓ | ✓ | ✓ | ✓ |
| Ammonia | ✓ | | | | |
| Carbon dioxide | | ✓ | ✓ | | |
| Carbon monoxide | ✓ | | ✓ | ✓ | ✓ |
| Chlorine | ✓ | | | | |
| Chlorine dioxide | ✓ | | | | |
| Ethylene | | | | | |
| Ethylene oxide | | | | | |
| Hydrogen chloride | | | | | |
| Hydrogen cyanide | | | | | |
| Hydrogen sulfide | ✓ | | | | |
| Nitric oxide | | | | | |
| Nitrogen dioxide | | | | | |
| $O_2$ deficiency/enrichment | | | ✓ | ✓ | |
| Phosphine | ✓ | | | | |
| Refrigerants | | | | | |
| Sulfur dioxide | ✓ | | | | |
| VOCs | ✓ | ✓ | ✓ | | ✓ |

# A Selection of Gases Typically Associated with Various Industries

| **Industry** | **Heavy Manufacturing** | | | | | |
|---|---|---|---|---|---|---|
| | **Vehicle manufacturing plants** | **Heat-transfer fluids** | **Vehicle emissions** | **Metal-plating** | **Manufacturing process emissions** | **Forklift and crane operations** |
| Combustible Gases | ✓ | | | | ✓ | ✓ |
| Ammonia | | | | ✓ | | |
| Carbon dioxide | | | ✓ | | ✓ | |
| Carbon monoxide | ✓ | | ✓ | | | ✓ |
| Chlorine | | | | | | |
| Chlorine dioxide | | | | | | |
| Ethylene | | | | | | |
| Ethylene oxide | | | | | | |
| Hydrogen chloride | | | | ✓ | | |
| Hydrogen cyanide | | | | ✓ | | |
| Hydrogen sulfide | | | | | ✓ | |
| Nitric oxide | | | ✓ | | ✓ | |
| Nitrogen dioxide | ✓ | | ✓ | | ✓ | ✓ |
| $O_2$ deficiency/enrichment | | | | | | |
| Phosphine | | | | | | |
| Refrigerants | ✓ | ✓ | | | | |
| Sulfur dioxide | | | ✓ | | ✓ | |
| VOCs | ✓ | ✓ | ✓ | | ✓ | |

# A Selection of Gases Typically Associated with Various Industries

| Industry | Heavy Manufacturing | | | |
|---|---|---|---|---|
| | Chemical loading/ off-loading | Paint booths | Degreasers | Mechanical equipment rooms |
| Combustible gases | ✓ | ✓ | ✓ | ✓ |
| Ammonia | ✓ | | | ✓ |
| Carbon dioxide | | | | |
| Carbon monoxide | | ✓ | | |
| Chlorine | ✓ | | | |
| Chlorine dioxide | | | | |
| Ethylene | | | | |
| Ethylene oxide | | | | |
| Hydrogen chloride | | | | |
| Hydrogen cyanide | | | | |
| Hydrogen sulfide | | | | |
| Nitric oxide | | | | |
| Nitrogen dioxide | | | | |
| $O_2$ deficiency/enrichment | | ✓ | | ✓ |
| Phosphine | | | | |
| Refrigerants | | | | ✓ |
| Sulfur dioxidet | | | | |
| VOCs | ✓ | ✓ | ✓ | |

# A Selection of Gases Typically Associated with Various Industries

| **Industry** | **HVAC** | | | | | | |
|---|---|---|---|---|---|---|---|
| | Heating boilers or ducting, general office applications | Parking garages, warehouses | Occupied buildings, office buildings, research labs | Parking garages, tunnels, furnace rooms, maintenance garages | Ventilation ducts | Cold storage & transport facilities, meat packing plants, supermarkets, refrigerator storage locations, food storage system monitoring | Mechanical rooms |
| Combustible Gases | ✓ | | ✓ | ✓ | ✓ | | ✓ |
| Ammonia | | ✓ | ✓ | ✓ | | ✓ | ✓ |
| Carbon dioxide | ✓ | | ✓ | | ✓ | ✓ | |
| Carbon monoxide | ✓ | ✓ | | ✓ | ✓ | | |
| Chlorine | | | | | | | |
| Chlorine dioxide | | | | | | | |
| Ethylene | | | | | | | |
| Ethylene oxide | | ✓ | | | | ✓ | |
| Hydrogen chloride | | | | | | | |
| Hydrogen cyanide | | | | | | | |
| Hydrogen sulfide | | | | | | | |
| Nitric oxide | | | | | | | |
| Nitrogen dioxide | | ✓ | | ✓ | ✓ | | |
| $O_2$ deficiency/enrichment | | | ✓ | ✓ | | ✓ | ✓ |
| Phosphine | | | | | | | |
| Refrigerants | | | ✓ | ✓ | | ✓ | ✓ |
| Sulfur dioxide | | | | | | | |
| VOCs | | | ✓ | | ✓ | | |

# A Selection of Gases Typically Associated with Various Industries

| **Industry** | **Indoor Air Quality** | |
|---|---|---|
| | Occupied buildings (industrial, commercial, residential), office buildings, research labs | Parking garages, tunnels, furnace rooms, maintenance garages, crawl spaces |
| Combustible Gases | ✓ | ✓ |
| Ammonia | | |
| Carbon dioxide | ✓ | ✓ |
| Carbon monoxide | ✓ | ✓ |
| Chlorine | | |
| Chlorine dioxide | | |
| Ethylene | | |
| Ethylene oxide | | |
| Hydrogen chloride | | |
| Hydrogen cyanide | | |
| Hydrogen sulfide | | |
| Nitric oxide | | |
| Nitrogen dioxide | | ✓ |
| $O_2$ deficiency/enrichment | ✓ | ✓ |
| Phosphine | | |
| Refrigerants | ✓ | ✓ |
| Sulfur dioxide | | |
| VOCs | ✓ | |

# A Selection of Gases Typically Associated with Various Industries

| **Industry** | **Iron & Steel** | | | | | | |
|---|---|---|---|---|---|---|---|
| | Blast furnace operation and maintenance, converter operation, furnace & gas pipeline leaks | Metal-mining, finishing work, fuel storage | Coking operations | Welding | Confined space | Maintenance rooms (chillers) | Motor maintenance & cleaning, coke oven emissions |
| Combustible Gases | ✓ | ✓ | ✓ | ✓ | ✓ | | ✓ |
| Ammonia | | ✓ | | ✓ | | ✓ | |
| Carbon dioxide | | ✓ | | | | | ✓ |
| Carbon monoxide | ✓ | | ✓ | | ✓ | | ✓ |
| Chlorine | | | | | | | |
| Chlorine dioxide | | | | | | | |
| Ethylene | | | | | | | |
| Ethylene oxide | | | | | | | |
| Hydrogen chloride | | | | | | | |
| Hydrogen cyanide | | | | | | | |
| Hydrogen sulfide | | ✓ | ✓ | | ✓ | | |
| Nitric oxide | | | | ✓ | | | |
| Nitrogen dioxide | | | | ✓ | | | ✓ |
| $O_2$ deficiency/enrichment | ✓ | | | | ✓ | | |
| Phosphine | | | | | | | |
| Refrigerants | | | | | | ✓ | |
| Sulfur dioxide | | | ✓ | | | | ✓ |
| VOCs | | | | | ✓ | | ✓ |

# A Selection of Gases Typically Associated with Various Industries

| Industry | Medical | | | | | | |
|---|---|---|---|---|---|---|---|
| | Operating rooms, occupied areas | Alcohols, “sick building syndrome” | Central supply, sterilization areas | MRI | Parking garages | Decontamination areas | Mechanical equipment rooms |
| Combustible Gases | | | | | | | ✓ |
| Ammonia | | | | | | | ✓ |
| Carbon dioxide | ✓ | ✓ | | | | | |
| Carbon monoxide | | | | | ✓ | | ✓ |
| Chlorine | | | | | | | |
| Chlorine dioxide | | | | | | | |
| Ethylene | ✓ | ✓ | | | | | |
| Ethylene oxide | ✓ | ✓ | ✓ | | | | |
| Hydrogen chloride | | | | | | | |
| Hydrogen cyanide | | | | | | | |
| Hydrogen sulfide | | | | | | | |
| Nitric oxide | | | | | | | |
| Nitrogen dioxide | | | | | | | |
| $O_2$ deficiency/enrichment | ✓ | | | ✓ | | | |
| Phosphine | | | | | | | |
| Refrigerants | | | | | | | ✓ |
| Sulfur dioxide | | | | | | | |
| VOCs | | ✓ | ✓ | | | ✓ | |

# A Selection of Gases Typically Associated with Various Industries

| **Industry** | **Mining** | | | | | | |
|---|---|---|---|---|---|---|---|
| | Confined space | Mechanized coal cutting | Mining process | Result of combustion (fire), diesel-powered machinery exhaust, confined space blasting | Metal mining | Diesel exhaust | Diesel-powered machinery, blasting |
| Combustible Gases | ✓ | ✓ | ✓ | ✓ | | | |
| Ammonia | | | | | ✓ | | |
| Carbon dioxide | ✓ | | ✓ | | ✓ | | |
| Carbon monoxide | ✓ | | | ✓ | ✓ | ✓ | ✓ |
| Chlorine | | | | | | | |
| Chlorine dioxide | | | | | | | |
| Ethylene | | | | | | | |
| Ethylene oxide | | | | | | | |
| Hydrogen chloride | | | | | | | |
| Hydrogen cyanide | | | | | ✓ | | |
| Hydrogen sulfide | | | ✓ | | ✓ | | |
| Nitric oxide | | | | | | ✓ | ✓ |
| Nitrogen dioxide | | | | ✓ | | ✓ | ✓ |
| $O_2$ deficiency/enrichment | ✓ | | | | ✓ | | |
| Phosphine | | | | | | | |
| Refrigerants | | | | | ✓ | | |
| Sulfur dioxide | | | | | | | |
| VOCs | | | | | | | |

# A Selection of Gases Typically Associated with Various Industries

| **Industry** | **Oil & Gas** | | | | | |
|---|---|---|---|---|---|---|
| | Petroleum refining | Pipeline compressor stations and pumping stations | Refineries | Refineries, petrochemical facilities, perimeter monitoring | Incomplete combustion, conversion, coking, general processing, leak detection | Conversion processes, isomerization, catalytic reforming, treatment processes, leak detection, storage vessels, perimeter monitoring |
| Combustible Gases | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Ammonia | ✓ | | ✓ | | | |
| Carbon dioxide | | | | | | |
| Carbon monoxide | | | ✓ | | ✓ | |
| Chlorine | | | | | | |
| Chlorine dioxide | | | | | | |
| Ethylene | | | | | | |
| Ethylene oxide | | | | | | |
| Hydrogen chloride | ✓ | | ✓ | | | ✓ |
| Hydrogen cyanide | | | | | | |
| Hydrogen sulfide | ✓ | | ✓ | ✓ | ✓ | ✓ |
| Nitric oxide | | | | | | |
| Nitrogen dioxide | | | | | ✓ | |
| $O_2$ deficiency/enrichment | | | | | | ✓ |
| Phosphine | | | | | | |
| Refrigerants | | | | | | |
| Sulfur dioxide | ✓ | | ✓ | ✓ | | |
| VOCs | ✓ | | ✓ | ✓ | | ✓ |

# A Selection of Gases Typically Associated with Various Industries

| **Industry** | **Oil & Gas** | | | | | | |
|---|---|---|---|---|---|---|---|
| | **Refining process, general leak detection, treatment processes, crude separation, drilling rigs** | **Confined space (tank cleaning operations, enclosed bldgs or structures)** | **Natural gas lines** | **Offshore drilling platforms-storage & processing areas, control rooms, living spaces, power generation rooms** | **Refining process, process stream sample collection, general plant operations** | **Mechanical equipment rooms** | **Thermal oxidizers** |
| Combustible Gases | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Ammonia | | | | | | | |
| Carbon dioxide | ✓ | | | | ✓ | | |
| Carbon monoxide | | | | | | | |
| Chlorine | | | | | | | |
| Chlorine dioxide | | | | | | | |
| Ethylene | | | | | | | |
| Ethylene oxide | | | | | | | |
| Hydrogen chloride | | | | | | | |
| Hydrogen cyanide | | | | | | | |
| Hydrogen sulfide | ✓ | | ✓ | ✓ | ✓ | | |
| Nitric oxide | | | | | | | |
| Nitrogen dioxide | | | | | | | |
| $O_2$ deficiency/enrichment | | ✓ | | | | | |
| Phosphine | | | | | | | |
| Refrigerants | | | | | | ✓ | |
| Sulfur dioxide | ✓ | | | | ✓ | | |
| VOCs | ✓ | ✓ | | | ✓ | | |

# A Selection of Gases Typically Associated with Various Industries

| Industry | Paper & Pulp | | | | |
|---|---|---|---|---|---|
| | Paper production (bleaching) | Chemical pulping, Kraft pulping | Confined spaces (tanks, pits, sumps, vats) | Paper production (coating & dying) | Mechanical equipment rooms |
| Combustible Gases | | | ✓ | ✓ | ✓ |
| Ammonia | | ✓ | | | ✓ |
| Carbon dioxide | | | | | |
| Carbon monoxide | | | | | |
| Chlorine | ✓ | | ✓ | | |
| Chlorine dioxide | ✓ | | | | |
| Ethylene | | | | | |
| Ethylene oxide | | | | | |
| Hydrogen chloride | | | | | |
| Hydrogen cyanide | | | | | |
| Hydrogen sulfide | | ✓ | ✓ | ✓ | |
| Nitric oxide | | | | | |
| Nitrogen dioxide | ✓ | | | ✓ | |
| $O_2$ deficiency/enrichment | | | ✓ | | |
| Phosphine | | | | | |
| Refrigerants | ✓ | | | | ✓ |
| Sulfur dioxide | ✓ | ✓ | | | |
| VOCs | | | | ✓ | |

# A Selection of Gases Typically Associated with Various Industries

| **Industry** | **Pharmaceutical** | | | | |
|---|---|---|---|---|---|
| | Manufacturing, gas leaks | Solvent vapor process monitoring | Chemical synthesis operations | Labs, fine chemical manufacturing | Labs, organic synthesis, liquid-solid separation, compounding, granulating & tablet-coating operations, drying & packaging, fine chemical manufacturing |
| Combustible Gases | ✓ | ✓ | ✓ | ✓ | ✓ |
| Ammonia | ✓ | ✓ | ✓ | ✓ | ✓ |
| Carbon dioxide | | ✓ | | | ✓ |
| Carbon monoxide | | | | ✓ | |
| Chlorine | ✓ | | | ✓ | ✓ |
| Chlorine dioxide | ✓ | | | | |
| Ethylene | | ✓ | | | |
| Ethylene oxide | ✓ | | ✓ | ✓ | ✓ |
| Hydrogen chloride | | | | | |
| Hydrogen cyanide | ✓ | | ✓ | ✓ | |
| Hydrogen sulfide | | | | | |
| Nitric oxide | | | | | |
| Nitrogen dioxide | | | | | |
| $O_2$ deficiency/enrichment | | | ✓ | | |
| Phosphine | | | | | |
| Refrigerants | | | | | ✓ |
| Sulfur dioxide | ✓ | | | | |
| VOCs | | ✓ | ✓ | | ✓ |

# A Selection of Gases Typically Associated with Various Industries

| **Industry** | **Pharmaceutical** | | |
|---|---|---|---|
| | **Nitrogen blanketing of storage vessels, reactors and centrifuges** | **Compressed breathing air** | **Utilities** |
| Combustible Gases | | | ✓ |
| Ammonia | | | |
| Carbon dioxide | | ✓ | |
| Carbon monoxide | ✓ | ✓ | ✓ |
| Chlorine | | | |
| Chlorine dioxide | | | |
| Ethylene | | | |
| Ethylene oxide | | | |
| Hydrogen chloride | | | |
| Hydrogen cyanide | | | |
| Hydrogen sulfide | | | |
| Nitric oxide | | | |
| Nitrogen dioxide | | | |
| $O_2$ deficiency/enrichment | ✓ | ✓ | |
| Phosphine | | | |
| Refrigerants | | | ✓ |
| Sulfur dioxide | | | |
| VOCs | | | |

# A Selection of Gases Typically Associated with Various Industries

| **Industry** | **Power Generation** | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **Home furnace leaks** | **Transformer insulation** | **Power generation plants** | **Fuel storage** | **Fuel transport loading & unloading** | **Fossil fuel power plants** | **Confined space** | **Coal & fuel oil oxidization in combustion process (emissions)** |
| Combustible Gases | ✓ | | ✓ | ✓ | ✓ | ✓ | ✓ | |
| Ammonia | | | ✓ | | | ✓ | | ✓ |
| Carbon dioxide | | | ✓ | | | | ✓ | ✓ |
| Carbon monoxide | ✓ | | ✓ | | ✓ | ✓ | ✓ | ✓ |
| Chlorine | | | ✓ | | | | | |
| Chlorine dioxide | | | | | | | | |
| Ethylene | | | | | | | | |
| Ethylene oxide | | | | | | | | |
| Hydrogen chloride | | | ✓ | | | | | ✓ |
| Hydrogen cyanide | | | | | | | | |
| Hydrogen sulfide | | | | | | | | |
| Nitric oxide | | | | | | ✓ | | |
| Nitrogen dioxide | | | ✓ | | | ✓ | | ✓ |
| $O_2$ deficiency/enrichment | | | ✓ | | | | ✓ | |
| Phosphine | | | | | | | | |
| Refrigerants | | | | | | | | |
| Sulfur dioxide | | | ✓ | | | ✓ | | ✓ |
| Sulfur hexafluoride | | ✓ | | | | | | |
| VOCs | | | | | ✓ | | ✓ | |

# A Selection of Gases Typically Associated with Various Industries

| Industry | Semiconductor Fabs | | | | | |
|---|---|---|---|---|---|---|
| | Manufacturing, processing | As doping agent in manufacturing, diffusion and ion implementation, chemical vapor deposition | Cleaning agents, fluorinated compounds | Lithography, etching, oxidation, metalization, assembly & testing | Chiller plant | Compressed breathing air |
| Combustible Gases | ✓ | | ✓ | | | |
| Ammonia | | | | | ✓ | |
| Arsine | ✓ | | | | | |
| Bromine | ✓ | | | | | |
| Carbon monoxide | ✓ | | | | | ✓ |
| Chlorine | ✓ | | | | | |
| Chlorine dioxide | ✓ | | | | | |
| Diborane | ✓ | | | | | |
| Germane | ✓ | | | | | |
| Hydrogen chloride | ✓ | | | ✓ | | |
| Hydrogen cyanide | ✓ | | | | | |
| Nitric oxide | ✓ | | | | | |
| Nitrogen dioxide | ✓ | | | | | |
| $O_2$ deficiency/enrichment | | | | | | ✓ |
| Phosphine | | ✓ | | | | |
| Refrigerants | | | ✓ | | ✓ | |
| Silane | ✓ | | | | | |
| VOCs | | | ✓ | ✓ | | |

# A Selection of Gases Typically Associated with Various Industries

| **Industry** | **Shipyard/Marine** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Confined space (storage holds) | Fuel storage and pumping facilities | Engine room | Waste treatment | Chillers | LNG transport | Oil tanker pumps | U.S. Navy ships | Ferry boats |
| Combustible Gases | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ |
| Ammonia | | | ✓ | | ✓ | | | ✓ | ✓ |
| Carbon dioxide | | ✓ | | | | | | | |
| Carbon monoxide | ✓ | | ✓ | | | | | ✓ | ✓ |
| Chlorine | | | | | | | | | |
| Chlorine dioxide | ✓ | | | | | | | | |
| Ethylene | | | | | | | | | |
| Ethylene oxide | | | | | | | | | |
| Hydrogen chloride | | | | | | | | | |
| Hydrogen cyanide | | | | | | | | | |
| Hydrogen sulfide | | | | ✓ | | | | ✓ | |
| Nitric oxide | | | | | | | | | |
| Nitrogen dioxide | | | | | | | | | |
| $O_2$ deficiency/enrichment | ✓ | | | ✓ | | | | | |
| Phosphine | | | | | | | | | |
| Refrigerants | | | ✓ | | ✓ | | | ✓ | ✓ |
| Sulfur dioxide | | | | | | | | | |
| VOCs | ✓ | | | | | | | ✓ | |

# A Selection of Gases Typically Associated with Various Industries

| Industry | Water & Wastewater | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Processing; storage tanks, rooms & pipes | Digesters, digester gas storage | Stagnant gas, incinerators | Plant pumps, plant sewage basin monitoring for solvent leaks or dumping | General processes | Sewer work | Confined space | Dechlorinization, storage tanks | Wet well influent | Pump stations |
| Combustible Gases | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ |
| Ammonia | ✓ | | | | | | | | | |
| Carbon dioxide | | ✓ | ✓ | | | | ✓ | | | |
| Carbon monoxide | | | | | | | | | ✓ | ✓ |
| Chlorine | ✓ | | | | | | ✓ | ✓ | | |
| Chlorine dioxide | ✓ | | | | | | ✓ | ✓ | | |
| Ethylene | | | | | | | | | | |
| Ethylene oxide | | | | | | | | | | |
| Hydrogen chloride | | | | | | | | | | |
| Hydrogen cyanide | | | | | | | | | | |
| Hydrogen sulfide | ✓ | ✓ | | | ✓ | ✓ | ✓ | | ✓ | ✓ |
| Nitric oxide | | | | | | | | | | |
| Nitrogen dioxide | | | | | | | | | | ✓ |
| $O_2$ deficiency/enrichment | | | | | ✓ | ✓ | ✓ | | | |
| Phosphine | | | | | | | | | | |
| Refrigerants | | | | | | | | | | |
| Sulfur dioxide | | | | | | | | ✓ | | |
| VOCs | ✓ | | | | | | ✓ | | | |

## A Selection of Gases Typically Associated with Various Industries

| **Industry** | **Welding** | | |
|---|---|---|---|
| | **Confined space, arc air cutting, flux-shielded & gasshielded arc welding, metal cutting & flame gouging, gas pressure welding** | **General operations** | **Thermite and stud welding, laser welding & chilling, arc air cutting, arc welding, electric resistance & gas pressure welding, metal cutting & flame gouging, brazing** |
| Combustible Gases | ✓ | | ✓ |
| Ammonia | ✓ | | |
| Carbon dioxide | ✓ | | |
| Carbon monoxide | ✓ | | ✓ |
| Chlorine | | | |
| Chlorine dioxide | | | |
| Ethylene | ✓ | | |
| Ethylene oxide | | | |
| Hydrogen chloride | | | |
| Hydrogen cyanide | | | |
| Hydrogen sulfide | | | |
| Nitric oxide | | | |
| Nitrogen dioxide | | | |
| $O_2$ deficiency/enrichment | ✓ | | ✓ |
| Phosphine | | | |
| Refrigerants | | | |
| Sulfur dioxide | | | |
| VOCs | | | |

# A Selection of Gases Typically Associated with Various Industries

| Industry | Welding | |
|---|---|---|
| | Arc welding & cutting, stud welding, arc + air cutting, gas pressure welding, metal cutting & flame gouging | Confined space welding, electron beam welding |
| Combustible Gases | ✓ | ✓ |
| Ammonia | | |
| Carbon dioxide | | |
| Carbon monoxide | | ✓ |
| Chlorine | | |
| Chlorine dioxide | | |
| Ethylene | | |
| Ethylene oxide | | |
| Hydrogen chloride | | |
| Hydrogen cyanide | | |
| Hydrogen sulfide | | |
| Nitric oxide | | |
| Nitrogen dioxide | ✓ | |
| $O_2$ deficiency/enrichment | ✓ | ✓ |
| Phosphine | | |
| Refrigerants | | |
| Sulfur dioxide | | |
| VOCs | | |

# Section 6

## Hazardous Locations Classification

### Class I: Flammable Gases, Vapors, or Liquids

### Class II: Combustible Dusts

### Class III: Ignitable Fibers & Flyings

## ATEX - Explosive Atmospheres

## A Selection of Recognized Testing Laboratories

## System Installation

## Safety Integrity Levels

## Hazardous Locations Classification

The hazardous location classification system was designed to promote the safe use of equipment in environments defined as “hazardous areas”. A hazardous area is a location in which the potential presence of a flammable mixture requires special precautions to reduce the possibility of any equipment in the hazardous area becoming a source of ignition.

In gas detection applications, hazardous areas are generally defined by two factors: the type of gas that may be present, and the degree of probability that it will be present at any given instant. Different classification methods may be used depending on the local authority, but essentially the same result is achieved.

Areas are classified according to hazardous material that may be present and the likelihood that they will produce an explosive or ignitable mixture. In a hazardous area, the equipment must possess the appropriate protection method for safe operation in that area (i.e., to ensure that it does not become a source of ignition). Various methods of protection are used to meet this need.

### Area Classification

Each area is classified according to the likelihood that the hazard will be present at any given instant.
**There are two major hazardous location classifications:**

- Zones: This is the primary method used throughout the world to indicate the probability of the explosive hazard being present. There are three different zone options: Zone 0, 1, or 2. Zone 0 indicates the highest probability that the explosive hazard is present and Zone 2 the least likely.
- Divisions: This method is used primarily in the United States and Canada. The hazardous area can be classified as Division 1 or 2. Division 1 is essentially the same as Zone 0 or 1 and Division 2 correlates with Zone 2 in the Zone classification method.

### Material Type

The hazardous material may be a gas, dust, or fiber/flying. The different types of material may be grouped according to their explosion-hazard properties.

# Hazardous Locations Classification

## Temperature Class

Gases are also grouped according to their ignition temperature. This is the maximum surface temperature that can be attained by an apparatus or component at maximum-rated ambient temperature. Six basic temperature classes are used to categorize this factor (T1 through T6). The higher the temperature class, the lower the maximum surface temperature; thus, the wider the range of gases for which the apparatus is suitable.

## Protection Methods

Various forms of protection are used, such as intrinsic safety, explosion-proof, flameproof, purging/pressurization, hermetic sealing, and non-sparking design.

## Environmental Protection

Environmental protection refers to design methods used to minimize equipment exposure to invasive environmental conditions such as water, ice, dust, and corrosion. As with Hazardous Area Classifications, equipment environmental protection ratings vary somewhat within and outside of North America. As seen in the following two tables, National Electrical Manufacturers Association (NEMA) and Ingress Protection (IP) Codes provide similar information regarding instrument protection against various environmental conditions.

Attaining one rating does not imply that the other ratings have also been met.

# Hazardous Locations Classification

**INGRESS PROTECTION (IP) CODES**
(IEC/EN 60529)

| **FIRST NUMERAL**<br>Protection against solid bodies | | | **SECOND NUMERAL**<br>Protection against liquids |
|---|---|---|---|
| **No Protection** | 0 | 0 | **No Protection** |
| **Objects Greater than 50mm** | 1 | 1 | **Vertically dripping water** |
| **Objects Greater than 12mm** | 2 | 2 | **Enclosure titled up to 15 degrees** |
| **Objects Greater than 2.5mm** | 3 | 3 | **Sprayed Water** |
| **Objects Greater than 1.0mm** | 4 | 4 | **Splashed Water** |
| **Dust-Protected** | 5 | 5 | **Water Jets** |
| **Dust-Tight** | 6 | 6 | **Heavy Seas** |
| | | 7 | **Effects of Immersion** |

# Hazardous Locations Classification

## Enclosure Ratings

| NEMA, UL, & CSA Type Rating | Approximate IEC/IP classification | Abbreviated protection description |
|---|---|---|
| 1 | IP30 | Indoor, from contact with contents |
| 2 | IP31 | Indoor, limited, from dirt and water |
| 3 | IP64 | Outdoor, from rain, sleet, windblown dust, and ice damage |
| 3R | IP32 | Outdoor, from rain, sleet, and ice damage |
| 4 | IP66 | Indoor and outdoor, from windblown dust, rain, splashing and hose directed water, and ice damage |
| 4X | IP66 | Indoor and outdoor, from corrosion, windblown dust, rain, splashing and hose directed water, and ice damage |
| 6 | IP67 | Indoor and outdoor, from hose-directed water, water entry during submersion, and ice damage |
| 12 | IP55 | Indoor, from dust, falling dirt, and dripping non-corrosive liquids |
| 13 | IP65 | Indoor, from dust, spraying water, oil, and non-corrosive liquids |

# **Hazardous Locations Classification** – Class I: Flammable Gases, Vapors, or Liquids

## Class I Area Classification

**Division 1:**

Where ignitable concentrations of flammable gases, vapors, or liquids can exist all of the time or some of the time under normal operating conditions.

**Division 2:**

Where ignitable concentrations of flammable gases, vapors, or liquids are not likely to exist under normal operating conditions.

**Zone 0:**

Where ignitable concentrations of flammable gases, vapors, or liquids are present continuously or for long periods of time under normal operating conditions.

**Zone 1:**

Where ignitable concentrations of flammable gases, vapors, or liquids are likely to exist under normal operating conditions.

**Zone 2:**

Where ignitable concentrations of flammable gases, vapors, or liquids are not likely to exist under normal operating conditions.

## Class I Groups, Divisions 1 and 2

**A** Acetylene.

**B** Hydrogen, fuel and combustible process gases containing more than 30% hydrogen by volume, or gases or vapors of equivalent hazard such as butadiene, ethylene oxide, propylene oxide, and acrolein.

**C** Cyclopropane, ethyl ether, ethylene, or gases or vapors of equivalent hazard.

**D** Acetone, ammonia, benzene, butane, ethanol, gasoline, hexane, methane, natural gas, naptha, propane, or gases or vapors of equivalent hazard.

**Zones 0, 1, and 2**

IIC acetylene and hydrogen, fuel, and combustible process gases containing more than 30% hydrogen by volume, or gases or vapors of equivalent hazard such as butadiene, ethylene oxide, propylene oxide, and acrolein.

IIB cyclopropane, ethyl ether, ethylene, or gases or vapors of equivalent hazard.

IIA acetone, ammonia, benzene, butane, ethanol, gasoline, hexane, methane, natural gas, naptha, propane, or gases or vapors of equivalent hazard.

## Class I Temperature Codes

(Maximum surface temperature of apparatus)

| Divisions 1 and 2 | Zones 0, 1, and 2 |
|---|---|
| T1 (≤450°C) | T1 (≤450°C) |
| T2 (≤300°C) | T2 (≤300°C) |
| T2A, T2B, T2C, T2D<br>(≤280°C, ≤260°C, ≤230°C, ≤215°C) | – |
| T3 (≤200°C) | T3 (≤200°C) |
| T3A, T3B, T3C<br>(≤180°C, ≤165°C, ≤160°C) | – |
| T4 (≤135°C) | T4 (≤135°C) |
| T4A (≤120°C) | |
| T5 (≤100°C) | T5 (≤100°C) |
| T6 (≤85°C) | T6 (≤85°C) |

## **Hazardous Locations Classification** – Class I: Flammable Gases, Vapors, or Liquids

| Class I, Divisions 1 and 2 Protection Methods | | | |
|---|---|---|---|
| | | Applicable Certification Documents | |
| **Area** | **Protection Methods** | **USA** | **Canada** |
| **Div. 1** | • Explosion-proof<br>• Intrinsic safety (2 fault)<br>• Purged/pressurized (Type X or Y) | UL 1203<br>UL 913<br>NFPA 496 | UL 1203<br>UL 913<br>NFPA 496 |
| **Div. 2** | • Nonincendive<br>• Purged/Pressurized (Type Z)<br>• Any Class I, Div. 1 method<br>• Any Class I, Zone 0, 1, or 2 method | ISA 12.12.01<br>NFPA 496<br>—<br>UL 60079 Series | ISA 12.12.01<br>NFPA 496<br>—<br>UL 60079 Series |

## **Hazardous Locations Classification** – Class I: Flammable Gases, Vapors, or Liquids

### Class I, Zones 0, 1, and 2 Protection Methods

| | | **Applicable Certification Documents** | | | |
|---|---|---|---|---|---|
| **Area** | **Protection Methods** | **USA** | **Canada** | **IECEx Scheme** | **Europe** |
| **Zone 0** | • Intrinsic safety, 'ia' (2 fault)<br>• Special requirements | ISA 60079-11<br>No | E60079-11<br>No | IEC 60079-11<br>IEC 60079-26 | EN 60079-11<br>EN 60079-26 |
| **Zone 1** | • Encapsulation, ‘m’ | ISA 60079-18 | E60079-18 | IEC 60079-18 | EN 60079-18 |
| | • Flameproof, ‘d’ | ISA 60079-1 | E60079-1 | IEC 60079-1 | EN 60079-1 |
| | • Increased safety, ‘e’ | ISA 60079-7 | E60079-7 | IEC 60079-7 | EN 60079-7 |
| | • Intrinsic safety, ‘ib’ (1 fault) | ISA 60079-11 | E60079-11 | IEC 60079-11 | EN 60079-11 |
| | • Oil immersion, ‘o’ | ISA 60079-6 | E60079-6 | IEC 60079-6 | EN 50015 |
| | • Powder filling, ‘q’ | ISA 60079-5 | E60079-5 | IEC 60079-5 | EN 60079-5 |
| | • Pressurization, ‘px’ or ‘py’ | ISA 60079-2 | E60079-2 | IEC 60079-2 | EN 60079-2 |
| | • Any Class I, Zone 0 | Yes | Yes | Yes | Yes |
| | • Any Class I, Div. 1 | Yes | Yes | No | No |
| **Zone 2** | • Non-sparking, 'nA' | ISA 60079-15 | E60079-15 | IEC 60079-15 | EN 60079-15 |
| | • Enclosed break, 'nC' | ISA 60079-15 | E60079-15 | IEC 60079-15 | EN 60079-15 |
| | • Energy limited, 'nL' | ISA 60079-15 | E60079-15 | IEC 60079-15 | EN 60079-15 |
| | • Restricted breathing, 'nR' | ISA 60079-15 | E60079-15 | IEC 60079-15 | EN 60079-15 |
| | • Pressurization, 'pz' | ISA 60079-2 | E60079-2 | IEC 60079-2 | EN 60079-2 |
| | • Intrinsic safety, ‘ic’ | ISA 60079-11 | E60079-11 | IEC 60079-11 | EN 60079-11 |
| | • Any Class I, Zone 0 or 1 method | Yes | Yes | Yes | Yes |
| | • Any Class I, Div. 1 or 2 method | Yes | Yes | No | No |

**Note 1:** 60079-0 General requirements used in conjunction with 60079-xx. UL 60079-xx.

**Note 2:** Requirements subject to change without notice.
Check your local authority having jurisdiction for current requirements.

**Note 3:** The ‘ic’ concept will replace the ‘energy-limited’ (nL) of the type ‘n’ standard IEC 60079-15 and possibly the ‘non-incendive’ concept of North American standards.

# **Hazardous Locations Classification** – Class II: Combustible Dusts

## Class II Area Classification

**Division 1:**

Where ignitable concentrations of combustible dusts can exist all of the time or some of the time under normal operating conditions.

**Division 2:**

Where ignitable concentrations of combustible dusts are not likely to exist under normal operating conditions.

## Class II Groups

**Divisions 1 and 2:**

**E** (metals – Div. 1 only)

**F** (coal)

**G** (grain)

## Class II Temperature Codes[1]

| **Divisions 1 and 2** |
|---|
| T1 (≤450°C) |
| T2 (≤300°C) |
| T2A, T2B, T2C, T2D<br>(≤280°C, ≤260°C, ≤230°C, ≤215°C) |
| T3 (≤200°C) |
| T3A, T3B, T3C<br>(≤180°C, ≤165°C, ≤160°C) |
| T4 (≤135°C) |
| T4A (≤120°C) |
| T5 (≤100°C) |
| T6 (≤85°C) |

1: Temperature class of equipment determined with dust layer per the applicable standard.

# **Hazardous Locations Classification** – Class II: Combustible Dusts

### Class I, Divisions 1 and 2 Protection Methods

| | | Applicable Certification Documents | |
|---|---|---|---|
| **Area** | **Protection Methods** | **USA** | **Canada** |
| **Div. 1** | • Dust-ignition proof | UL 1203 | CSA-25 or CSA-E1241-1-1 |
| | • Intrinsic safety | UL 913 | CSA-157 |
| | • Pressurized | NFPA 496 | NFPA 496 |
| **Div. 2** | • Dust-tight | ISA 60079-31 | CSA-25 or CSA-E1241-1-1 |
| | • Nonincendive | ISA 12.12.01 | — |
| | • Pressurized | NFPA 496 | NFPA 496 |
| | • Any Class II, Div. 1 method | — | — |

## **Hazardous Locations Classification:** Hazardous Locations Markings

### Class I, II, & III, Divisions 1 & 2 (USA & Canada)

**This marking may include:**
Class(es), Division(s), Gas/Dust Group(s), Temperature Code
Example: Class I, Division 1, Group C & D, T4A

### Class I, Zones 0, 1, & 2 (USA)

**This marking may include:**
Gases: Class, Zone, AEx, Protection Method(s), Gas Group, Temperature Code
*Example:* Class I, Zone 1, AEx de IIB T4

Dusts: Zone, AEx, Protection method, Temperature Code
*Example:* Zone 21 AEx tD T135˚C

### Class I, Zones 0, 1, & 2 (Canada)

**This marking may include:**
Class, Zone, Ex, Protection Method(s), Gas Group, Temperature Code
*Example:* Class I, Zone 1, Ex de IIB T4

### Zones 0, 1 & 2 (IECEx Scheme)

**This marking may include:**
Gases: Ex, Protection Method(s), Gas Group, Temperature Code, Equipment protection level
*Example:* Ex de IIB T4

Dusts: Ex, Protection method, Group, Temperature code
*Example:* Ex tb IIIC T135˚C

### Zones 0, 1 & 2 (Europe)

**This marking may include:**
Gases: Ex, Protection Method(s), Gas Group, Temperature Code Example: Ex de IIB T4

Dusts: Ex, Protection method, Group, Temperature code
*Example:* Ex tb IIIC T135˚C

### ATEX Directive (Europe)

In addition to the European Ex marking string noted above, this marking may include:

**Non-mining:**
CE, Notified Body (NB) Identifier, Ex, Equipment Group & Category, G (gas)/D (dust)
Example: (for DEMKO): CE 0539 Ex II 2 D

**Mining:**
CE, Notified Body (NB) Identifier, Ex, Equipment Group & Category
Example: (for DEMKO): CE 0539 I 2 G

# **Hazardous Locations Classification:** Class III: Ignitable Fibers & Flyings

## Class III Area Classification

**Division 1:**

Where easily ignitable fibers or materials producing combustible flyings are handled, manufactured, or used.

**Division 2:**

Where easily ignitable fibers are stored or handled.

## Class III Groups

**Divisions 1 and 2:**

None

## Class III Temperature Codes

**Divisions 1 and 2:**

None

Note: Article 503 of the NEC limits the maximum temperature for Class III equipment to 165 ˚C for equipment not subject to overloading and to 120 ˚C for equipment that may be overloaded.

## **Hazardous Locations Classification:** Class III: Ignitable Fibers & Flyings

| Class I, Divisions 1 and 2 Protection Methods | | | |
|---|---|---|---|
| | | **Applicable Certification Documents** | |
| **Area** | **Protection Methods** | **USA** | **Canada** |
| **Div. 1** | • Dust-tight<br>• Intrinsic safety | ISA 60079-31<br>UL 913 | CSA-25<br>CSA-157 |
| **Div. 2** | • Nonincendive<br>• Any Class III, Div. 1 method | ISA 60079-31<br>— | —<br>— |

### CE Mark

The CE mark (Conformité Européene, or European Conformity) on a product is a declaration by the responsible person (typically the manufacturer) that the product conforms to all the applicable European Union provisions and all appropriate conformity assessment procedures have been completed. Typical Directives for gas detection products include ATEX, EMC, and Low Voltage.

### ATEX Directive

The ATEX Directive 2014/34/EU covers equipment and protective systems intended for use in potentially explosive atmospheres. The Directive defines the essential health and safety requirements and conformity assessment procedures, to be applied before products are placed on the EU market. *(Details on next page.)*

### EMC Directive

The Electromagnetic Compatibility Directive 2004/108/EC is intended to limit the electromagnetic emission of equipment such that it does not adversely effect the operation of other equipment and to ensure the equipment has an intrinsic level of immunity to electromagnetic interference. For gas detection equipment this is typically accomplished by designing it to comply with the requirements of EN 50270.

### Low Voltage Directive

The Low Voltage Directive (LVD) 2014/35/EU is a European personal safety Directive that is comparable to a US/Canadian fire/shock and safety approval. It applies any equipment designed for use with a voltage rating of between 50 and 1000 volts for alternating current and between 75 and 1500 volts for direct current. A typical standard used for designing to compliance is EN 61010-1.

# ATEX – Explosive Atmospheres

ATEX (ATmosphère EXplosible, or Explosive Atmospheres) is the term used for the European Union's Directive 2014/34/EU (replaces the previous 94/9/EC Directive) which concerns equipment and protective systems intended for use in potentially explosive atmospheres. The purpose of the directive is to facilitate trade within the EU by aligning the laws of the Member States in Europe regarding safety requirements for hazardous area products.

**ATEX compliance requires that the following issues be met:**

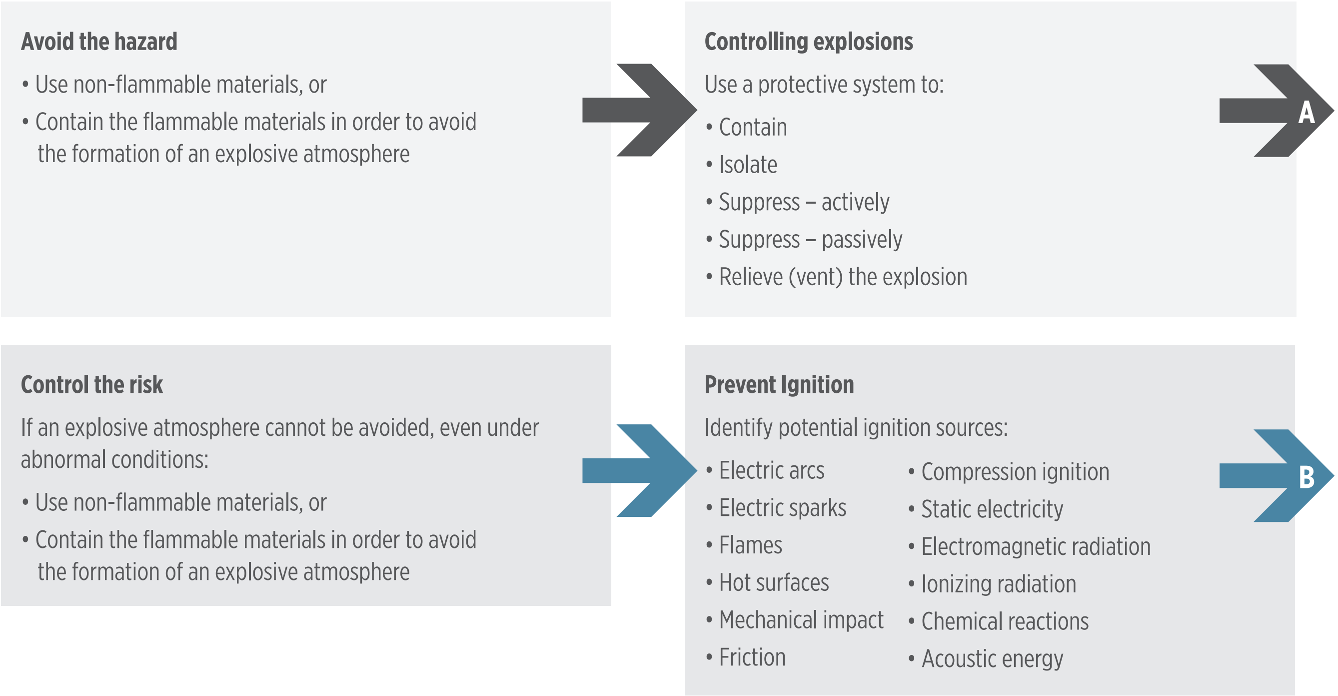
**1. Safety requirements**
The product must meet the applicable hazardous location requirements.

**2. Performance requirements**
If the product is designed to monitor combustible gas and/or oxygen, then it must meet certain performance criteria in fields such as response time, accuracy, and linearity.

**3. Quality management certification**
The manufacturer must have an approved quality management system.

## EXPLOSION SAFETY HIERARCHY

(European Standard EN 1127-1)



**Avoid the hazard**

- Use non-flammable materials, or
- Contain the flammable materials in order to avoid the formation of an explosive atmosphere

**Controlling explosions**

Use a protective system to:

- Contain
- Isolate
- Suppress – actively
- Suppress – passively
- Relieve (vent) the explosion

**Control the risk**

If an explosive atmosphere cannot be avoided, even under abnormal conditions:

- Use non-flammable materials, or
- Contain the flammable materials in order to avoid the formation of an explosive atmosphere

**Prevent Ignition**

Identify potential ignition sources:

- Electric arcs
- Electric sparks
- Flames
- Hot surfaces
- Mechanical impact
- Friction
- Compression ignition
- Static electricity
- Electromagnetic radiation
- Ionizing radiation
- Chemical reactions
- Acoustic energy

**A**

### Protective Systems

- Explosion suppression systems
- Explosion-proof equipment
- Flame arresters
- Explosion venting devices
- Inerting
- Limitation of concentration of combustibles
- Dust explosion venting systems
- Gas explosion venting systems
- Explosion suppression devices
- Active explosion extinguishing barriers
- Explosion barriers for mines
- Mechanical explosion barriers

**B**

### Protect Ignition Systems

**Category of protection**
(EU Directive 2014/34/EU – ATEX)

**Mining equipment – Group I Category M1**
Very high level of protection. Equipment can be operated in presence of explosive atmosphere

**Category M2**
High level of protection. Equipment to be de-energized in presence of explosive atmosphere

**Non-mining equipment – Group II**

**Category 1**
Very high level of protection. Used where explosive atmosphere is present continuously or for long periods of time (Zone 0, 20)*

**C**

**Category 2**
High level of protection. Used where explosive atmosphere is likely to occur in normal service (Zone 1, 21)*

**D**

**Category 3**
Normal level of protection. Used where explosive atmosphere is unlikely to occur and would be infrequent and for short time (Zone 2, 22)*

* EN 1127-1:2019. Clause 6.3

## Methods Of Protection: Standards

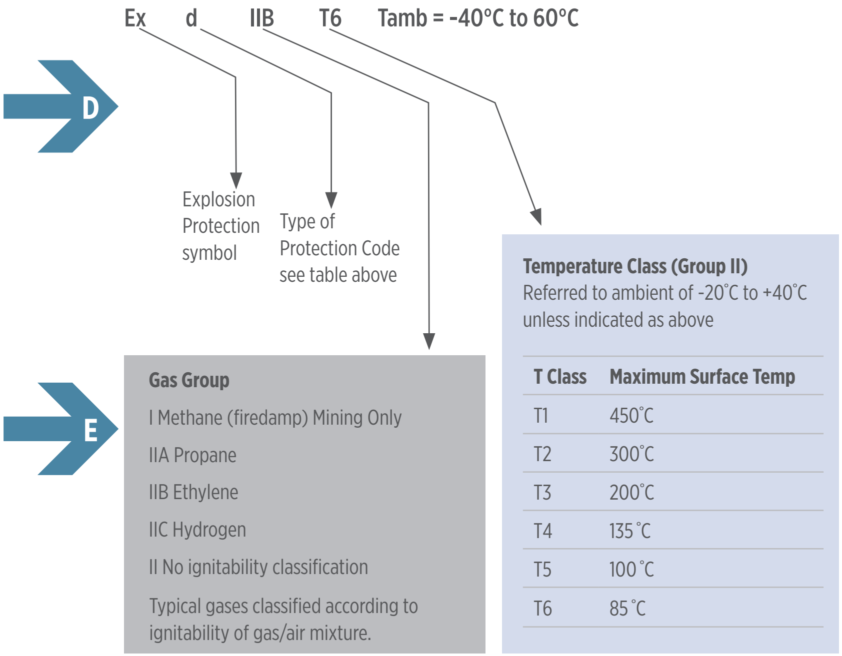
C

| **Electrical equipment for gas, vapors, and mists (G)** | | | | **Category** | | | | |
|---|---|---|---|---|---|---|---|---|
| | **Code** | **Cenelec EN** | **IEC** | **M1** | **M2** | **1** | **2** | **3** |
| General requirements | | 60079-0 | 60079-0 | + | + | + | + | + |
| Oil immersion | o | 60079-6 | 60079-6 | | | | + | |
| Pressurized | p | 60079-2 | 60079-2 | | | | + | |
| Powder filled | q | 60079-5 | 60079-5 | | | | + | |
| Flameproof | d | 60079-1 | 60079-1 | | + | | + | |
| Increased safety | e | 60079-7 | 60079-7 | | + | | + | |
| Intrinsic safety | ia | 60079-11 | 60079-11 | + | | + | | |
| Encapsulated | m | 60079-11 | 60079-11 | | + | | + | |
| Type of protection ‘n’ | n | 60079-18 | 60079-18 | | | | + | + |
| Category 1 G | | 60079-15 | 60079-15 | | | + | | |
| Category M 1 | | 60079-26 | - | + | | | | |
| **Electrical equipment for flammable dusts (D)** | | | | | | | | |
| Construction and testing | | 60079-31 | | | | + | + | + |
| **Non-electrical equipment (CEN EN)** | | | | | | | | |
| General requirements | | | | + | + | + | + | + |
| Restrictive breathing enclosure | | | | | | | | + |
| Flameproof enclosure | | | | | + | | + | |
| Constructional safety | | | | | + | + | + | |
| Control of ignition sources | | | | | + | + | + | + |
| Liquid immersion | | | + | + | + | + | + | + |

E

# Equipment Markings

## IEC/CENELEC



Ex d IIB T6 Tamb = -40°C to 60°C

Ex – Explosion Protection symbol

d – Type of Protection Code see table above

IIB – Gas Group

T6 – Temperature Class

**Gas Group**

I Methane (firedamp) Mining Only

IIA Propane

IIB Ethylene

IIC Hydrogen

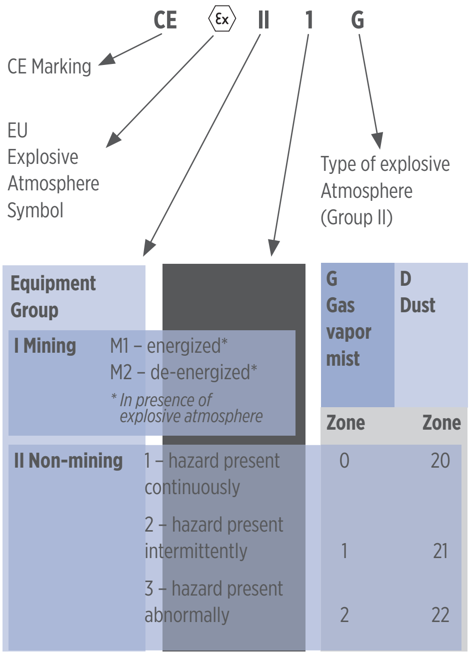
II No ignitability classification

Typical gases classified according to ignitability of gas/air mixture.

**Temperature Class (Group II)**
Referred to ambient of -20˚C to +40˚C unless indicated as above

| T Class | Maximum Surface Temp |
|---|---|
| T1 | 450˚C |
| T2 | 300˚C |
| T3 | 200˚C |
| T4 | 135˚C |
| T5 | 100˚C |
| T6 | 85˚C |

## EU ATEX Directive 2014/34/EU



CE ⟨Ex⟩ II 1 G

CE – CE Marking

⟨Ex⟩ – EU Explosive Atmosphere Symbol

G – Type of explosive Atmosphere (Group II)

| Equipment Group | | G<br>Gas vapor mist | D<br>Dust |
|---|---|---|---|
| I Mining | M1 – energized*<br>M2 – de-energized*<br>** In presence of explosive atmosphere* | | |
| | | Zone | Zone |
| II Non-mining | 1 – hazard present continuously | 0 | 20 |
| | 2 – hazard present intermittently | 1 | 21 |
| | 3 – hazard present abnormally | 2 | 22 |

## A Selection of Testing Laboratories

| | |
|---|---|
| **North America** | |
| CSA | CSA International or Canadian Standards Association |
| ETL | Intertek Testing Services NA |
| FM | FM Approvals LLC |
| MET | MET Laboratories, Inc. |
| MSHA | Mine Safety and Health Administration |
| UL | Underwriters Laboratories Inc. |
| **Australia** | |
| TestSafe | TestSafe Australia Safety Engineering, Testing and Certification Services |
| **Brazil** | |
| CEPEL | Centro De Pesquisas De Energia Electrica |
| **France** | |
| INERIS | Institut National De L'Environnemant Industriel Et Des Risques (INERIS) |
| **Germany** | |
| Dekra EXAM | |
| TÜV SÜD | |
| **Russia** | |
| GOSSTAND ART | Gosstandart of Russia |

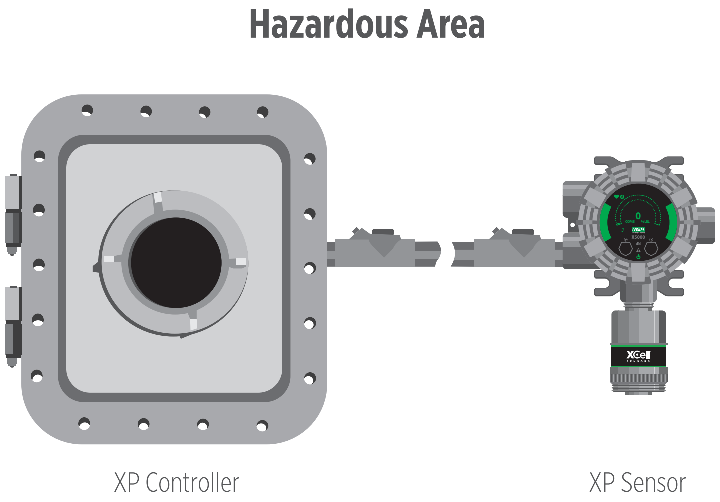
# Approvals

### System Installation

The gas detection system installation will depend on the area classification, protection technique, and wiring method. An example of this would be the installation of an explosion-proof infrared gas detector suitable for use in Class I, Division 1, Group A-D hazardous (classified) location with explosion-proof conduit. A different area classification, protection method, or wiring method might be chosen to save on installation costs.

### I. Explosion-proof (XP)

The device prevents an explosion in a hazardous location by containing any combustion within the device, and thereby preventing it from spreading into the atmosphere surrounding the enclosure.

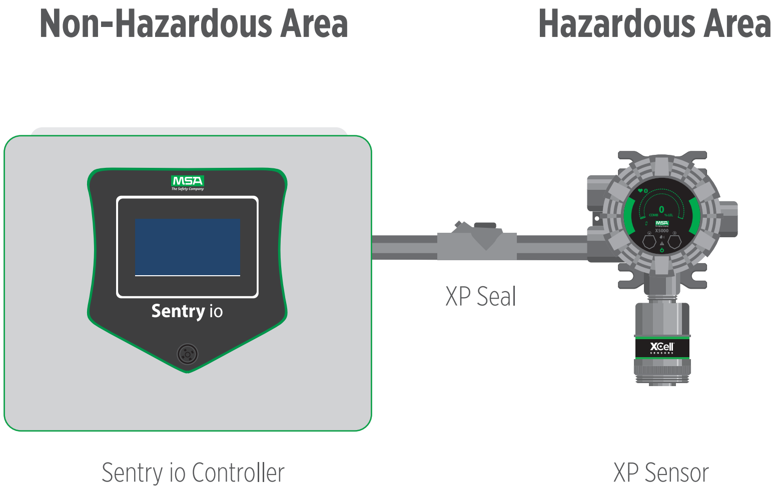


NOTE: *Typically the wiring installation is explosion-proof conduit although other wiring methods are possible per the US or Canadian electrical code.*

# Approvals

Instead of having both the sensor and the controller rated explosion-proof (XP), explosion-proof sensor housings are sometimes used with general purpose (GP) controllers that are located in non-hazardous locations.

- Widely used in US
- More costly to install and maintain
- Typically requires conduit and seals
- Non-intrusive calibration enhances installation
- If atmosphere ignites, it remains inside enclosure



# Approvals

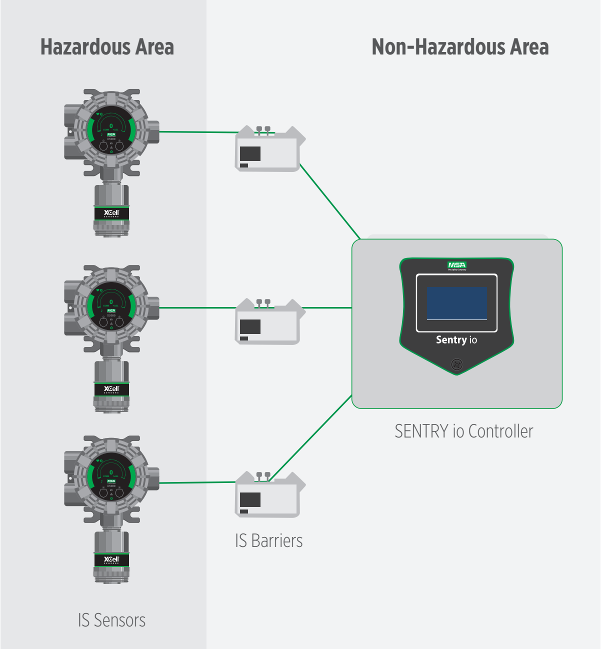
## II. Intrinsically Safe (IS)

The device prevents explosions in hazardous locations through an electrical design in which the possibility of ignition is eliminated.

To achieve this, protective components are often added in series with energy storage devices. The protective components eliminate the risk of ignition from sparks
or an increased component surface temperature.

In this situation, an intrinsically safe sensor assembly is located in the hazardous area and an intrinsically safe barrier is installed in the non-hazardous area to reduce the chance of an electrical spark reaching the hazardous area. If multiple sensors are required, then multiple barriers are used.

- Eliminates explosion-proof conduit for electrical safety
- Requires electrical barriers to limit energy to sensor
- Both heat and electrical energy are kept below ignition thresholds



# Approvals

### III. Purged/Pressurized

Purged/pressurized equipment cabinets containing spark-producing devices exclude flammable atmospheres. This is done by using compressed air or an inert gas such as nitrogen to pressurize the cabinet's interior. The unit is also designed to turn off the spark-producing device and trigger an alarm in the event of a pressurization failure. NFPA-496 contains specific design requirements for purged/pressurized equipment.

**There are three types of purging:**

- **Type X purging** – Reduces the classification within an enclosure from Division 1 to nonhazardous
- **Type Y purging** – Reduces the classification within an enclosure from Division 1 to Division 2
- **Type Z purging** – Reduces the classification within an enclosure from Division 2 to nonhazardous

When a purged/pressurized system is used, the unit is located in the hazardous area.
Purging/pressurization works in one of two ways: by either preventing outside atmospheres from entering the enclosed unit, or by removing flammable gases from the enclosure by flushing it with inert gas and maintaining internal pressure on the unit.

*NOTE: When installing a gas detection system, always install in accordance with the authority having jurisdiction and the manufacturer's installation instructions.*

The following labels provide examples of approval markings:

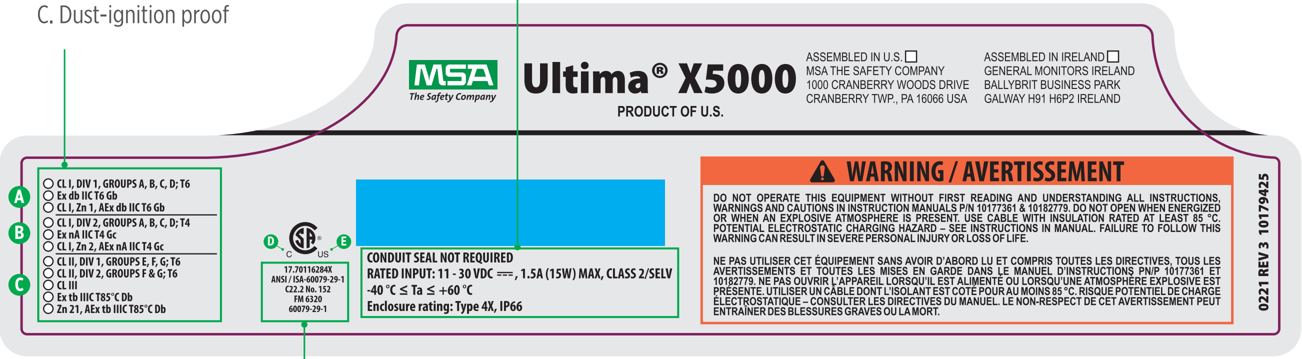
### Explosion-proof approval markings

A. Explosion-proof

B. Nonincendive

C. Dust-ignition proof

### Equipment Ratings



MSA
The Safety Company

**Ultima® X5000**

PRODUCT OF U.S.

ASSEMBLED IN U.S. ☐
MSA THE SAFETY COMPANY
1000 CRANBERRY WOODS DRIVE
CRANBERRY TWP., PA 16066 USA

ASSEMBLED IN IRELAND ☐
GENERAL MONITORS IRELAND
BALLYBRIT BUSINESS PARK
GALWAY H91 H6P2 IRELAND

○ CL I, DIV 1, GROUPS A, B, C, D; T6
○ Ex db IIC T6 Gb
○ CL I, Zn 1, AEx db IIC T6 Gb

○ CL I, DIV 2, GROUPS A, B, C, D; T4
○ Ex nA IIC T4 Gc
○ CL I, Zn 2, AEx nA IIC T4 Gc

○ CL II, DIV 1, GROUPS E, F, G; T6
○ CL II, DIV 2, GROUPS F & G; T6
○ CL III
○ Ex tb IIIC T85°C Db
○ Zn 21, AEx tb IIIC T85°C Db

17.70116284X
ANSI / ISA-60079-29-1
C22.2 No. 152
FM 6320
60079-29-1

CONDUIT SEAL NOT REQUIRED
RATED INPUT: 11 - 30 VDC ⎓ , 1.5A (15W) MAX, CLASS 2/SELV
-40 °C ≤ Ta ≤ +60 °C
Enclosure rating: Type 4X, IP66

**⚠ WARNING / AVERTISSEMENT**

DO NOT OPERATE THIS EQUIPMENT WITHOUT FIRST READING AND UNDERSTANDING ALL INSTRUCTIONS, WARNINGS AND CAUTIONS IN INSTRUCTION MANUALS P/N 10177361 & 10182779. DO NOT OPEN WHEN ENERGIZED OR WHEN AN EXPLOSIVE ATMOSPHERE IS PRESENT. USE CABLE WITH INSULATION RATED AT LEAST 85 °C. POTENTIAL ELECTROSTATIC CHARGING HAZARD – SEE INSTRUCTIONS IN MANUAL. FAILURE TO FOLLOW THIS WARNING CAN RESULT IN SEVERE PERSONAL INJURY OR LOSS OF LIFE.

NE PAS UTILISER CET ÉQUIPEMENT SANS AVOIR D'ABORD LU ET COMPRIS TOUTES LES DIRECTIVES, TOUS LES AVERTISSEMENTS ET TOUTES LES MISES EN GARDE DANS LE MANUEL D'INSTRUCTIONS PN/P 10177361 ET 10182779. NE PAS OUVRIR L'APPAREIL LORSQU'IL EST ALIMENTÉ OU LORSQU'UNE ATMOSPHÈRE EXPLOSIVE EST PRÉSENTE. UTILISER UN CÂBLE DONT L'ISOLANT EST COTÉ POUR AU MOINS 85 °C. RISQUE POTENTIEL DE CHARGE ÉLECTROSTATIQUE – CONSULTER LES DIRECTIVES DU MANUEL. LE NON-RESPECT DE CET AVERTISSEMENT PEUT ENTRAÎNER DES BLESSURES GRAVES OU LA MORT.

0221 REV 3 10179425

### Gas Performance Approvals

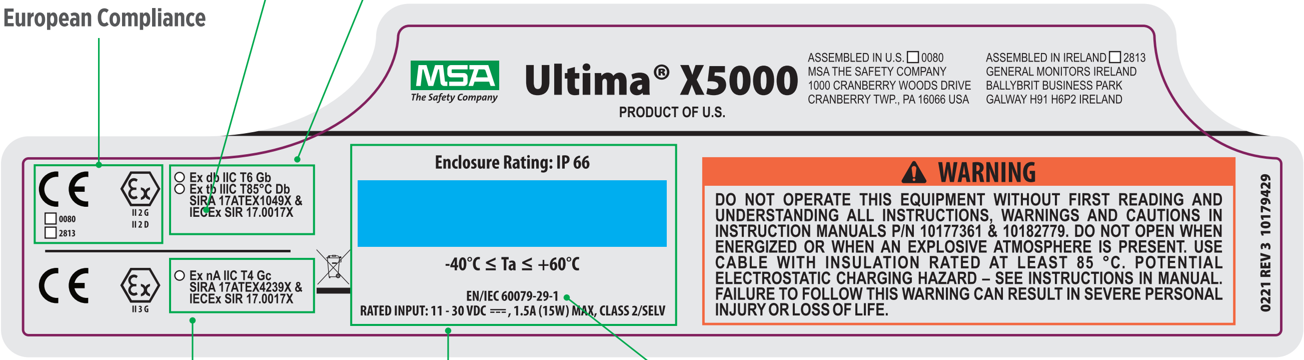
D. Canadian Standards Compliance

E. United States Standards Compliance

Flameproof and dust-ignition proof protection concepts

International Compliance

European Compliance



Ultima® X5000

PRODUCT OF U.S.

ASSEMBLED IN U.S. ☐ 0080
MSA THE SAFETY COMPANY
1000 CRANBERRY WOODS DRIVE
CRANBERRY TWP., PA 16066 USA

ASSEMBLED IN IRELAND ☐ 2813
GENERAL MONITORS IRELAND
BALLYBRIT BUSINESS PARK
GALWAY H91 H6P2 IRELAND

CE
☐ 0080
☐ 2813
II 2 G
II 2 D

○ Ex db IIC T6 Gb
○ Ex tb IIIC T85°C Db
SIRA 17ATEX1049X &
IECEx SIR 17.0017X

CE
II 3 G

○ Ex nA IIC T4 Gc
SIRA 17ATEX4239X &
IECEx SIR 17.0017X

Enclosure Rating: IP 66

-40°C ≤ Ta ≤ +60°C

EN/IEC 60079-29-1

RATED INPUT: 11 - 30 VDC ⎓, 1.5A (15W) MAX, CLASS 2/SELV

⚠ WARNING

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0221 REV 3 10179429

Non-sparking protection concept

Equipment Rating

Gas Performance Approval

# Safety Integrity Levels (SIL)

The global importance of SIL (Safety Integrity Levels) has grown substantially in the oil/gas, petrochemical, and other process industries over the last 20 years.

Functional Safety, as defined by IEC standard 61508, is the safety that control systems provide to an overall process or plant. Functional Safety is a term used to describe the safety system that is dependent on the correct functioning of the logic solver, sensors, and final elements to achieve a desired risk reduction level. Functional Safety is achieved when every safety function is successfully carried out and the process risk is reduced to the desired level.

A Safety Instrumented System (SIS) is designed to prevent or mitigate hazardous events by taking a process to a safe state when predetermined conditions are violated. Each SIS has one or more Safety Instrumented Functions (SIF). To perform its function, a SIF loop has a combination of logic solver(s), sensor(s), and final element(s). Every SIF within a SIS will have a SIL designation. These SIL designations may be the same, or may differ, depending on the process. It is a common misconception that an entire system must have the same SIL for each safety function.

A SIL is a measure of safety system performance, in terms of probability of failure on demand (PFD). This convention was chosen based on the numbers: it is easier to express the probability of failure rather than that of proper performance (e.g., 1 in 100,000 vs. 99,999 in 100,000). There are four discrete integrity levels associated with SIL: SIL 1, SIL 2, SIL 3, and SIL 4. The higher the SIL level, the higher the associated safety level, and the lower probability that a system will fail to perform properly.

| Safety Integrity Level | Risk Reduction Factor | Probability of Failure on Demand |
|---|---|---|
| SIL 4 | 100,000 to 10,000 | $10^{-5}$ to $10^{-4}$ |
| SIL 3 | 10,000 to 1,000 | $10^{-4}$ to $10^{-3}$ |
| SIL 2 | 1,000 to 100 | $10^{-3}$ to $10^{-2}$ |
| SIL 1 | 100 to 10 | $10^{-2}$ to $10^{-1}$ |

It is a very common misconception that individual products or components have SIL ratings. Rather, products and components are suitable for use within a given SIL environment, but are not individually SIL rated. SILs apply to safety functions and safety systems (SIFs and SISs). The logic solvers, sensors, and final elements are only suitable for use in specific SIL environments, and only the end user can ensure that the safety system is implemented correctly. The equipment or system must be used in the manner in which it was intended in order to successfully obtain the desired risk reduction level. Just buying SIL 2 or SIL 3 suitable components does not ensure a SIL 2 or SIL 3 system.

## Risk Management and Selecting a SIS or SIL Level

The identification of risk tolerance is subjective and site-specific. The owner/operator must determine the acceptable level of risk to personnel and capital assets based on company philosophy, insurance requirements, budgets, and a variety of other factors.
A risk level that one owner determines is tolerable may be unacceptable to another owner.

When determining whether a SIL 1, SIL 2, or SIL 3 system is needed, the first step is to conduct a Process Hazard Analysis to determine the functional safety need and identify the tolerable risk level. After all of the risk reduction and mitigation impacts from the Basic Process Control System (BPCS) and other layers of protection are taken into account, a user must compare the residual risk against their risk tolerance.
If there is still an unacceptably high level of risk, a risk reduction factor (RRF) is determined and a SIS/SIL requirement is calculated.
The RRF is the inverse of the Probability of Failure on Demand for the SIF/SIS (see table on previous page).

Selecting the appropriate SIL level must be done carefully. Typically in the process industry, companies accept SIS designs up to SIL 2.

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# Section 7

## Sensor Placement Guide

## Quantity and Placement of Sensors

MSA gas detection systems monitor the concentration of specified gases at the immediate location of the sensor. The installation instructions and other information from MSA provide only basic guidance on the properties of the gas in question, as well as the effects of certain environmental conditions on the function of the sensor. While this information may be used to help determine the number of sensors needed and the optimum sensor placement, do not rely on this information alone to determine the appropriate quantity and placement of the sensors for any particular site or area to be monitored.  It is recommended that the user consult with appropriate industrial hygiene, environmental, and/or health professionals when determining the quantity and placement of sensors to adequately monitor the specific area in question.

Such service is offered with MSA's fire and gas mapping solution (www.MSAsafety.com/gas-mapping) which assists in the evaluation of flame and gas risks within a process facility and reduces them towards an acceptable risk profile.

**WARNING: MSA gas detection systems monitor the gas concentration only at the immediate location of the sensor. The user must perform an appropriate environmental analysis on the specific installation site to determine the preferred quantity of sensors and optimum sensor placement. Improper installation can cause a gas release to be undetected and result in serious personal injury or loss of life.**

# Sensor Placement Guide

## MSA Guide to Gas Sensor Selection and Placement

**STEP 1:** To determine where to place sensors, perform an analysis of the potential gas hazards in your facility.

**STEP 2:** Create drawings indicating all potential leak sites, as well as the severity of each site's hazard potential.

**There are two main categories of hazardous locations:**

A. Potential gas discharge points. These are places where hazardous gases may be released, such as valve stem seals, gaskets, compression fittings, and expansion joints.

B. Potential contact areas. These are places where hazardous gases may endanger workers or damage equipment or property. Examples include populated areas, confined spaces, pits, stairwells, crawl spaces, shelters, and residential, business, and industrial environments located nearby.

**STEP 3:** Since gases do not always behave in the same way, take air flow conditions, as well as potential gas pockets, into consideration before placing sensors. MSA smoke tubes (P/N 458481) can be useful in measuring the direction and rate of air flow to determine areas where gases may accumulate.

## Sensor Placement Guide

**In general, when placing sensors, the following principles should be considered:**

- Place sensors in areas where the air currents are likely to produce the highest gas concentration, including areas where gas buildup is likely, such as corners or stopping points of moving devices that release gas.
- If you are attempting to take a representative room sample, do not place sensors near entrances or fresh air vents (because sample concentration will be diluted by incoming air) unless there is a need to sample that specific area of the room.
- Place sensors close to the possible gas/leak source.
- Place combustible gas sensors between the potential leak and the ignition source.
- Place toxic (and oxygen deficiency) sensors between the potential leak and the populated area, and in the workers' breathing zone.
- Consider ease of access to the sensor for maintenance requirements, such as periodic calibration. Use a remote sensor (fitted with an MSA remote calibration adapter, P/N 10179871) for high or inaccessible locations.
- Avoid mounting sensors near radio transmitters or other RFI-producing sources (e.g., welding activity and induction heaters), to reduce possible RFI interference.
- Avoid locations where airborne particles may coat or contaminate the sensor, such as paint booths.
- Install in a position that prevents water or dust accumulation on the sensor head (which may impede the diffusion of gas into the sensor). Preferred position is facing downward; horizontal placement is also acceptable.
- Facility air intakes are generally good locations for sensors.
- Ensure that the entire area in question is sufficiently monitored, including infrequently used areas such as closets, warehouses, and other storage areas.
- Factor in the vapor density of the monitored gases, when compared to air.

# Sensor Placement Guide

## Combustible Gas Sensors

- Hydrogen and methane are lighter than air, so place sensors near the ceiling, and in ceiling corners where pockets of air may collect.
- For electric motor monitoring, place sensors near the ignition source.
- Gasoline is heavier than air, so place sensors near – but not directly on – the floor.
- When monitoring multiple combustible gases, calibrate the instrument for the least sensitive gas.

## Toxic and Oxygen Gas Sensors

- Place carbon monoxide and carbon dioxide sensors for indoor air quality monitoring near air intake ducts.
- In general, in occupied areas (e.g., confined spaces), monitor for oxygen and toxic gases in the workers' breathing zone (4-6 feet). This will vary, depending on whether the density of the gas is heavier, the same as, or lighter than, air or oxygen.

## Toxic and Combustible Sensors

- Place sensors near the potential release source for process monitoring applications (e.g. pipelines, valves).
- Gas cylinder storage areas: If they are ventilated, place sensor near the return air vent.
- Acid/solvent drum storage areas: These gases are heavier than air (e.g., heavy hydrocarbons) so place sensors close to the ground and in corners where air may collect in pockets.
- If the hazard is outside, place sensors near the air intake for both combustible and toxic gas monitoring; if the hazard is inside, place sensors near the exhaust.
- Some gases may collect in pockets in room corners, at both floor and ceiling levels. Place sensors in these areas if necessary.

| Gases | Gas Density | Sensor Placement |
|---|---|---|
| Carbon dioxide, heavy hydrocarbons | Greater than air | Closer to the ground (6 inches above floor) |
| Hydrogen, methane | Less than air | Near the ceiling |
| Carbon monoxide, nitrogen | Similar to air | According to air current path, at or near breathing level (usually 4 to 6 ft. from floor) |

# Sensor Placement Guide

## Refrigerant Monitor Placement

- ASHRAE 15 states that a refrigerant monitor capable of detecting the TLV for a refrigerant gas must be installed in a mechanical equipment room.
- Place the end of the sample line in the location most likely to develop a refrigerant gas leak or spill. Such areas include valves, fittings, and the chiller itself. Also, monitor any refrigerant storage location. It is good practice to keep all sampling lines as short as possible when an aspirated or pumped sampling system is used.
- Since most refrigerant gases are heavier than air, monitor these gases close to the floor. Any pits, stairwells, or trenches are likely to fill with refrigerant gas before the main area. It may be necessary to monitor these locations for refrigerant gas.
- If ventilation exists in the chiller room, MSA smoke tubes (P/N 458481) will help to determine the most appropriate gas monitoring locations.
- Remote monitor displays can be placed just outside the doorway of the monitored area. Personnel can check the status of the instrument before entering the area.
- ASHRAE Standard 147P states the following:

  4.8 Refrigerant Monitor. On large refrigerating systems for which a refrigerant monitor is required per ASHRAE 15, a refrigerant monitor capable of detecting refrigerant concentrations of 1 ppm by volume or less shall be used to provide early warning of leaks.

## Guideline for Sensor Placement

When monitoring multiple combustible gases, calibrate the instrument for the least sensitive gas.

**Note:** *This is for informational purposes only and is intended for use as a general guide to important considerations in sensor placement. It is not intended to serve as an exhaustive review of all considerations. Due to the large number of variables present, each site should be considered individually by a trained professional. The services of a Certified Industrial Hygienist (CIH) or Certified Safety Professional (CSP) should be considered if an onsite survey is required.*

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# Section 8

## Calibration

# Calibration

### Instrument Calibration

Whether an instrument warns and/or alarms at the proper time depends on its ability to translate the quantity of gas it detects into an accurate reading. “Calibration” refers to an instrument’s measurement accuracy relative to a known concentration of gas. Gas detectors perform relative measurements: rather than independently assessing the quantity of gas present, they measure the concentration of the air sample and then compare it to the known concentration of the gas that the instrument is configured to sample. This “known concentration” serves as the instrument’s measurement scale, or reference point.

If the instrument’s reference point has moved, then its reading will also move. This is called “calibration drift”, and it happens to most instruments over time. (Common causes of calibration drift include the normal degradation of sensors, exposure of the sensor to poisons, and harsh operating conditions.) When an instrument experiences calibration drift, it can still measure the quantity of gas present, but it cannot convert it into an accurate numerical reading. Regular calibration with a certified standard gas concentration updates the instrument’s reference point, re-enabling it to produce accurate readings.

There are two methods of verifying instrument calibration: through a functional or “bump” test (or span check) or by performing a full calibration. Each is appropriate under certain conditions.

### Bump (or Span) Check

A bump check is a means of verifying the detector is capable of detecting gas, the display is functioning correctly and the sensor is measuring accurately, by exposing the instrument to a known concentration of test gas. The instrument reading is then compared to the actual concentration of gas present (as indicated on the cylinder). If the instrument’s response is within an acceptable range of the actual concentration, then its functionality and accuracy is verified. When performing a bump test, the test gas concentration should be high enough to trigger the instrument alarm. If the bump test results are not within the acceptable range, then a full calibration must be performed.

# Calibration

## Full Calibration

A full calibration is the adjustment of the instrument's reading to coincide with known concentrations (generally a certified standard) of zero and span gases, to compensate for calibration drift. In most cases, a full calibration is only necessary when an instrument does not pass the bump test or is outside of local regulations and/or the manufacturer's recommendations.

## Zero Check

A zero check is performed to verify that the instrument reads true zero (also referred to as the "baseline") in an environment in which no amount of target gas is present. Common situations in which a zero check is performed include:

- After exposure of the sensor to a sensor contaminant
- After the sensor has been exposed to a very high concentration of the target gas
- As the sensor ages, since it may gradually drift
- After the unit has operated in varying background conditions (e.g. humidity levels)
- After exposure to extreme conditions (e.g. high temperature or humidity)

If the instrument fails the zero check, then a zero adjustment should be performed to adjust to a true zero.

## Frequency of Calibration

The frequency of calibration depends on the sensor's operating time, conditions of use (including chemical exposure), and user experience with the instrument. New sensors should be calibrated more often until the calibration records prove sensor stability. The calibration frequency can then be reduced to the schedule set by the safety officer or plant manager. Before calibrating the sensors, it is good practice to apply power to the unit to allow the sensor to adapt to the new environment. Sensors should be powered at least one full hour before any calibration attempt is made.

The latest MSA $H_2S$ and CO electrochemical sensors with TruCal® and Diffusion Supervision technology (www.MSAsafety.com/trucal) allow for sensor calibrations to be extended up to 24 months. The automatic self-tests every 6 hours ensure accurate sensor measurements and self adjusts its sensitivity if it has drifted. It also checks if the sensor inlet is blocked, which would prevent gas from reaching the sensor.


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# Section 9

## Resources

# Resources:

*Code of Federal Regulations (CFR) Title 29 Part 1910*, U.S. Department of Labor (DOL), Occupational Safety and Health Administration (OSHA), Washington, D.C. Available online at: **www.osha.gov/laws-regs**

*NIOSH Pocket Guide to Chemical Hazards*, Department of Health and Human Services (DHHS), National Institute of Occupational Safety and Health (NIOSH), 85-114. Available online at: **www.cdc.gov/niosh/npg/**

*Occupational Health Guidelines for Chemical Hazards*, DHHS, DOL, Washington, D.C., 1995, DHHS (NIOSH) No. 81-123. Available online at: **www.cdc.gov/niosh/docs/81-123/**

*Fire Protection Guide to Hazardous Materials*, 14th edition,
National Fire Protection Association (NFPA)
One Battery Park, Quincy, MA 02269 (2010)
Available online at: **www.nfpa.org**

**Government Agencies**

Agency for Toxic Substances and Disease Registry (ATSDR) **www.atsdr.cdc.gov**

Bureau of Labor Statistics (BLS) **www.bls.gov**

Center for Disease Control and Prevention (CDC) **www.cdc.gov**

Code of Federal Regulations (CFR) **www.govinfo.gov/help/cfr**

Department of Transportation (DOT) Pipeline and Hazardous Materials Safety Administration **www.phmsa.dot.gov**

Federal Mine Safety and Health Review Commission **www.fmshrc.gov**

National Institute of Environmental Health Sciences **www.niehs.nih.gov**

National Institute for Occupational Safety and Health (NIOSH) **www.cdc.gov/niosh**

National Institute of Health (NIH) **www.nih.gov**

National Safety Council (NSC) **www.nsc.org**

Nuclear Regulatory Commission (NRC) **www.nrc.gov**

Occupational Safety and Health Administration (OSHA) **www.osha.gov**

Office for Mine Safety and Health Research **www.cdc.gov/niosh/mining**

U.S. Department of Health and Human Services (US DHHS) **www.hhs.gov**

U.S. Department of Labor, Mine Safety and Health Administration (MSHA) **www.msha.gov**

U.S. Environmental Protection Agency (EPA), Washington, D.C. **www.epa.gov**

# Resources:

## Professional and Trade Associations

Air and Waste Management Association **www.awma.org**

American Conference of Governmental Industrial Hygienists (ACGIH) **www.acgih.org**

American Industrial Hygiene Association (AIHA) **www.aiha.org**

American Society of Heating, Refrigerating and Air Conditioning Engineers **www.ashrae.org**

American Society of Safety Professionals (ASSP) **www.assp.org**

Board for Global EHS Credentialing (BGC) **www.gobgc.org**

Center for Chemical Process Safety, American Institute of Chemical Engineers **www.aiche.org/ccps**

Compressed Gas Association **www.cganet.com**

International Code Council (ICC) **www.iccsafe.org**

International Electrotechnical Commission (IEC) **www.iec.ch**

International Society for Measurement and Control (ISA) **www.isa.org**

National Fire Protection Association (NFPA) **www.nfpa.org**

National Safety Council (NSC) **www.nsc.org**

Society of Chemical Manufacturers & Affiliates **www.socma.org**

Water Environment Federation® (WEF) **www.wef.org**

World Health Organization (WHO) **www.who.int**

World Safety Organization **www.worldsafety.org**

## Approvals and Standards Organizations

American National Standards Institute (ANSI) **www.ansi.org**

CSA Group **www.csagroup.org**

European Electrotechnical Committee for Standardization (CENELEC) **www.cencenelec.eu**

National Electrical Manufacturers Association (NEMA) **www.nema.org**

UL Solutions **www.ul.com**

## Gas Detection Instrumentation Supplier

MSA – Safety **www.MSAsafety.com/detection**

The Safety Company

MSA operates in over 40 countries worldwide. To find an MSA office near you, please visit ***MSAsafety.com/offices***.

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