C9E-0020

RIKEN KEIKI

# Riken Sensors

# TECHNICAL OVERVIEW

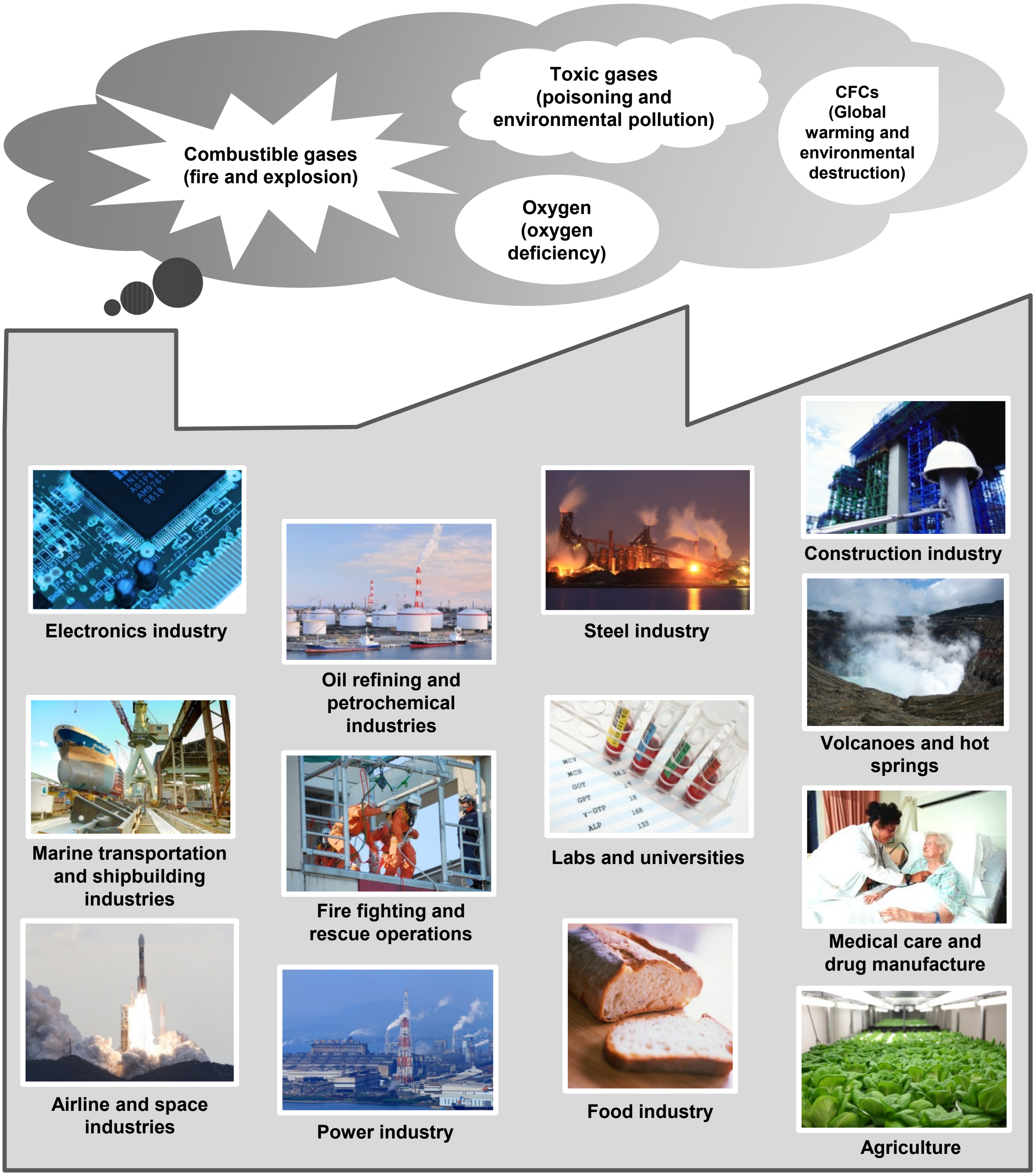
## Sensor Technology of Riken Provides the Basis of Reliability

**RIKEN KEIKI Co., Ltd.**

# Areas Where Gas Sensors Are Used

## Creating safe working environment for workers

Under the permanent theme of *Creating safe working environment for workers*, we are uniquely developing industrial-use gas detectors and sensors—devices that monitor, night and day, safety of work and equipment in sites where gas is used, produced, stored, or released, including semiconductor and liquid crystal factories, petrochemical complexes, ironworks, tankers, oil (storage) depots, underground gas facilities, and volcanoes. This booklet briefly describes the principles of the gas sensors used in gas detectors and the other products handled by our companies and other sensors handled by us in the past.



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Ionization Method Sensor*
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Ionization Tendency Electrode Method Sensor*
Geiger - Muller Counter*
Stress Detection Method Sensor*
Test Paper Type Photo-Electric Photometry Method Sensor (for Black Smoke)*
Opacimeter (Light - transmission Smoke Meter)*

## Appendix 34-36

Understanding Combustible and Toxic Gases
Understanding Particular High-pressure Gases, Oxygen, and Hydrogen Sulfide
List of Risks of Dangers of Combustible and Toxic Gases


Notes: The acronym inside each 【 】 is the prefix of the corresponding series of models.
The sensors with an asterisk (*) are not dealt in by us.

# Principles of Gas Sensors and Their Detectable Concentration

## Detectable gases (combustible gases)

| Page # | Category | Principles | Model* |
|---|---|---|---|
| 5 | Solid | Catalytic combustion Method | HW |
| 6 | | New Ceramic Catalytic Method | NC |
| 7 | | Semi-Conductor Method | SG |
| 8 | | Hot Wire Type Semi-Conductor Method | SH |
| 9 | | Thermal Conductivity Method | TE |
| 14,15 | Optical | Non-Dispersive Infrared Method | DE |
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| 18 | | Differential Optical Absorption Spectroscopy (DOAS) | - |
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| 24 | | Interference Enhanced Reflection Method (IER) | - |

## Detectable gases (toxic gases)

| Page # | Category | Principles | Model* |
|---|---|---|---|
| 7 | Solid | Semi-Conductor Method | SG |
| 8 | | Hot Wire Type Semi-Conductor Method | SH |
| 10 | Electrochemical | Potentiostatic Electrolysis Method | ES |
| 11 | | Membrane-Separated Electrode Method | ES-K |
| 13 | | Membrane-Covered Electrode Method | - |
| 14,15 | Optical | Non-Dispersive Infrared Method | DE |
| 17 | | Chemical Tape Method | FP |
| 19 | | Arc Ultraviolet Photo-electric Photometry Method | - |
| 21 | Other methods | Chemiluminescence Method | - |
| 22 | | Photo-Ionization Detector (PID) | - |
| 23 | | Pyrolysis-Particle Detection Method | SS |
| 24 | | Interference Enhanced Reflection (IER) Method | - |
| 25 | | Thermal Ionization Detector Method | - |
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## Detectable gases (oxygen)

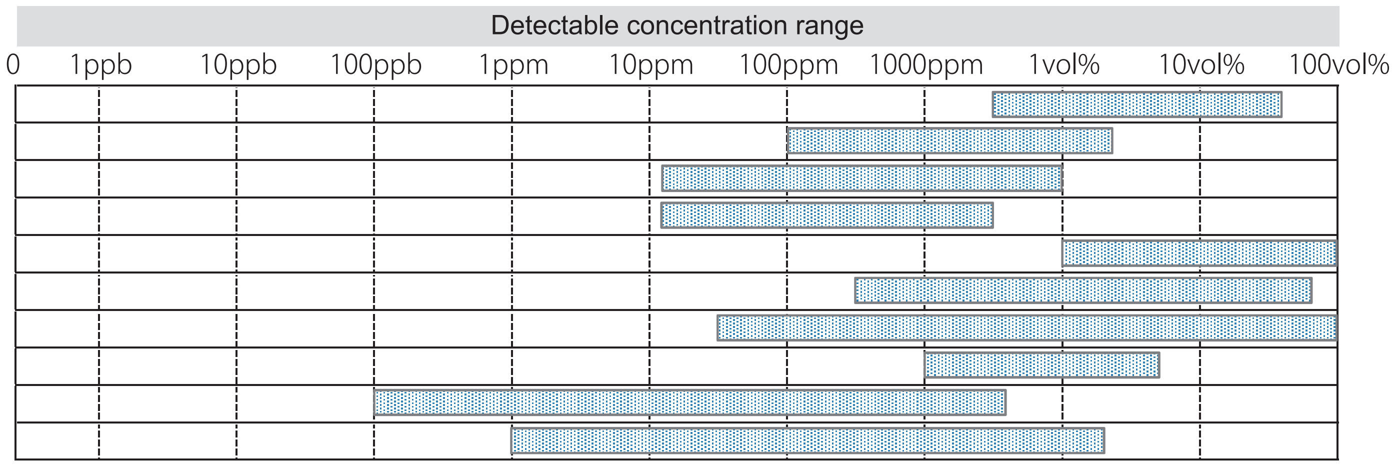
| Page # | Category | Principles | Model* |
|---|---|---|---|
| 12 | Electrochemical | Membrane Type Galvanic Cell Method | OS |
| 13 | | Zirconia Method | - |

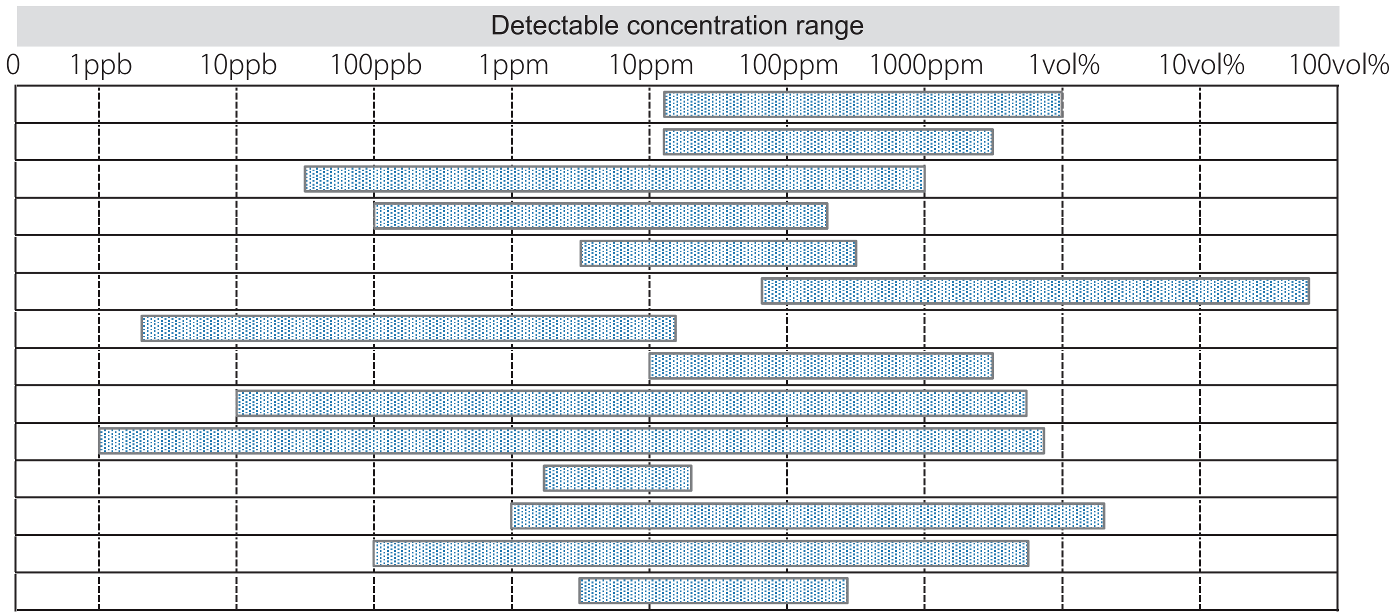
* If a hyphen (-) is indicated in the Principles column for a sensor, that sensor is not assigned a type or not manufactured by us.

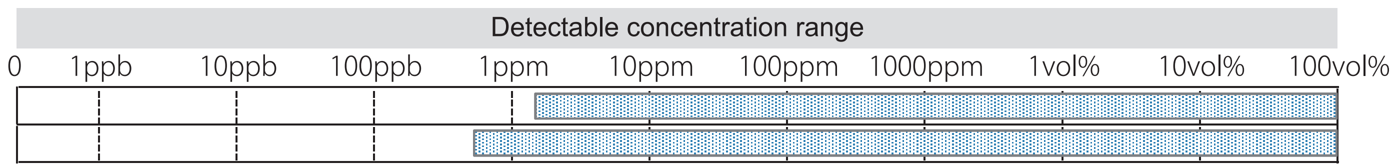
# Principles of Instruments That Are Not Gas Sensors

| Page# | Principles | Detectable object |
|---|---|---|
| 26 | X-ray diffractometer equipped with an X-ray fluorescence spectrometer | [Measurement of diffraction and fluorescent X rays] Corrosive compounds such as those used in cultural as sets and metal alloys |
| 27 | Open Counter for Low Energy Electron Counting Sensor | [Substance surface analysis] Work function, surface contamination, film thickness, etc. |
| 28 | Band Gap Analyzer | [Band gap measurement based on reflection spectrum] Powder and thin films |
| 29 | Flame Detector (Triple Infrared - Ultraviolet - Ultra violet and Infrared combined) | [Flame] Factories, plants, etc. |
| 30 | Ion-Selective Electrode Method Sensor | [Salt in solutions] Fresh concrete |
| | Ionization Tendency Electrode Method Sensor | [Oily water in the sea] Oil tanker, etc. |

# Ranges




| Page# | Principles | Detectable object |
|---|---|---|
| 31 | Photo Elasticity Method Sensor | [Internal stress of a transparency model] Design of machinery and civil engineering and construction |
| | Geiger - Muller Counter | [β, γ, and X rays] Measurement of surface contamination caused by radiation |
| 32 | Ionization Method Sensor | [γ and X rays] Exposure measurement in hospitals and laboratories |
| | Stress Detection Method Sensor | [Imbbalance in wheels] Automobiles and autobicycles |
| 33 | Test Paper Type Photo-Electric Photo metry Method Sensor (for Black Smoke) | [Black smoke from diesel engines] Diesel engine vehicles |
| | Opacimeter (Light - transmission Smoke Meter) | [Exhaust gas pollution] Vehicle emission |

# Catalytic Combustion Method Sensor: HW

Stationary sensor
Example: HW-6239

| Category | Detectable gas |
|---|---|
| Solid | Combustible |

## 1. Brief description

This sensor detects gas based on heat generated by combustible gas burning on an oxidation catalyst. It is the most widely used gas sensor designed specifically for combustible gases.

## 2. Structure and principles

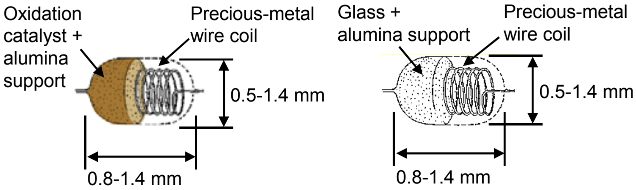
### [Structure]

This sensor consists of a detector element and a compensation element. The detector element consists of a coil of a precious-metal (e.g., platinum) wire and an oxidant catalyst—a substance active against combustible gas—sintered on the coil along with an alumina support. The element burns in reaction to any detectable gas. The compensation element consists of a coil of a precious-metal wire and glass—a substance inactive against combustible gas—sintered on the coil along with an alumina support. This element corrects the effect of the atmosphere.

### [Principles]

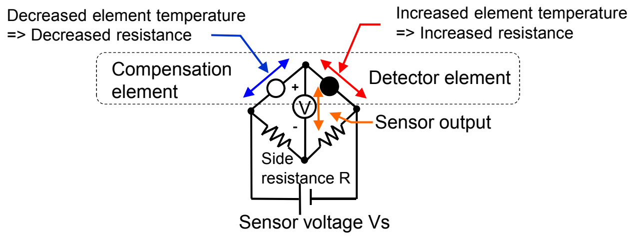
The precious-metal wire coil heats the detector element to 300℃ to 450℃. Then, a combustible gas burns on the surface of the detector element, increasing the temperature of the element. With changes in temperature, the precious-metal wire coil, a component of the element, changes in resistance. The resistance changes almost in proportion to the concentration of the gas. The bridge circuit shown in the right figure allows the sensor to recognize the change in resistance as the voltage to determine the concentration of the gas.

### [Conceptual rendering of the sensor elements]




Detector element Compensation element

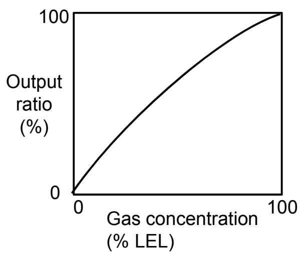
### [Bridge circuit]




## 3. Features (of the sensor HW-6239 as an example)

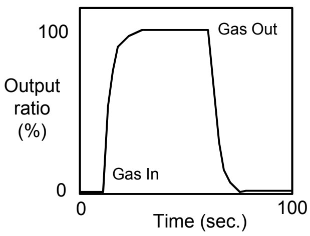
○ **Output characteristics**

The precious-metal wire coil, the heat source, linearly changes in temperature resistance coefficient. In the lower-explosion-limit (LEL) concentration region, the burning reaction is proportional to the gas concentration. In this region, the output from the sensor slowly changes according to the change in gas concentration.



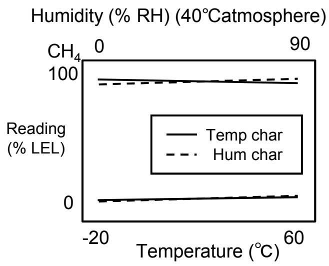

○ **Responsiveness**

The combustion heat produced on the surface of the detector element transfers to the precious-metal wire coil, changes the resistance of the bridge circuit, and then transforms into signals. With a high reaction rate, this sensor excels in responsiveness, accuracy, and reproducibility.




○ **Temperature and humidity characteristics**

The materials used in the elements have high electrical resistances and are less likely to be affected by the temperature and humidity in the use environment, allowing the reading to stay almost constant.




○ **Catalyst development**

The detector element uses a catalyst that promotes burning reaction. Having been developed in-house for gas sensors, this catalyst makes use of our proprietary know-how, providing long-term stability.

## 4. Detectable gas, molecular formula, model, and detection range (examples)

| Detectable gas | Molecular formula | Model # | Detection range |
|---|---|---|---|
| Combustible gases in general | - | HW-6211 | 0-100% LEL |
| Methane | $CH_4$ | HW-6239 | |
| Vinyl chloride | $C_2H_3Cl$ | HW-6214 | |
| High-boiler gases | - | HW-6228 | |

## 5. Products of this type (examples)

○ **Stationary products**

... GD-A80, GD-A80D, SD-1 (Type GP), SD-D58･DC (Type GP), SD-2500

○ **Portable products**

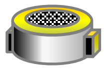
... GP-1000

SD-1 (Type GP)

# New Ceramic Catalytic Method Sensor: NC

Stationary sensor
Example: NC-6239

Portable sensor
Example: NC-6264AZP



## 1. Brief description

This sensor uses a ultra-atomized oxidant catalyst (a new ceramic) to detect gas in a wide range of concentrations from a low level (ppm) to the lower-explosion-limit (LEL). It is an epoch-making sensor independently developed by us as a sensor designed specifically for combustible gas.

| Category | Detectable gas |
|---|---|
| Solid | Combustible |

## 2. Structure and principles

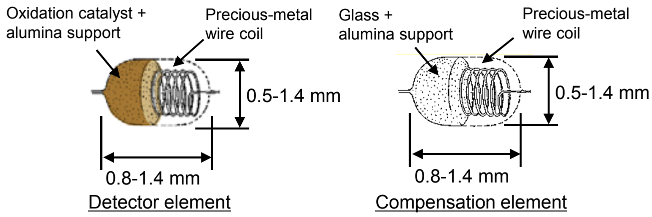
### [Structure]

A new ceramic-based sensor consists of a detector element and a compensation element (some models include no compensation element). The detector element consists of a coil of a precious-metal wire and a ultra-atomized oxidant catalyst (a new ceramic)—a catalyst active against combustible gas—sintered on the coil along with an alumina support. The element burns in reaction to any detectable gas. The compensation element consists of a coil of a precious-metal wire and glass—a substance inactive against combustible gas—sintered on the coil along with an alumina support. This element corrects the effect of the atmosphere.

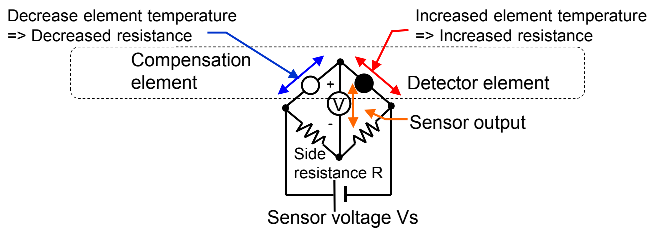
### [Principles]

The precious-metal wire coil heats the detector element to 300℃ to 450℃. Then, a combustible gas burns on the surface of the detector element, increasing the temperature of the element. With changes in temperature, the precious-metal wire coil, a component of the element, changes in resistance. The resistance changes almost in proportion to the concentration of the gas. The bridge circuit allows the sensor to recognize the change in resistance as the voltage to determine the concentration of the gas.

### [Conceptual rendering of the sensor elements]



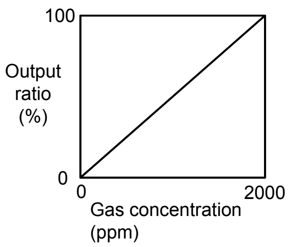

### [Bridge circuit]




## 3. Features(of the sensor NC-6239 as an example)

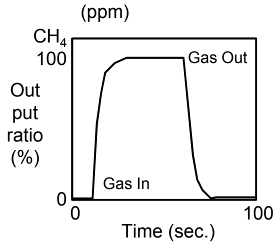
### ○ Output characteristics

The catalyst used in the detector element provides improved combustion reactivity. This efficiently produces combustion heat, allowing the sensor to detect lower concentrations (ppm) of gases undetectable by catalytic combustion-based sensors.



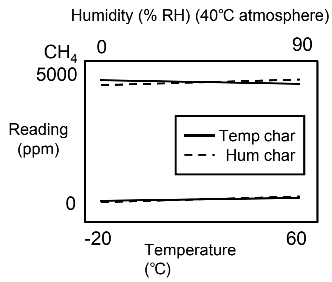

### ○ Responsiveness

The combustion heat produced on the surface of the detector element transfers to the precious-metal wire coil, changes the resistance of the bridge circuit, and then transforms into signals. With a high reaction rate, this sensor excels in responsiveness, accuracy, and reproducibility.




### ○Temperature and humidity characteristics

The materials used in the elements have high electrical resistances and less likely to be affected by the temperature and humidity in the use environment, allowing the reading to stay almost constant.




### ○ Detectable concentrations

The sensor detects a wide range of concentrations from low levels (ppm) to high levels (% LEL).

## 4. Detectable gas, molecular formula, model, and detection range (examples)

| Detectable gas | Molecular formula | Model # | Detection range |
|---|---|---|---|
| Combustible gases in general | - | NC-6211 | ppm level to 100% LEL |
| Methane | $CH_4$ | NC-6239 | |
| Vinyl chloride | $C_2H_3Cl$ | NC-6214 | |

## 5. Products of this type (examples)

### ○ Stationary products

... GD-A80, GD-A80D, SD-1 (Type NC), SD-D58･DC (Type NC)

### ○ Portable products

... GP-03, GX-2009, GX-2012, GX-8000

GX-2009

# Semi-Conductor Method
# Sensor: SG

Stationary sensor
Example: SG-8581

## 1. Brief description

This sensor uses a metal oxide semiconductor, which changes in resistance when it comes into contact with a detectable gas. The sensor detects this change in resistance as the gas concentration. It is a general-purpose sensor that detects all types of gases ranging from toxic gases to combustible gases.

| Category | Detectable gas |
|---|---|
| Solid | Combustible / Toxic |

## 2. Structure and principles

**[Structure]**

The sensor consists of a heater coil and a metal oxide semiconductor ($SnO_2$) formed on an alumina tube. The tube is equipped with two Au electrodes at its ends to measure the resistance of the semiconductor.

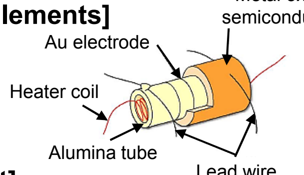
**[Principles]**

The heater coil heats the surface of the metal oxide semiconductor to 350 to 400°C. With atmospheric oxygen adsorbed on this surface in forms of $O^-$ and $O^{2-}$, the semiconductor keeps a constant resistance. Then, methane gas or the like comes into contact with the surface and becomes chemisorbed by it, which is in turn oxidized by $O^{2-}$ ions and separated. The reaction occurring on the surface of the sensor is represented as follows:

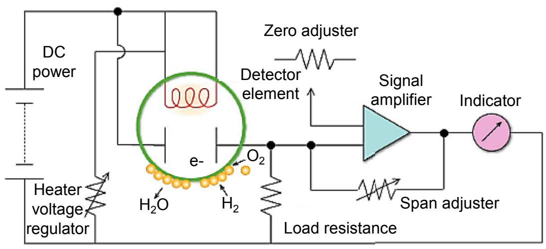
$$CH_4 + 4O^{2-} \rightarrow CO_2 + 2H_2O + 8e^-$$

In short, methane gas adsorbs on the surface of the sensor and takes the absorbed oxygen away; this increases free electrons inside the sensor, reducing the resistance. By measuring the change in resistance, the sensor determines the gas concentration.

**[Conceptual rendering of the sensor elements]**




**[Drive circuit]**



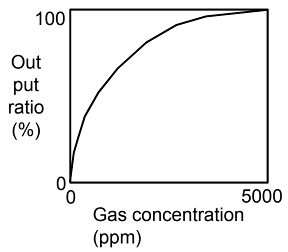

$$H_2 + O^{2-} \rightarrow H_2O + 2e^-$$

## 3. Features (of the sensor SG-8521 as an example)

### ○ Output characteristics

The sensor detects changes in the resistance of the semiconductor, meaning that it detects even low concentrations (ppm level) that cannot be detected by new ceramic-based sensors.

The sensor is highly sensitive with a high sensor output level for low concentrations.




### ○ Aging characteristics

The sensor maintains stability over the long term with a long life. Compared with the catalytic combustion-based sensor, this type sensor is highly resistant to toxicity and severe atmosphere.

### ○ Detection of toxic gases

Since, in principle, the resistance changes according to changes in the number of electrons and the electron mobility, the sensor detects a variety of gases, including toxic gases, which produce less combustion heat.

### ○ Gas selectivity

Adding an impurity to the semiconductor material changes the interference effect. This characteristic allows the sensor to selectively detect some gases.

## 4. Detectable gas, molecular formula, model, and detection range (examples)

| Detectable gas | Molecular formula | Model # | Detection range |
|---|---|---|---|
| Solvents Combustible gases in general | - | SG-8511 | 0-5000 ppm |
| | | SG-8521 | |
| Hydrogen | $H_2$ | SG-8541 | 0-200 ppm |
| Methane | $CH_4$ | SG-8581 | |

## 5. Products of this type (examples)

### ○ Stationary products

... GD-A80V, GD-A80DV, GD-70D, SD-1GH, SD-D58·DC·GH

GD-70D

# Hot Wire Type Semi-Conductor Method Sensor: SH



## 1. Brief description

This sensor uses a metal oxide semiconductor, which changes in resistance when it comes into contact with a detectable gas. The sensor detects this change in resistance as the gas concentration. It is a high-sensitivity gas sensor for low concentrations.

| Category | Detectable gas |
|---|---|
| Solid | Combustible / Toxic |

## 2. Structure and principles

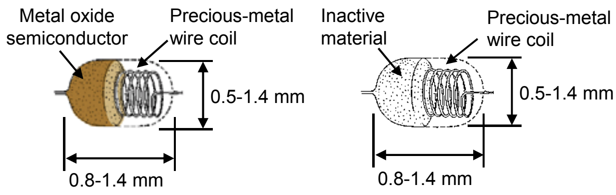
**[Structure]**

The sensor consists of a detector element, which consists of a coil of a precious-metal (e.g., platinum) wire and a metal oxide semiconductor sintered on the coil, and a compensation element with a material inactive against detectable gases sintered on it.

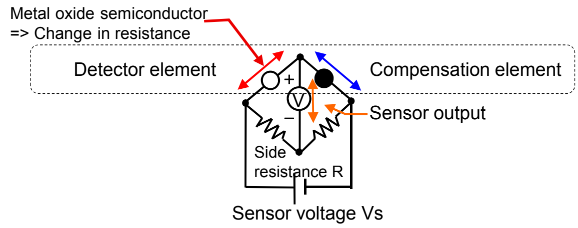
**[Principles]**

The resistance (R) of the detector element is the combined resistance of the resistance (RS) of the semiconductor and the resistance (RH) of the precious-metal wire coil. The detector element is heated 300℃ to 400℃ by the precious-metal wire coil and keeps a constant resistance. Then, methane gas or the like comes into contact with the detector element and separates the oxygen adsorbed on the surface of the metal oxide semiconductor. This increases the number of electrons that can freely move inside the semiconductor, reducing the resistance of the semiconductor. This results in the reduced resistance of the entire detector element. By allowing the bridge circuit to detect the change in resistance, the sensor determines the gas concentration.

**[Conceptual rendering of the sensor elements]**



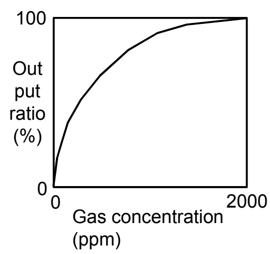

**[Bridge circuit]**




## 3. Features (of the sensor SH-8616 as an example)

**○ Output characteristics**

The sensor detects changes in the resistance of the semiconductor, meaning that it detects even low concentrations (ppm level) that cannot be detected by new ceramic-based sensors.
The sensor is highly sensitive with a high sensor output level for low concentrations.




**○ Aging characteristics**

The sensor maintains stability over the long term with a long life. Compared with the catalytic combustion-based sensor, this type sensor is highly resistant to toxicity and severe atmosphere.

**○ Miniaturization and power saving**

The precious-metal wire coil for the heater can be downsized to provide a smaller sensor that requires less power.

**○ Gas selectivity**

Adding an impurity to the metal oxide semiconductor changes the interference effect. This characteristic allows the sensor to selectively detect some gases.

## 4. Detectable gas, molecular formula, model, and detection range (examples)

| Detectable gas | Molecular formula | Model # | Detection range |
|---|---|---|---|
| Hydrogen | $H_2$ | SH-8612 | 0-2000 ppm |
| City gas | - | SH-8616 | |
| Combustible gases in general | - | SH-8616 | |
| | | SH-8639 | |
| | | SH-8640 | |
| | | SH-8641 | |

## 5. Products of this type (examples)

**○Stationary products**

... GD-A80S, GD-A80DS

**○Portable products**

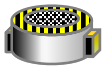
... SP-220, GX-2012GT

GX-2012GT

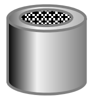
# Thermal Conductivity Method Sensor: TE

Stationary sensor
Example: TE-7559

Portable sensor
Example: TE-7561



Portable sensor
Example: TE-7515



## 1. Brief description

This sensor detects the difference in thermal conductivity to determine the gas concentration. It is a proven combustible gas sensor that effectively detects high-concentration gases.

| Category | Detectable gas |
|---|---|
| Solid | Combustible |

## 2. Structure and principles

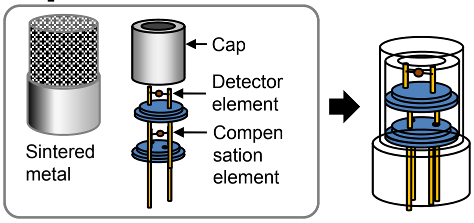
### [Structure]

This sensor consists of a detector element and a compensation element. The detector and compensation elements are available in two types: one consists of a coil of a platinum wire and a mixture of glass—a substance inactive against combustible gas—and an alumina support sintered on the coil and the other consists of a coil and an inactive metal or the like coated over the coil. The detector element is designed to allow detectable gases to contact it. The compensation element is enclosed so as not to allow any detectable gas to contact it.

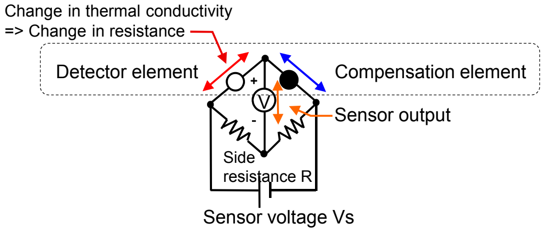
### [Principles]

The platinum wire coil heats the detector element to 200℃ to 500℃. Then, a detectable gas comes into contact with the detector element and changes the heat dissipation condition because of the gas-specific thermal conductivity, increasing the temperature of the detector element. With this change in temperature, the platinum wire coil, a component of the element, changes in resistance. The resistance changes almost in proportion to the concentration of the gas.
By allowing the bridge circuit to detect the change in resistance, the sensor determines the gas concentration.

### [Structure]



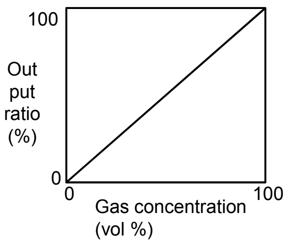

### [Bridge circuit]




## 3. Features (of the sensor TE-7559 as an example)

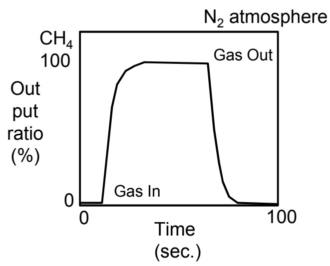
### ○ Output characteristics

Since the sensor detects changes in the resistance of the platinum wire coil, the output is almost proportional to the concentration until it reaches 100 volume percent. The sensor is suitable for detecting high-concentration gases.




### ○ Anoxic detection

Since the sensor detects changes in thermal conductivity, it can detect gases even under an anoxic atmosphere. However, it does not detect gases with a small difference in thermal conductivity with the reference gas.




### ○ Aging characteristics

The sensor physically detects changes in the thermal conductivity of gas, not involving a chemical reaction such as a combustion reaction. This means that it has noting to do with catalyst deterioration or poisoning, providing long-term stability.

### ○ Detection of incombustible gases

Since the sensor uses gas-specific thermal conductivity, it detects even incombustible gases with a large difference in thermal conductivity, such as high-concentration argon, nitrogen, and carbon dioxide.

## 4. Detectable gas, model, and detection range (examples)

| Detectable gas | Model # | Detection range |
|---|---|---|
| Combustible gases in general | TE-7515 | 0-100 vol % |
| | TE-7559 | |
| | TE-7560 | |
| | TE-7561 | |

## 5. Products of this type (examples)

### ○ Stationary products

... GD-A80N, GD-A80DN

### ○ Portable products

... GX-2012, GX-8000

GX-8000

# Potentiostatic Electrolysis Method Sensor: ES

Stationary sensor
Example: ES-23 series

Portable sensor
Example: ES-18 series

## 1. Brief description

This sensor electrolyzes detectable gas using an electrode with the potential kept constant to allow a current to be generated, and then measures the current to determine the gas concentration. It is the gas sensor most suitable for detecting toxic gases. You can specify a particular potential to detect a particular gas.

| Category | Detectable gas |
|---|---|
| Electrochemical | Toxic |

## 2. Structure and principles

**[Structure]**

The sensor is structured with an electrode (action electrode) —a gas-permeable film with a catalyst (e.g., gold or platinum) placed over it—along with reference and counter electrodes; these electrodes are housed in a plastic container filled with an electrolytic solution.

**[Principles]**

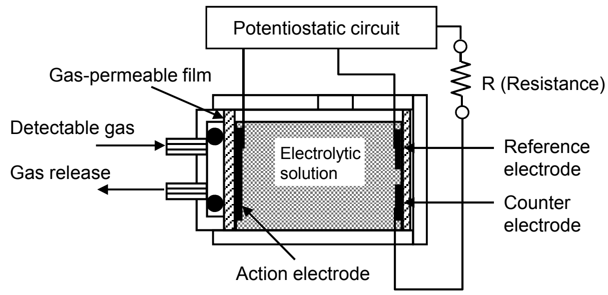
The sensor uses a potentiostatic circuit to keep the potential between the action and reference electrodes constant. The action electrode directly electrolyzes detectable gas. If the detectable gas is $H_2S$, the following reactions occur:

Action electrode: $H_2S + 4H_2O \rightarrow H_2SO_4 + 8H^+ + 8e^-$

Counter electrode: $2O_2 + 8H^+ + 8e- \rightarrow 4H_2O$

The current generated by the reactions is proportional to the gas concentration. By measuring the current that flows between the action and counter electrodes, the sensor determines the gas concentration.

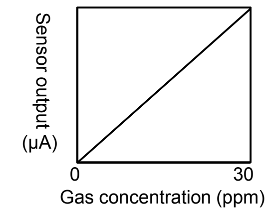
**[Structure]**




## 3. Features (of the sensor ES-237iF ($H_2S$ sensor) as an example)

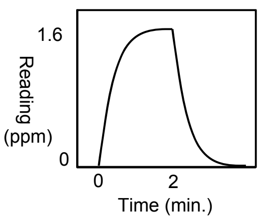
**○Output characteristics**

The gas concentration is proportional to the current value. The sensor outputs the current value without any change and the gas concentration is, therefore, proportional to the sensor output.




**○Responsiveness**

The response curve is as shown in the right figure.
The sensor makes gas react based on catalysis reaction to determine the current value.
Since $H_2S$ does not alter the electrode catalyst, the sensor excels in accuracy and reproducibility.

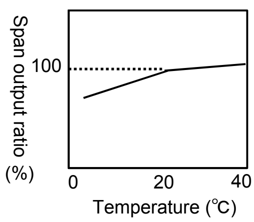



**○Aging characteristics**

For approximately two years, the sensor keeps its sensitivity at a level approximately 80% of the original level. Since humidity slightly affects the sensitivity, the reading may vary depending on the season.

**○ Temperature characteristics**

With almost stable readings at high temperatures, the sensor is likely to decrease its sensitivity with a decrease in temperature. Even at 0°C, the sensor maintains its sensitivity at a level not lower than 80%. By performing temperature corrections, it minimizes reading fluctuations.




## 4. Detectable gas, molecular formula, model, and detection range (examples)

| Detectable gas | Molecular formula | Model # | Detection range |
|---|---|---|---|
| Carbon monoxide | $CO$ | ES-23 | 0-75/150/300 ppm |
| | | ES-2031 | 0-150 ppm |
| Hydrogen sulfide | $H_2S$ | ES-237iF | 0-1/3/30 ppm |
| | | ES-1827iF | 0-3 ppm |
| Phosphine | $PH_3$ | ES-23DF | 0-1 ppm |

## 5. Products of this type (examples)

**○Stationary products**

... EC-600, GD-70D, SD-1EC

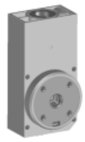
**○Portable products**

... CO-03, CO-FL1, GX-2009, GX-2012, GX-8000, HS-03, SC-01

CO-FL1

# Membrane-Separated Electrode Method Sensor: ES-K

Stationary sensor
Example: ES-K2 series



| Category | Detectable gas |
|---|---|
| Electrochemical | Toxic |

## 1. Brief description

Based on the principles of the potentiostatic electrolysis-based sensor, this sensor is structured with a gas-permeable film (separating membrane) and an action electrode completely separated from each other. It is a toxic gas sensor with an excellent selectivity.

## 2. Structure and principles

### [Structure]

The sensor is structured with an action electrode—a metal electrode with a gas-permeable film placed over it—along with reference and counter electrodes; these electrodes are housed in a plastic container filled with an electrolytic solution. Between the action electrode and the film is a very thin layer of an electrolytic solution.

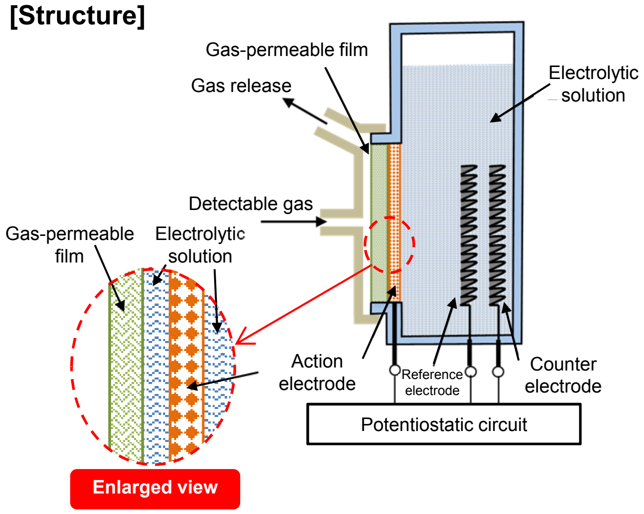
### [Principles]

A detectable gas passes through the gas-permeable film and reacts with ions in the electrolytic solution, which produces halogen. If the detectable gas is $Cl_2$, the following reaction occurs:

$$Cl_2 + 2I^- \rightarrow 2Cl^- + I_2$$

The $I_2$ generated by this reaction is reduced at the action electrode, causing a current to pass through the circuit. Since this current is proportional to the gas concentration, the sensor measures the current value to determine the gas concentration. Detectable gas reacts with the electrolytic solution before it reacts with the action electrode and therefore no interference occurs with gases that do not react with the electrolytic solution; this provides the sensor with an excellent selectivity.

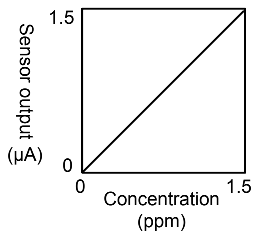
### [Structure]




## 3. Features (of the sensor ES-K233 ($Cl_2$ sensor) as an example)

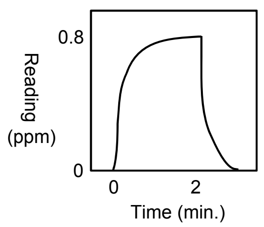
**○ Output characteristics**

The gas concentration is proportional to the current value. The sensor outputs the current value without any change and the gas concentration is, therefore, proportional to the sensor output.




**○ Responsiveness**

The sensor responds quickly. Since the electrodes or electrolytic solution is rarely corroded by $Cl_2$, the sensor excels in accuracy and reproducibility.

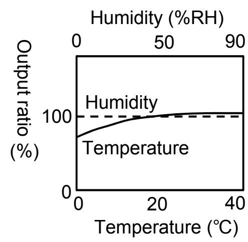



**○ Aging characteristics**

The sensor does not degrade in performance over time with almost no changes in output. If, however, the gas-permeable film is degraded in gas permeability due to a foreign matter adhering to it, this may lead to reduced output.

**○ Temperature and humidity characteristics**

High temperatures have almost no effect on the output while low temperatures are likely to reduce the output. Even at 0℃, the sensor maintains its sensitivity at a level not lower than 80%. By performing temperature corrections, it minimizes reading fluctuations. The output is not affected by humidity.




## 4. Detectable gas, molecular formula, model, and detection range (examples)

| Detectable gas | Molecular formula | Model # | Detection range |
|---|---|---|---|
| Chlorine | $Cl_2$ | ES-K233 | 0-1.5 ppm |
| Hydrogen fluoride | HF | | 0-9 ppm |
| Fluorine | $F_2$ | | 0-3 ppm |
| Chlorine trifluoride | $ClF_3$ | ESK-233C | 0-1 ppm |
| Ozone | $O_3$ | ES-K239C | |

## 5. Products of this type (examples)

**○ Stationary products**

... GD-70D

**○ Portable products**

... SC-8000, TP-70D

SC-8000

# Membrane Type Galvanic Cell Method Sensor: OS

Stationary sensor
Example: OS-B11

Portable sensor
Example: OS-BM2

| Category | Detectable gas |
|---|---|
| Electrochemical | Oxygen |

## 1. Brief description

This is a simple, traditional sensor based on the principles of cells. Requiring no external power supply, the sensor maintains stability over the long term.

## 2. Structure and principles

**[Structure]**
The sensor is structured with a cathode (precious metal) and anode (lead) placed in an electrolytic solution and with a separation membrane closely attached to the outside of the cathode. With the cathode and anode connected via a fixed resister, it outputs a voltage value.

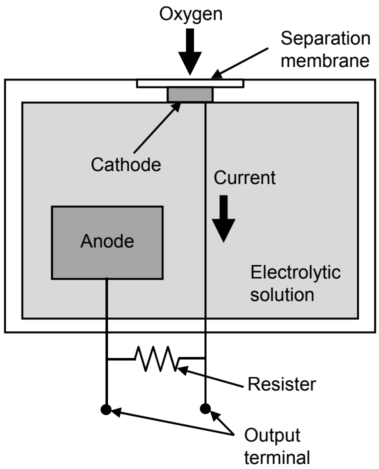
**[Principles]**
Oxygen passes through the separation membrane and becomes reduced at the cathode; at the same time, at the anode, lead dissolves into the electrolytic solution (becomes oxidized). At the electrodes, the following reactions occur:

Cathode: $O_2 + 2H_2O + 4e^- \rightarrow 4OH^-$

Anode: $2Pb \rightarrow 2Pb^{2+} + 4e^-$

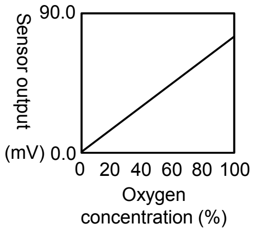
The current that flows because of the reduction reaction is converted into a voltage by the resister and then output from the output terminal. The sensor output is proportional to the oxygen concentration (partial pressure).

**[Structure]**

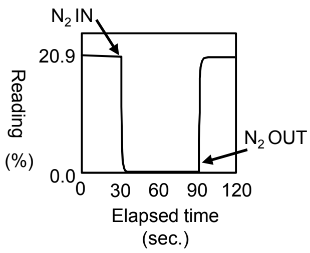



## 3. Features (of the sensor OS-B11 as an example)

○ **Output characteristics**
The oxygen concentration is proportional to the current value. The sensor converts the current value into a voltage value before outputting it and the oxygen concentration is, therefore, proportional to the sensor output in the range between 0 and 100%.

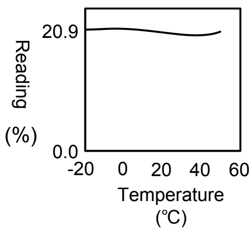



○ **Responsiveness**
With a high response speed, this sensor excels in accuracy and reproducibility.




○ **Aging characteristics**
With a long life, the sensor can be actually used for two to three years.

○ **Temperature and humidity characteristics**
The sensor uses a thermistor built in it to perform temperature compensation and therefore readings almost do not depend on temperature.




## 4. Detectable gas, molecular formula, model, and detection range (examples)

| Detectable gas | Molecular formula | Model # | Detection range |
|---|---|---|---|
| Oxygen | $O_2$ | OS-B11 | 0-25% |
| | | OS-BM1 | |
| | | OS-BM2 | |

## 5. Products of this type (examples)

○ **Stationary products**
... GD-70D, GD-F3A-A, GD-F4A-A, OX-600, SD-1OX

○ **Portable products**
... GX-2009, GX-2012, GX-8000 (TYPE $O_2$ L/N), OX-03, OX-07

OX-07

# Zirconia Method Sensor

| Category | Detectable gas |
|---|---|
| Electrochemical | Oxygen |

## 1. Brief description

This is an oxygen sensor that uses, as the solid electrolyte, zirconia, a stabilized substance that allows ions to flow in it in high temperature. It detects trace concentrations (ppm level) of oxygen present in inert gas.

## 2. Structure and principles

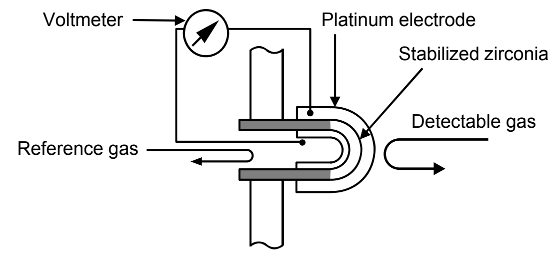
### [Structure]

The sensor consists of a cell unit—stabilized zirconia (zirconia stabilized by adding an oxide, such as calcium oxide (CaO) or yttrium oxide ($Y_2O_3$) , and then allowing its cubic crystals to cool to a low temperature until they are stable) equipped with porous platinum electrodes on both sides—and an electric oven for heating the cell unit to a certain high temperature.

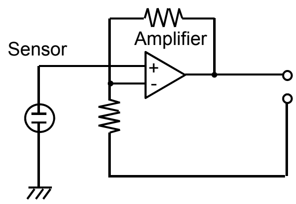
### [Principles]

Stabilized zirconia, a solid electrode, is heated to a certain high temperature and makes it easy for ions to move inside it; in other words, it increases oxygen ion conductivity. When a difference occurs in oxygen concentration between the inside and outside of the platinum electrodes attached to the stabilized zirconia, electromotive force is generated between the two electrodes, which act as an oxygen concentration cell. The sensor voltage is proportional to the logarithm of the oxygen concentration and the sensor, therefore, measures the sensor voltage to determine the oxygen concentration.

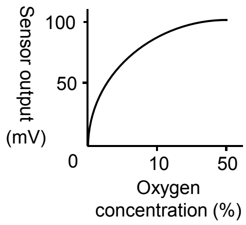
### [Structure]




### [Basic circuit]




### [Output characteristics]




# Membrane-Covered Electrode Method Sensor

| Category | Detectable gas |
|---|---|
| Electrochemical | Toxic |

## 1. Brief description

This sensor consists of a gas-permeable film (separation membrane) and an ion selective electrode (glass electrode). It uses a glass electrode for pH value measurement to detect ammonia and amine gases.

## 2. Structure and principles

### [Structure]

The sensor is structured with an ion-selective electrode, such as a pH electrode and a reference electrode placed in an internal liquid. The gas-permeable (plastic) film is in close contact with the ion-selective electrode.

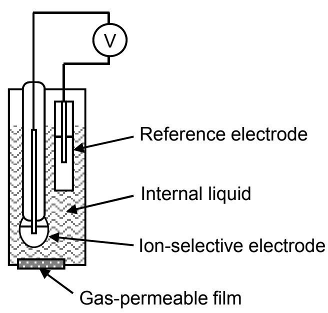
### [Principles]

Through the gas-permeable film, a detectable gas dissolves into the internal liquid. For a sensor for ammonia, for example, ammonia gas dissolves into the internal liquid to produce OH- (hydroxide ions) as follows:

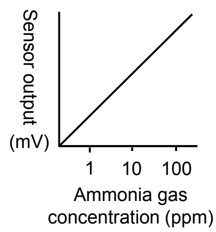
$$NH_3 + H_2O \rightarrow NH_4^+ + OH^-$$

The internal liquid alkalifies, causing a change in pH. The ion-selective electrode detects this change in pH of the internal liquid. Between the ion-selective electrode and reference electrode, electromotive force (voltage) is generated that is proportional to the logarithm of the ammonia gas concentration. The sensor measures this electromotive force to determine the gas concentration.

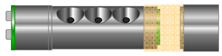
### [Structure]



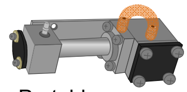

### [Basic circuit]



# Non-Dispersive Infrared Method
# Sensor: DE



Stationary sensor
Example: DE-3313-5



Portable sensor
Example: DE-3123-1

## 1. Brief description

Based on the fact that many gases absorb infrared rays, this sensor applies infrared light to the measurement cell to detect changes in infrared light caused by the absorption of a detectable gas. It seamlessly detects all infrared light in a particular wavelength range without separating (dispersing) infrared light on a wavelength basis.

| Category | Detectable gas |
|---|---|
| Optical | Combustible / Toxic |

## 2. Structure and principles

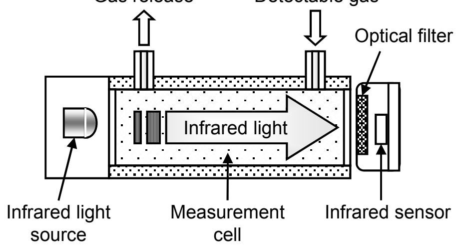
### [Structure]

This sensor is structured with an infrared light source and an infrared sensor, between which a measurement cell and an optical filter are placed. The infrared light source emits infrared light, which passes through the measurement cell and optical filter to be detected by the infrared sensor. The optical filter selectively allows the infrared wavelengths that the appropriate detectable gas absorbs to pass through it.

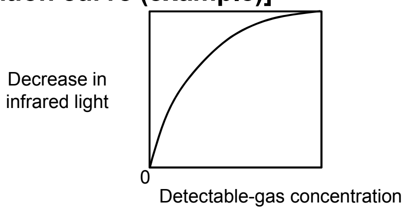
### [Principles]

A detectable gas enters the measurement cell and absorbs infrared light. This reduces the amount of infrared light detected by the infrared sensor. Some detectable gases where the concentrations are known are entered to determine the relationship (calibration curve) between the decrease in infrared light amount and the concentration of each detectable gas. When a detectable gas where the concentration is unknown is entered, the sensor uses the calibration curve based on the measured decrease in infrared light amount to determine the gas concentration.

**[Structure]**



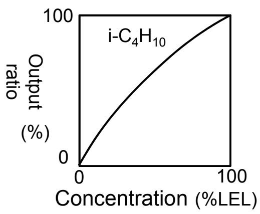

**[Calibration curve (example)]**




## 3. Features (of the sensor DE-3313-5 as an example)

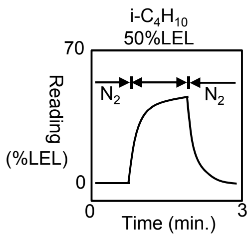
**○ Output characteristics**

The gas concentration and sensor output are not in proportional to each other but in a relationship as shown by the curve in the right figure. ($i$-$C_4H_{10}$: isobutane)




**○ Responsiveness**

When gas is supplied to the gas sensor at a constant flow rate, the sensor excellently reproduces responses.

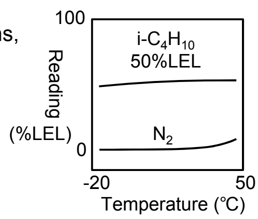



**○ Aging characteristics**

In an environment with small variations in temperature, the sensor remains stable without showing large deterioration in reading accuracy over time. Depending on the environment, the sensor may significantly deteriorate over time. If this is the case, you can minimize the deterioration by performing gas calibration every six months or so.

**○ Temperature and humidity characteristics**

By performing temperature corrections, you can minimize the dependency of readings on temperature within the specified temperature range.
When no condensation has formed inside the gas cell, the sensor is almost not affected by humidity.




## 4. Detectable gas, molecular formula, model, and detection range (examples)

| Detectable gas | Molecular formula | Model # | Detection range |
|---|---|---|---|
| HFC-134a | $C_2H_2F_4$ | DE-2113-35 | 0-5000 ppm |
| Methane tetrafluoride | $CF_4$ | DE-2113-42 | 0-500 ppm |
| Sulfur hexafluoride | $SF_6$ | DE-2113-43 | |
| Combustible gases in general | - | DE-3313-5 | 0-100% LEL |
| | | DE-3123-1 | 0-100% LEL<br>0-100 vol % |
| Carbon dioxide | $CO_2$ | DE-3313-13 | 0-2000 ppm<br>0-5000 ppm<br>0-10000 ppm |

## 5. Products of this type (examples)

**○ Stationary products**

... RI-257, SD-1RI

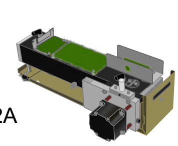
**○ Portable products**

... RX-8000, RX-8500, RX-8700, RI-557

RX-8000

# Non-Dispersive Infrared Method (Gas Filter Correlation Method) Sensor: DE

Stationary sensor
Example: DE-4416-2A



| Category | Detectable gas |
|---|---|
| Optical | Combustible / Toxic |

## 1. Brief description

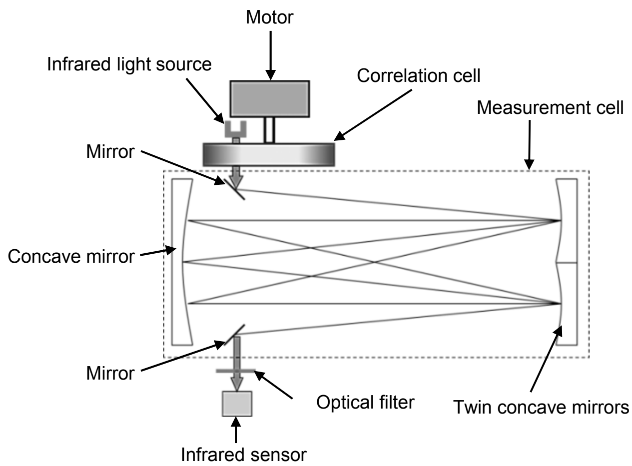
This is a high-performance infrared gas sensor featuring an optical structure—a structure with an infrared light source and an infrared sensor arranged at each end—that includes a correlation cell filled with a detectable gas and a gas that is not absorbed at the detected wavelength.

## 2. Structure and principles

**[Structure]**
The infrared light source emits infrared light, which passes through the correlation cell and then the measurement cell to be finally detected by the infrared sensor. The measurement cell is a multi-reflection cell (such as a white cell), which internally reflects light more than once. The correlation cell is divided into two rooms; one room is filled with a high concentration of detectable gas and the other with gas that is not absorbed at the detected wavelength (such as nitrogen).

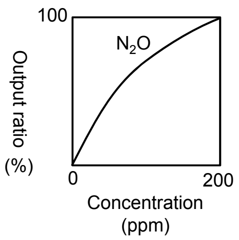
**[Principles]**
While the correlation cell rotates, infrared light enters this cell and alternately passes through the room filled with the detectable gas and the room with nitrogen and finally reaches the infrared sensor. Based on the difference (or ratio) between the infrared rays that alternately reach the infrared sensor, this sensor determines the gas concentration.

**[Structure]**

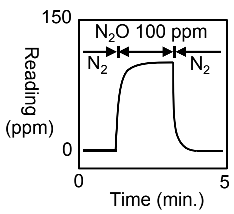



## 3. Features (of the sensor DE-4416-2A as an example)

**○ Output characteristics**
The gas concentration and sensor output are not in proportion to each other but in a relationship as shown by the curve in the right chart.
($N_2O$: nitrous oxide)

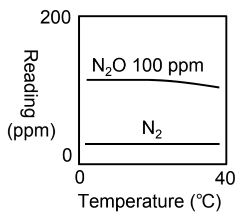



**○ Responsiveness**
When gas is supplied to the gas sensor at a constant flow rate, the sensor excellently reproduces responses.




**○ Aging characteristics**
In an environment with small variations in temperature, the sensor remains stable without showing large deterioration in reading accuracy over time. The detector equipped with this gas sensor comes standard with an auto-zero capability that further suppresses variations.

**○ Temperature and humidity characteristics**
The gas sensor is heated to a certain temperature to minimize the dependency of readings on temperature within the specified temperature range. The sensor unit is warmed at a certain temperature and therefore is less likely to cause condensation and is almost not affected by humidity.




## 4. Detectable gas, molecular formula, model, and detection range (examples)

| Detectable gas | Molecular formula | Model # | Detection range |
|---|---|---|---|
| Dinitrogen monoxide | $N_2O$ | DE-4416-2A | 0-200 ppm |

## 5. Products of this type (examples)

○ Stationary products
... RI-2000W, RI-2000R

RI-2000W

# Interferometer  Method Sensor: FI

Stationary sensor
Example: FI-23

| Category | Detectable gas |
|---|---|
| Optical | Combustible |

## 1. Brief description

This gas detector, one of the oldest gas sensors of ours, recognizes changes in the refractive index of gas. With a high accuracy, it maintains stability over the long term. In early times, it was used inside coal mines to measure the methane concentration and in recent years, it is widely used to measure solvent concentrations or heat quantities of fuel gases such as natural gas.

## 2. Structure and principles

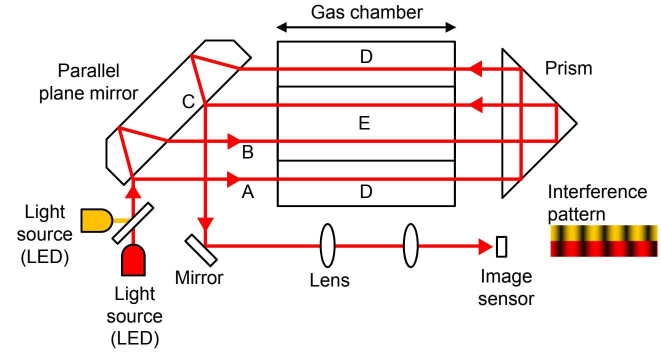
### [Structure]

The light source emits light, which is split by a parallel plane mirror into two light rays (A and B) and reflected by a prism. Ray A makes one round trip within the gas chamber, D, where the detectable gas flows, and ray B makes one round trip within the gas chamber, E, where the reference gas flows. The two light rays, A and B, meet each other at point C of the parallel plane mirror, and form an interference pattern on the image sensor through the mirror and lens.

### [Principles]

An interference pattern moves in proportion to the difference in the refractive index between the detectable gas and reference gas. The light wave interferometer-based sensor measures the distance the interference pattern has travelled to determine the refractive index of the detectable gas and convert it to a gas concentration or heat quantity.

**[Conceptual rendering of the sensor elements]**




## 3. Features

The travel distance of the interference pattern, Δθ, measured by this sensor is represented as the equation below:

$$\Delta\theta = \frac{2\pi L(n_{GAS} - n_{REF})}{\lambda} \times \frac{273.15}{T} \times \frac{P}{101.325}$$

$L$ : Gas chamber length
$n_{GAS}$ : Refractive index of the detectable gas
$n_{REF}$ : Refractive index of the reference gas
$\lambda$ : Light source wavelength
$T$ : Temperature
$P$ : Pressure

**○ Output characteristics**

Since the change in the refractive index is proportional to the change in gas concentration, the sensor provides a very high linearity.

**○ Responsiveness**

The sensor finishes measurement by completing the substitution within the gas chamber with a volume of 0.5 to 5 mL. Some models finish measurement in 5 to 10 seconds with a 90% response.

**○ Aging characteristics**

The most striking feature of this sensor is that it does not degrade in sensitivity. The sensitivity of the sensor depends only on the gas chamber length, L, and the light source wavelength, λ. Since both of these parameters are invariant, the sensor provides stable sensitivity over the long term. The optical element, even if soiled, does not affect the travel distance of the interference pattern; therefore, the sensor does not degrade in sensitivity so long as it can recognize the pattern.

**○ Pressure and temperature characteristics**

Although the refractive index of gas varies depending on the temperature, T, and pressure, P, the sensor measures the temperature and pressure to correct them and therefore is not affected by them.

## 4. Measurement type, detectable gas, molecular formula, and detection range (examples)

| Measurement type | Detectable gas | Molecular formula | Detection range |
|---|---|---|---|
| Purity measurement | Hydrogen | $H_2$ | 0-100 vol % |
| | Sulfur hexafluoride | $SF_6$ | |
| | Carbon dioxide | $CO_2$ | 99.50-100.00 vol % |
| Solvent concentration measurement | Toluene | $C_7H_8$ | 0-100% LEL |
| | Vinyl chloride | $C_2H_3Cl$ | |
| | Methyl ethyl ketone | $C_4H_8O$ | |
| Calorimetric measurement | Natural gas | - | 25-55 MJ/m$^3$ |
| | Propane air | - | 0-75 MJ/m$^3$ |
| | Butane air | - | 0-70 MJ/m$^3$ |

## 5. Products of this type (examples)

**○ Stationary products**

... FI-800, FI-815A

**○ Portable products**

... FI-8000

FI-800

# Chemical Tape Method Sensor: FP

Stationary tape
Example: FCL-002E

| Category | Detectable gas |
|---|---|
| Optical | Toxic |

## 1. Brief description

This sensor uses cellulose tape impregnated with a color former. It lets detectable gas enter this tape by allowing it to pass through it or diffuse into it. The sensor electrically measures reflected light based on the tape color caused by the reaction between the color former and detectable gas to quantitatively recognize a very low concentrations of toxic gas.

## 2. Structure and principles

**[Structure]**

The sensor has a gas chamber that lets in detectable gas. This chamber is a light-resistant container that is internally arranged and housed so that the light source and light-receiving section can recognize the tape color. The sensor consists of this gas chamber and other components such as a reel mechanism for rewinding tape after each measurement.

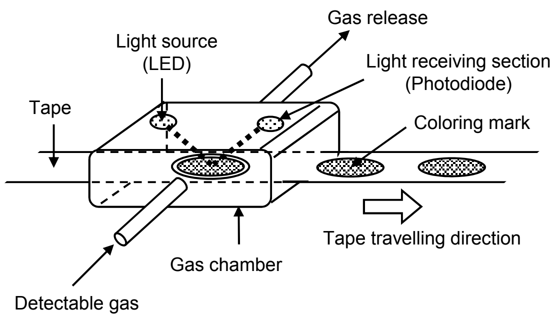
**[Principles]**

When a detectable gas comes in contact with the tape impregnated with a color former, a chemical reaction occurs, causing the tape to color. For example, if phosphine ($PH_3$) comes into contact with the tape, silver colloid is produced as shown in the formula below, causing a coloring mark to appear on the white tape.

$$PH_3 + AgClO_4 \rightarrow Ag + H_3PO_4 + 1/2\ Cl_2$$

The sensor applies light to the spot on the tape that has colored to determine the change in reflected light intensity before and after the entry of the detectable gas; thus it accurately quantifies the gas concentration.

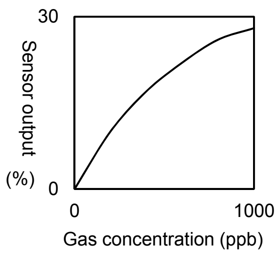
**[Structure]**




## 3. Features (of the sensors FP-300 and FCL-002E ($PH_3$) as examples)

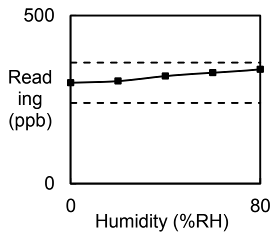
**○Output characteristics**

When a detectable gas enters the detection section, the tape starts to color and the output gradually increases. Since the sensor determines changes in color, the output forms a curve.




**○Temperature and humidity characteristics**

For $PH_3$, the tape-based sensors FP-300 or FCL-002E does not depend on temperature. Without greatly depending on humidity as well, this sensor provides accurate reading within the operating temperature and humidity ranges.




**○Aging characteristics**

Continuous running tests on the sensor indicate that with no deterioration in gas sensitivity, it provides stable measurement.

**○ Features of the tape-based sensor**

- Very high sensitivity with excellent selectivity
- Use of cassette tape, which is easy to replace
- Tape feed on a per-measurement basis, which allows no hysteresis
- Coloring caused by detectable gas accumulates on the tape, which allows for detection of very low concentrations of gas

## 4. Detectable gas, molecular formula, model, and detection range (examples*)

| Detectable gas | Molecular formula | Model # | Detection range |
|---|---|---|---|
| Arsine | $AsH_3$ | FCL-001 | 0-15/150 ppb |
| Hydrogen selenide | $H_2Se$ | | 0-200 ppb |
| Formaldehyde | HCHO | FCL-018 | 0-0.5/1/5 ppm |
| Phosphine | $PH_3$ | FCL-002E | 0-900 ppb |
| Diborane | $B_2H_6$ | | 0-300 ppb |
| Silane | $SiH_4$ | | 0-15 ppm |
| Disilane | $Si_2H_6$ | | 0-10 ppm |

* Tape FP-300 used as an example

## 5. Products of this type (examples)

○ Stationary products
... FP-300, FP-301

FP-300

# Differential Optical Absorption Spectroscopy (DOAS)

## 1. Brief description

Differential optical absorption spectroscopy (DOAS) measures gas concentrations based on the fact that the light of a wavelength that is absorbed depends on the type of gas. This method is used in open-path gas detectors.

| Category | Detectable gas |
|---|---|
| Optical | Combustible |

## 2. Structure and principles

**[Structure]**

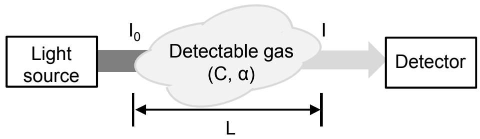
The sensor consists of a light source and detector unit to detect gas existing between them. The detector unit includes an optical filter and spectroscopes that allow only light of specific wavelengths to pass though it; the sensor thus detects only specific types of gases.

**[Principles]**

The light source emits light. Before it reaches the detector, gas absorbs a certain wavelength of the light, which is determined by the type of gas. The sensor determines the difference between the light in the presence and absence of the gas to calculate the gas concentration. The light intensities before and after the light absorption by gas are expressed by Lambert-Beer's equation:

$I = I_0 \exp(-\alpha CL)$ (1)

$I_0$ : Infrared intensity before light passes through gas
$I$ : Infrared intensity after light has passed through gas
$\alpha$ : Gas-specific absorption coefficient
$C$ : Gas concentration
$L$ : Hume length: L




Based on the above, the sensor measures the infrared intensities before and after transmission of gas to detect a certain gas if the target gas is specific.

## 3. Features

According to Equation (1), for an open-path gas detector based on differential optical absorption spectroscopy, the following equation holds:

$$CL = (1/\alpha) \ln (I_0 / I) \quad (2)$$

The sensor outputs the product of the length of fume-like gas and gas concentration to detect gas.

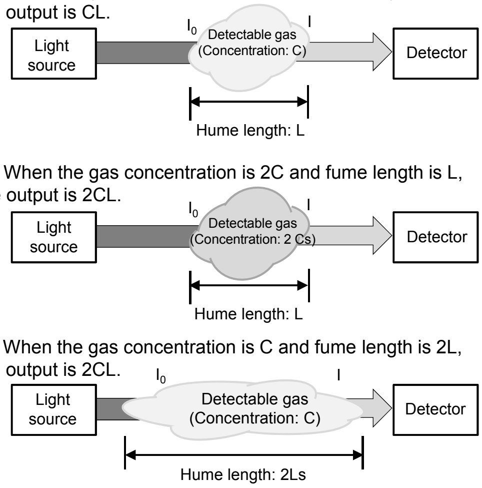
Detector output (LEL.m) = length of fume-like gas (m) x gas concentration (% LEL)

### ○ Gas concentration characteristics

When the length of the fume-like gas remains unchanged, the higher the gas concentration, the larger the detector output. Compared with (1) in the right figure, for (2), the fume length is the same but the gas concentration is twice and therefor the output is twice.

### ○ Gas range characteristics

When the gas concentration remains unchanged, the longer the fume-like gas length, the larger the detector output. Compared with (1) in the right figure, for (3), the gas concentration is the same but the fume length is twice, and therefor the output is twice.




## 4. Detectable gas and detection range (example*)

| Detectable gas | Detection range |
|---|---|
| Combustible gases in general (C1 to C8) | 0-5 LEL-m (Methane and propane) |

* The sensor SafEye Quaser is used as an example.

## 5. Products of this type (examples)

### ○ Stationary products

... SafEye Quaser 900

SafEye Quaser 900

# Arc Ultraviolet Photo-electric Photometry Method Sensor

| Category | Detectable gas |
|---|---|
| Optical | Toxic |

## 1. Brief description

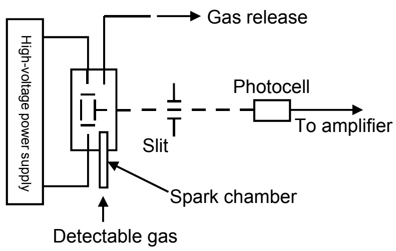
This sensor uses ultraviolet luminescence caused by arc discharge to detect halides (such as CFCs, trichloroethylene, perchloroethylene, carbon tetrachloride, methyl chloride, and methylene chloride).

## 2. Structure and principles

**[Structure]**

The sensor consists of a spark chamber (designed to intensify the ultraviolet luminescence when a halide exists in it), a high-voltage power supply (for regulating the voltage of the spark chamber), and a photocell (for detecting changes in ultraviolet intensity).

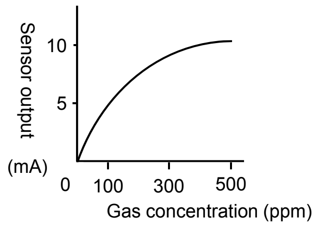
**[Structure]**




**[Principles]**

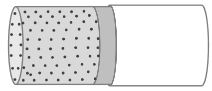
The spark chamber where the voltage is regulated by the high-voltage power supply arcs in the atmosphere. With this arc discharge, nitrogen dioxide ($NO_2$) and ozone ($O_3$) cause ultraviolet light to be generated. When a halide has entered the spark chamber, the ultraviolet light from $NO_2$ and $O_3$ is intensified. The photocell detects the increase in light to determine the gas concentration.

**[Output characteristics]**



# Flame Ionization Detector (FID)

Portable sensor
Example: FI-20



## 1. Brief description

This gas sensor ionizes molecules of a gas such as hydrocarbon in hydrogen flames to determine the amount of hydrocarbon.

| Category | Detectable gas |
|---|---|
| Other methods | Combustible |

## 2. Structure and principles

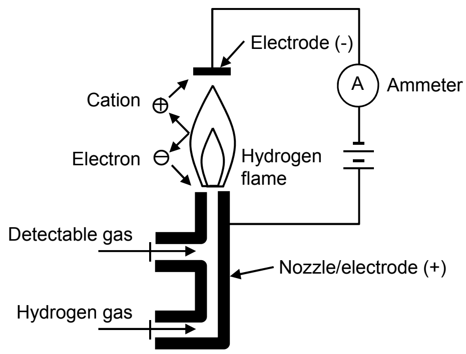
**[Structure]**

The sensor consists of a nozzle for generating hydrogen flames and electrodes for detecting ion currents.

**[Principles]**

Hydrocarbon, such as methane or alcohol, along with hydrogen gas is transferred to the nozzle, where it is thermally decomposed in high-temperature flames into carbon and hydrogen. Then, carbon is broken by heat into cations and electrons, which are drawn by the electrode with a voltage applied to it, generating a current.
The current is proportional to the quantity of cations, namely the concentration of hydrocarbon, and the sensor, therefore, can determine the gas concentration from the current. The output is almost proportional to the number of carbon atoms (e.g., hexane ($C_6H_{14}$) exhibits sensitivity six times higher than methane ($CH_4$)) and is highly sensitive to hydrocarbon in general; the sensor thus can be used to measure total volatile organic compounds (TVOC). The detection principles of the FID are recognized as an official method of measuring volatile organic compounds (JIS B7989).

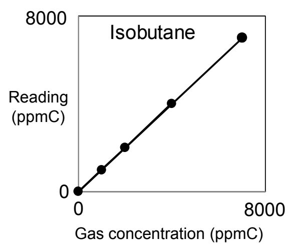
**[Structure]**




## 3. Features (of the sensor GL-103 as an example)

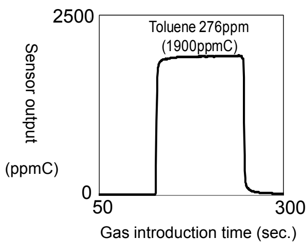
**○ Output characteristics**

The output from the sensor, which is proportional to the carbon number concentration of the detectable gas, is expressed in ppmC value. The output exhibits a high linearity in the measured concentration range.




**○ Responsiveness**

The sensor exhibits a response time as fast as a few seconds along with an excellent reproducibility.



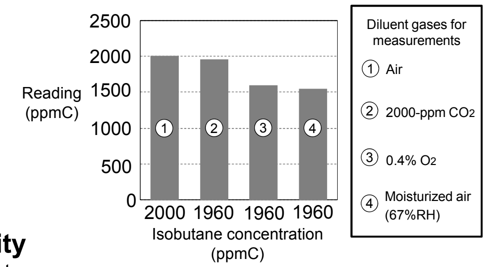

**○ Interference resistance**

For measurement in low-oxygen air or in a high-humidity environment, the sensor output decreases approximately 20% but is not affected by carbon dioxide.

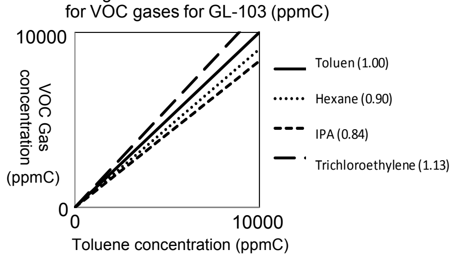
**○ Relative sensitivity**

For hydrocarbon, the output increases in proportion to the carbon number. Compared with linear saturated hydrocarbon, oxygenated compounds exhibit an approximately 20% lower sensitivity and halocarbon, ar approximately 20% higher sensitivity.

Environmental dependency of measurement




Reference gas toluene for the conversion chart for VOC gases for GL-103 (ppmC)




## 4. Detectable gas, model, and detection range (examples)

| Detectable gas | Model # | Detection range |
|---|---|---|
| Hydrogen gases in the air (e.g., 13A and 6B) | FI-20 | 0-100/1000/ 10000 ppmC ( Methane equivalent values) |

## 5. Products of this type (examples)

**○Portable products**

... GL-103A

# Chemiluminescence Method

## 1. Brief description

This gas sensor is based on light emission—chemiluminescence caused by mixture of a detectable gas (such as nitrogen monoxide or arsine) and ozone (chemiluminescence is energy emitted as light by molecules excited by the chemical reaction when they return to the ground state).

| Category | Detectable gas |
|---|---|
| Other methods | Toxic |

## 2. Structure and principles

### [Structure]

This sensor consists of a reaction tank for letting detectable gas react with ozone, a photomultiplier for measuring the quantity of light emitted when a detectable gas reacts with ozone, an ozone generator, and other components.

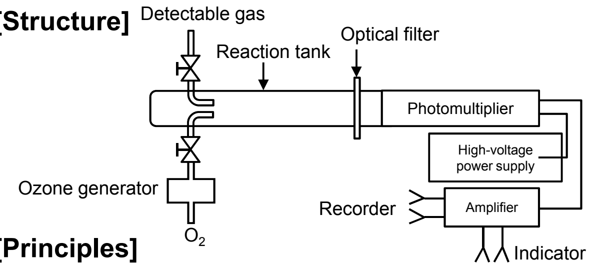
### [Principles]

In the reaction tank, the detectable gas reacts with the ozone ($O_3$) generated by the ozone generator. Shown below is an example of a chemical reaction caused by nitrogen monoxide (NO).

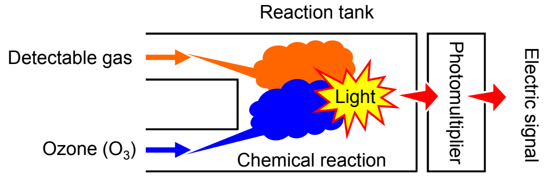
$$NO + O_3 \rightarrow NO_2^* + O_2 \qquad NO_2^* \rightarrow NO_2 + h\nu$$

In this chemical reaction, ozone excites the detectable gas, which emits light when it returns to a stable state. The quantity of light emitted is proportional to the concentration of the detectable gas. The photomultiplier measures the quantity of light to determine the gas concentration.

**[Structure]**



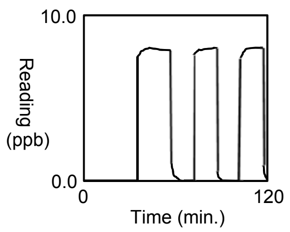

**[Principles]**




## 3. Features (of the arsine sensor GL-400 as an example)

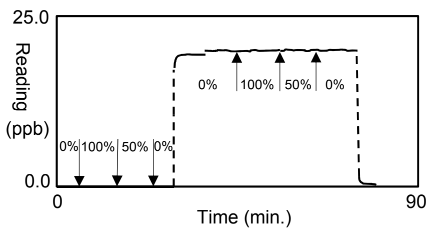
**○ Reproducibility**

The photomultiplier measures with an excellent reproducibility the quantity of light emitted when the detectable gas (arsine) reacts with ozone.



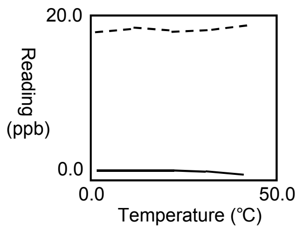

**○ Humidity characteristics**

Changes in humidity in the use environment hardly affect the reading.




**○ Temperature characteristics**

Changes in temperature in the use environment hardly affect the reading.




**○ Interference resistance**

The light emitted when the detectable gas chemically reacts with ozone is selected by the optical filter and hence the sensor is less likely to be interfered with by other gases, providing stable measurement.

## 4. Detectable gas, molecular formula, and detection range (examples)

| Detectable gas | Molecular formula | Detection range |
|---|---|---|
| Arsine | $AsH_3$ | 0-15 ppb |
| Nitrogen monoxide | NO | 0-5/5000 ppm |
| Nitrogen dioxide | $NO_2$ | |
| Nitrogen oxides | NOx | |

## 5. Products of this type (examples)

**○Stationary products**

... CL-400, T200H

CL-400

# Photo-Ionization Detector (PID)

## 1. Brief description

This gas sensor applies ultraviolet light to the detectable gas to ionize it. This causes an ion current to be generated. The sensor measures this current to determine the gas concentration. It detects a wide range of gases, irrespective of whether they are organic or inorganic. It is generally used to measure ppb to ppm levels of concentration of volatile organic compounds (VOCs).

| Category | Detectable gas |
|---|---|
| Other methods | Toxic |

## 2. Structure and principles

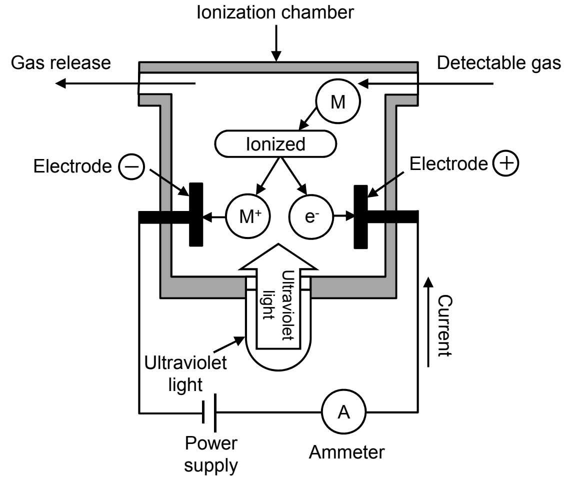
**[Structure]**

The sensor consists of an ionization chamber for letting in the detectable gas, a ultraviolet lamp for applying light, and positive and negative electrodes for detecting ion currents.

**[Principles]**

The detectable gas enters the ionization chamber and is exposed to ultraviolet light from the light source (ultraviolet lamp). This causes the gas to release electrons, generating cations. The generated cations and electrons are drawn by the positive and negative electrodes, which causes a current to be generated. Since this current is proportional to the gas concentration, the sensor measures the current value to determine the concentration of the detectable gas. Ionizing a detectable gas requires application of photon energy larger than the ionization energy specific to that gas. Photon energy is expressed in the unit electron volt (eV). This sensor uses a lamp having photon energies such as 10.6 eV and 11.7 eV. The larger the photon energy is, the larger amount of detectable gas the sensor can ionize.

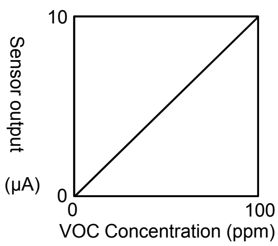
[Structure and principles]




## 3. Features

### ○ Output characteristics

For a gas with a low concentration of a few hundred ppm, the sensor output is almost proportional to the gas concentration, increasing linearly with the gas concentration.



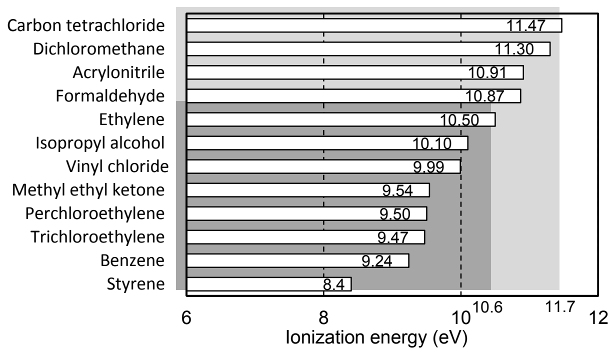

### ○ Ultraviolet lamp

The photon energy (eV) of a ultraviolet lamp is determined by the combination of the gas contained in the lamp and the material of the lamp window.

| Gas contained | Window material | Photon energy (eV) |
|---|---|---|
| Xenon | Sapphire | 8.4 |
| Krypton | Magnesium fluoride | 10.6 |
| Argon | Lithium fluoride | 11.7 |

### ○ Ionization energies of typical substances

By applying photon energy larger than the gas-specific ionization energy to each gas, the sensor ionizes the gas to determine the gas concentration. The sensor typically uses a lamp of 10.6 eV or 11.7 eV.




## 4. Detectable gas and molecular formula (examples)

| Detectable gas (for 10.6-eV lamp) | Molecular formula |
|---|---|
| Ethylene | $C_2H_4$ |
| Isopropyl alcohol | $C_3H_8O$ |
| Vinyl chloride | $C_2H_3Cl$ |
| Methyl ethyl ketone | $C_4H_8O$ |
| Perchloroethylene | $C_2Cl_4$ |
| Trichloroethylene | $C_2HCl_3$ |
| Benzene | $C_6H_6$ |
| Styrene | $C_8H_8$ |

| Detectable gas (for 11.7-eV lamp) | Molecular formula |
|---|---|
| Carbon tetrachloride | $CCl_4$ |
| Dichloromethane | $CH_2Cl_2$ |
| Acrylonitrile | $C_3H_3N$ |
| Formaldehyde | HCHO |
| Acetylene | $C_2H_2$ |
| Chloroform | $CHCl_3$ |
| Carbonyl sulfide | COS |
| Chlorine | $Cl_2$ |

## 5. Products of this type (examples)

### ○ Stationary products

... TVOC

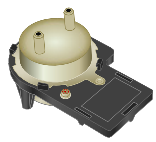
### ○ Portable products

... GX-6000, Tiger, Tiger Select

Tiger

# Pyrolysis-Particle Detection Method
# Sensor: SS

Stationary sensor
Example: SS-1923



| Category | Detectable gas |
|---|---|
| Other methods | Toxic |

## 1. Brief description

This gas sensor heats the detectable gas to produce an oxide and measures particles of the oxide using a particle sensor. Maintaining stability over the long term, it exhibits an excellent interference resistance and responsiveness. The particle sensor is based on the same principles as for ionization-based smoke sensors that use radiation.

## 2. Structure and principles

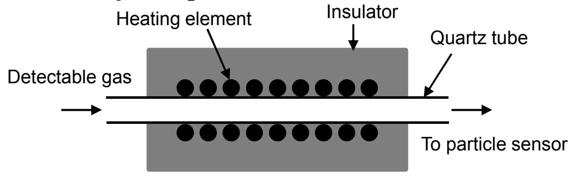
### [Structure]

This sensor is typically a combination of a heat decomposer and particle sensor. In the center of the heat decomposer is a quartz tube wrapped with a heating element.
The particle sensor is an integration of a measurement chamber, which continuously generates ion currents using α rays, and a compensation chamber. Detectable gas enters only the measurement chamber, with the compensation chamber open to the atmosphere.

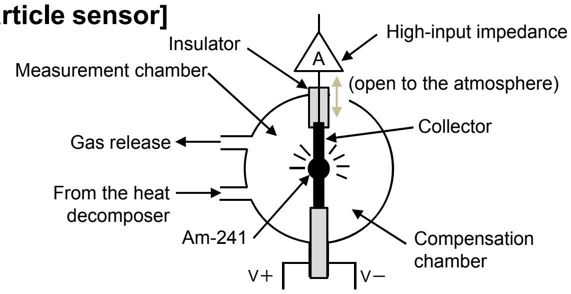
### [Principles]

Many of organic metal gases such as TEOS, when heated, produce a particulate oxide. Detectable gas passes through the heat decomposer to become oxidized and enters the particle sensor.
In the measurement chamber of the particle sensor, an alpha-ray source (Americium-241 (Am-241)) is used to ionize air, causing a current to flow. Particles enter the measurement chamber and absorb ions; this decreases the ion current, resulting in reduced sensor output. Based on the reduction in output, the sensor determines the gas concentration. The compensation chamber compensates fluctuations in sensor output caused by temperature, humidity, and/or pressure.

**[Heat decomposer]**



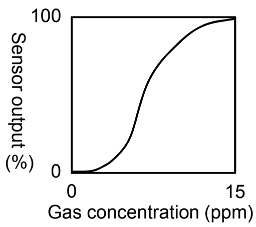

**[Particle sensor]**




## 3. Features (of the SSU-1925 (TEOS sensor) based on PLU + GD-70D as an example)

### ○ Output characteristics

The sensor output depends on the concentration of the particles produced through heat decomposition. The sensor uses a calibration curve so that the gas concentration will be linear with respect to the reading.

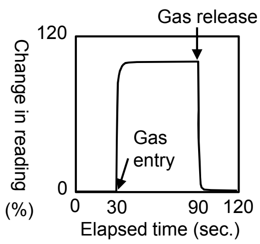



### ○ Aging characteristics

As the radiation source, the sensor uses Am-241, which has a very long half-life, approximately 400 years, and the sensor consequently hardly deteriorates in performance over time.

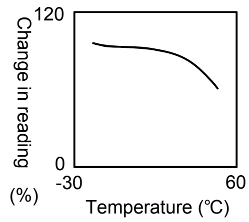
### ○ Responsiveness

Since the gas that enters the detection section is immediately oxidized in the heat decomposer, the sensor exhibits high response speed and excellent reproducibility.




### ○ Temperature characteristics

The sensor uses the compensation chamber to compensate temperature and thus exhibits excellent temperature characteristics.




## 4. Detectable gas, molecular formula, model, and detection range (examples)

| Detectable gas | Molecular formula | Model # | Detection range |
|---|---|---|---|
| Tetraethoxysilane (TEOS) | $C_8H_{20}O_4Si$ | SS-1923 | 0-15 ppm |
| | | SSU-1925 | |

## 5. Products of this type (examples)

### ○Stationary products

... GD-70D + PLU-70

GD-70D + PLU-70

# Interference Enhanced Reflection (IER) Method Sensor

## 1. Brief description

This gas sensor recognizes a swelling-caused change in the thickness of a polymer thin film as a change in the intensity of the light from the film—reflection of the light applied to the film—to convert it into a gas concentration. It measures the concentrations of volatile organic compounds (VOCs) with the lowest detectable concentrations of a few ppm to a few tens of ppm.

| Category | Detectable gas |
|---|---|
| Other methods | Combustible Toxic |

## 2. Structure and principles

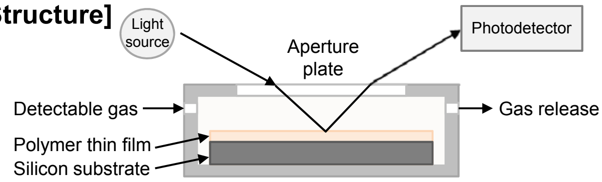
### [Structure]

The sensor consists of a polymer thin film that is placed on a silicon (Si) substrate and swells if it has absorbed a volatile organic substance drawn in, a laser light source, a photodetector for measuring reflected light, and other components.

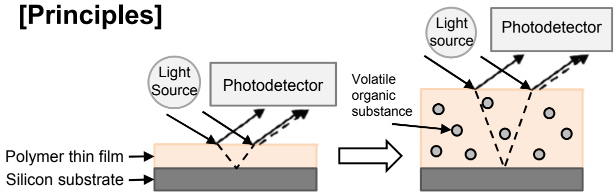
### [Principles]

A volatile organic compound comes into contact with the polymer thin film on the silicon substrate, which causes the film to swell (the compound enters the film, which causes the film to increase in thickness).
The amount of the change in film thickness caused by the swelling is proportional to the concentration of the substance in contact with the film.
Then, the light source lases the film and the laser beams reflected from the top and bottom of the film overlap each other. This causes an interference pattern of light-a phenomenon caused by the overlapped light beams intensifying or weakening each other. The sensor controls the thickness of the film so that the reflected light will intensify in proportion to the film thickness. The photodetector measures the intensity of the reflected light, which is in turn converted into the concentration of the volatile organic compound. The sensor thus determines gas concentrations.

**[Structure]**




**[Principles]**

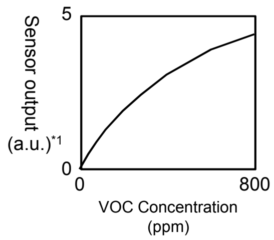



A volatile organic compound comes into contact with the polymer thin film, causing the film to swell and grow in thickness. This change in film thickness accompanied by a change in the refractive index intensifies reflected light.
The sensor measures the intensity of reflected light to determine the gas concentration.

## 3. Features (of the sensor VOC-121H as an example)

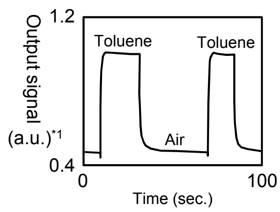
### ○ Output characteristics

This chart shows the output signal for the combination of air and toluene vapor as an example. The sensor output slowly changes according to the concentration of a volatile organic substance.




### ○ Responsiveness

The chart shows the response for toluene as an example of a volatile organic compound.
It indicates that in a few seconds after contact with toluene, the response is in equilibrium with stable signal output.




*1 au stands for arbitrary unit.

### ○ Measured value

The polymer thin film, a component of the sensor, absorbs any volatile organic compound and swells. This sensor recognizes a change in film thickness and converts it into a gas concentration and thus can measure the total amount of each volatile organic compound.

### ○ Detection range

With a high correlation with gas chromatography, which is used for identifying and quantifying compounds that are likely to gasify, the sensor can measure a wide range of concentrations from low levels (from a few ppm to a few tens of ppm) to high levels (a few thousand ppm to a few hundred thousand ppm).

## 4. Detectable gas, molecular formula, and detection range (examples*2)

| Detectable gas | Molecular formula | Detection range (low concentrations) | Detection range (high concentrations) |
|---|---|---|---|
| Toluene | $C_7H_8$ | 1.0-2500 ppm | 10.0-25000 ppm |
| E-xylene | $C_8H_{10}$ | 0.3-750 ppm | 75.0-7500 ppm |
| Methyl ethyl ketone | $C_4H_8O$ | 6.0-15000 ppm | 1500-150000 ppm |

*2 The sensor VOC-121H used as an example

## 5. Products of this type (examples)

### ○ Stationary products

... VM-501, VM-521R, VM-522R

### ○ Portable products

... VOC-121H, VOC-401P-Z

VOC-121H

# Thermal Ionization Detector Method Sensor

| Category | Detectable gas |
|---|---|
| Other methods | Toxic |

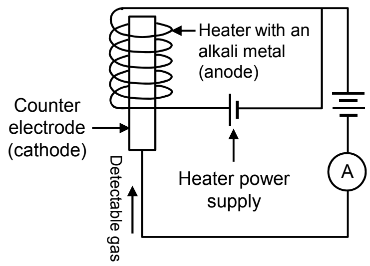
## 1. Brief description

A halide ionizes if it is thermally decomposed with a heater equipped with an alkali metal heated to a high temperature. This process generates an ion current. The sensor detects this current as the gas concentration. It is capable of detecting CFC gases in general, halogenated hydrocarbon solvent fumes, and other gases.

## 2. Structure and principles

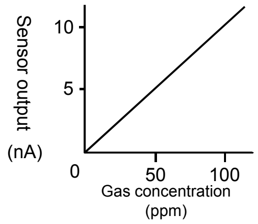
**[Structure]**
The sensor consists of a heater equipped with an alkali metal (anode) and a counter electrode (cathode)—a circuit for detecting ion currents.

**[Structure]**




**[Principles]**
A halide, such as a CFC, comes into contact with a heater equipped with a heated alkali metal and becomes decomposed and ionized (the alkali metal attached to the heater promotes cation emission, increasing the quantities of cations and anions). The generated ions are drawn by the anode and cathode. This process causes a flow of an ion current, which is proportional to the gas concentration; the sensor measures this current to determine the gas concentration.

**[Output characteristics]**




# Catalytic Oxidation Method Sensor

| Category | Detectable gas |
|---|---|
| Other methods | Toxic |

## 1. Brief description

This sensor measures the concentrations of carbon monoxide using heat of reaction generated when carbon monoxide is oxidized on a catalyst.

## 2. Structure and principles

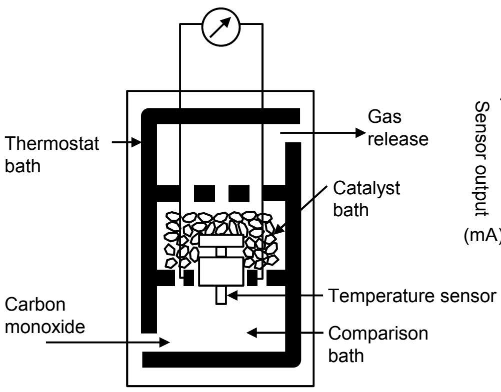
**[Structure]**
The sensor consists of a catalyst bath for oxidizing carbon monoxide, a comparison bath, and a thermostat bath containing a temperature sensor, and other components.

**[Principles]**
Carbon monoxide enters the thermostat bath and becomes oxidized on the oxidation catalyst. This oxidation process generates heat of reaction.

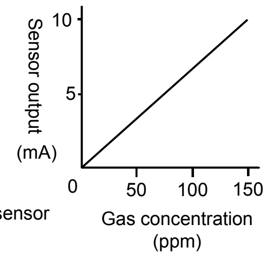
$$CO + 3/2\ O_2 \rightarrow CO_2 + x\ (Joule)$$

The temperature sensor measures this temperature change. Since the concentration of carbon monoxide is correlated with changes in temperature, the sensor measures the change in temperature to determine the concentration of carbon monoxide.

**[Structure]**

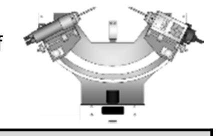



**[Output characteristics]**



# X-ray diffractometer equipped with an X-ray fluorescence spectrometer : DF

Example: Head of the DF-01



| Detectable objects |
| --- |
| [Measurement of diffraction and fluorescent X-rays]<br>Corrosive compounds such as those used in cultural assets and metal alloys |

## 1. Brief description

This instrument is a combination of a Si-PIN semiconductor detector designed for energy dispersive fluorescent X-ray analyzers and a goniometer integrated with the detector; it is capable of performing two types of analyses: X-ray diffraction analysis and fluorescent X-ray analysis. The instrument was developed in collaboration with Waseda University and commercialized by us.

## 2. Structure and principles

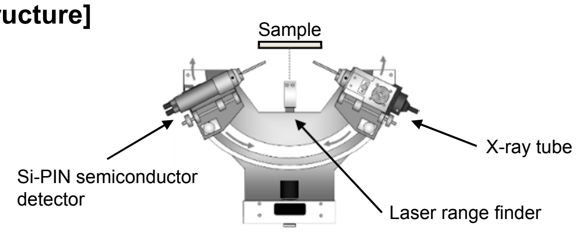
### [Structure]

The instrument is structured with an X-ray tube and a Si-PIN semiconductor detector placed on a goniometer, which allows for angle driving, with the capability of adjusting the distance to the sample using a laser range finder.

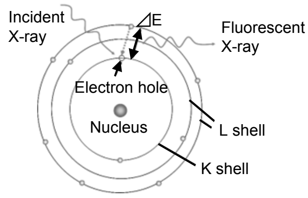
### [Principles]

With a Si-PIN semiconductor detector having a high level of energy resolution, energy dispersive fluorescence X-ray analysis allows concurrent measurement of multiple elements. Based on this high energy resolution, this instrument obtains diffraction patterns by selectively retrieving only the energy (wavelength) equivalent to the characteristic X-ray (Crk alpha ray) component of the incident X-rays while changing the angles of the X-ray tube and Si-PIN semiconductor detector.

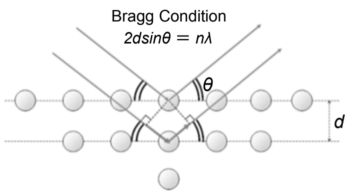
**[Structure]**




**[XRF (X-ray fluorescence) analysis]**



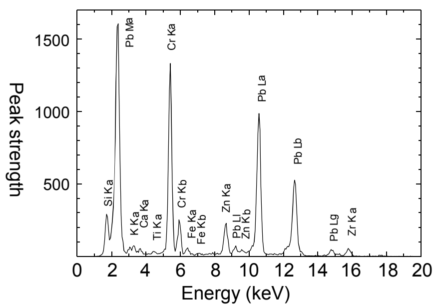

**[X-ray diffraction analysis]**




## 3. Features

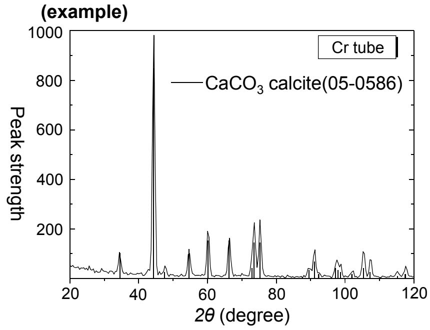
The instrument performs two different analyses, X-ray diffraction and fluorescent X-ray analyses, at the same point, and consequently provides more accurate information based on two different measurement methods. In addition, with the use of a compact X-ray tube and Si-PIN semiconductor detector, it can be used as a portable analyzer for on-site analysis. Since X-ray diffraction or fluorescent X-ray analysis is a nondestructive, non-contact method, the instrument can be used to measure large and irregular-shape test samples and remains and cultural assets, which are not allowed to be moved or carried out.

**○ Fluorescent X-ray analysis of an over glaze color (reddish brown of Aritanishiki) (example)**




The peak energy values (lateral axis) indicate what elements are contained in the sample and the peak strength values (vertical axis) provide an estimated quantity of each element.

**○ X-ray diffraction on a white pigment (example)**




The instrument performs analysis by searching the database for corresponding reference data. By narrowing down searches based on the element information obtained through fluorescent X-ray analysis at the same point, it provides accurate analysis results.

**○ Tutankhamun's golden mask**

Provided to Masayuki Uda, a professor emeritus at Waseda University

The photos show measurements made in the Cairo Museum in Egypt. The instrument is capable of performing on-site analyses even on pinpointed targets even if they are irregularly shaped as shown in the photos.

## 4. Applications (examples)

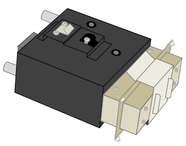
On-site diffraction and fluorescent X-ray analyses
- Analyses of archeological materials such as Tutankhamun's golden mask
- Analyses of cultural assets, identification of corrosive compounds such as metals and alloys, and estimation of crystallite diameters, degrees of orientation, and film thicknesses
- Initial examination for identifying any unknown material

## 5. Products of this type (examples)

○ **Portable product**
... DF-01

DF-01

# Open Counter for Low Energy Electron Counting Sensor : LE



Stationary sensor
Example: LE-6118

| Detectable objects |
| --- |
| [Substance surface analysis]<br>Work function, surface contamination, film thickness, etc. |

## 1. Brief description

This is the world's only sensor designed for surface analyses that is capable of counting low-energy electrons released into the air. RIKEN invented an initial model and Waseda University invented an improved version. Our company has commercialized them.

## 2. Structure and principles

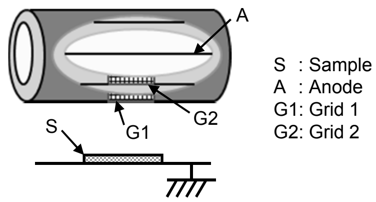
**[Structure]**

The sensor consists of two metal nets (G1 and G2), called grids, and an anode (A) made of a very thin wire.

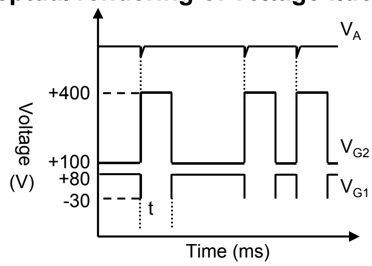
**[Principles]**

Low-energy electrons released from a sample enter the sensor through the grids. These electrons cause electric discharges near the anode, which are counted as discharge pulses. If a discharge continues, the sensor cannot count the second electron captured as the second pulse. As a solution to this, the sensor changes the voltages (VG1 and VG2) of G1 and G2 immediately after it has counted a pulse.
This stops the discharge to neutralize the cations generated in the discharge process and prevents the next electron from entering. After a certain duration, the sensor restores the voltages of G1 and G2 to count the next pulse. By repeating this process, the sensor counts electrons one by one.

**[Structure]**



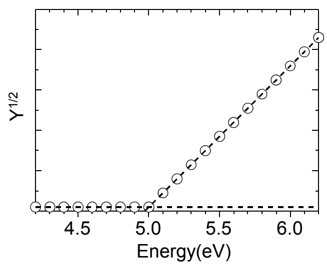

**[Conceptual rendering of voltage fluctuations]**




## 3. Features

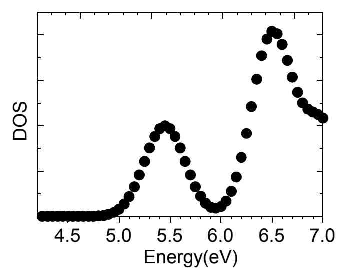
By combining a ultraviolet optical system, you can use this sensor to perform surface analyses in the atmosphere based on photoelectron yield spectroscopy. Typical photoelectron spectroscopy, a very effective method for obtaining information about the surface of a sample, requires a vacuum to measure electrons, which involves difficult measurement, and also requires expensive equipment. In contrast, this sensor allows you to easily make work function measurements and angstrom film-thicknesses measurements in the atmosphere, which had to be inevitably made in a vacuum before.

### ○ Photoemission characteristics



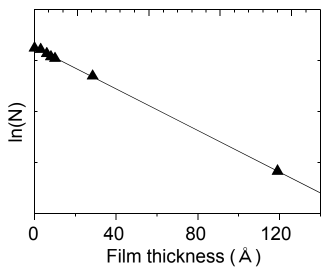

Measurement based on photoelectron yield spectroscopy provides a chart as shown in the figure. The vertical axis shows electron yield (Y) to the nth power; n is often 1/2 or 1/3. The point of intersection of the regression line of the linear part and the background is the threshold of photoemission.

### ○ Density of states




The electron yield differentiated with respect to the energy of the applied light is to reflect the density of states (DOS). This measurement provides the electronic state near the top of the valence band, which is an important element that determines various physical properties.

### ○ Film thickness and counting rate




If the surface is covered with another layer, the counting rate, N (ln (N)), and the film thickness, T, are linearly correlated with each other. Based on this correlation, the sensor estimates the thickness of any very thin film (such as an oxide film or lubricating oil film) formed on the surface of metal or a semiconductor.

## 4. Applications (examples)

Atmospheric photoelectron yield spectroscopy
- Analysis of the electronic states of materials
- Measurement of the thickness and contamination of ultrathin films on solid surfaces

## 5. Products of this type (examples)

**○Stationary products**

... AC-3, AC-5

AC-5

# Band Gap Analyzer

## 1. Brief descriptions

This instrument applies light from ultraviolet to visible to a sample, such as a thin film or powder and measures the reflectance to determine the band gap. You can subtract the band gap value obtained through this instrument from the HOMO value measured with our AC series product (AC-3 or AC-5) to derive a LUMO value and make a band diagram of the sample.

| Detectable objects |
|---|
| [Band gap measurement based on reflection spectrum]<br>Powder and thin films |

## 2. Structure and principles

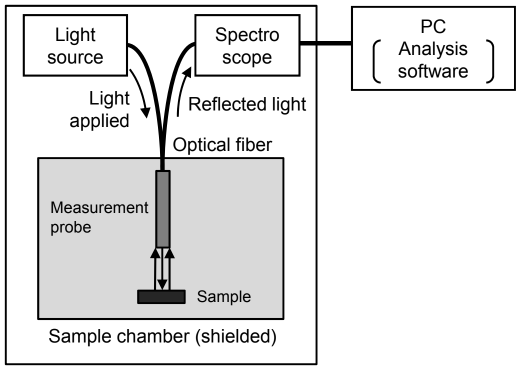
### [Structure]

The instrument consists of a light source, a measurement probe, and a spectroscope. The light source applies light through the measurement probe to a sample and the spectroscope captures reflected light. The sample chamber, used to apply light to the sample, is shielded to avoid the impact of any other light. An analysis software program is available designed to calculate band gaps from detected signals.

### [Principles]

The instrument applies light from ultraviolet to visible to a sample, disperses reflected light, and detects it to measure the reflectance. Based on the measured reflectance, the instrument calculates the band gap using an analysis method according to the shape of the sample such as powder or a thin film. If the sample is a powder, the instrument performs a calculation using the measured reflectance with consideration given to diffuse reflection to determine the band gap. If the sample is a thin film, the instrument performs a simulation according to the measured reflectance and calculates the film thickness, optical constant, and others to determine the band gap.

**[Diagram of the band gap analyzer]**




## 3. Features

### ○ Reflection measurement

This instrument applies light from ultraviolet to visible and measures reflected light and therefore can make measurements even for powder and other samples that are not light transmissive.

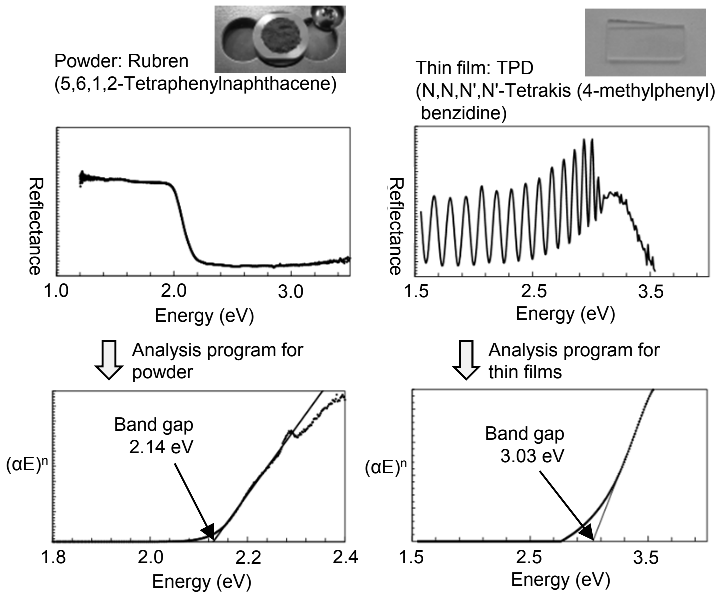
### ○ Sample shapes

Since each sample is placed on a sample stage, the instrument allows you to make measurements for samples where the HOMO values have been measured without having to rearrange them. It also allows you to make measurements even for powdery samples as they are without having to dissolve them into liquid.
The sample stage is designed to reflect no light, allowing the instrument to make measurements even for thin films and other light transmissive samples. The instrument determines the band gap of any thin film or substrate regardless of its material.

### ○ Measuring time

Using white light from ultraviolet to visible, the instrument concurrently detects reflected light over the wavelength region measured with the spectroscope. Based on this process, it finishes measurement as soon as several tens of seconds to a minute.

**Examples of measurement results**




## 4. Measurable objects and energy range (examples*)

| Measurable object | Measurable energy range |
|---|---|
| Reflection spectrum from powder, thin films, and other objects | 1.2 to 3.5 eV (wavelengths from 350 to 1000 nm) |

* Examples for a band gap analyzer

## 5. Products of this type (examples)

**○Stationary products**
... LAC-1

LAC-1

# Flame Detector
## (Triple Infrared - Ultraviolet - Ultraviolet and Infrared combined)

## 1. Brief description

The flame detector (based on three infrared wavelengths, ultraviolet light, and combined use of ultraviolet and infrared light) is based on the principles for equipment for detecting flames. When a substance burns, it generates gas, which emits intense ultraviolet and infrared light. By sensing this intense light, the detector recognizes the existence of a flame. As with a gas sensor, it uses a detection system appropriate for each substance or application.

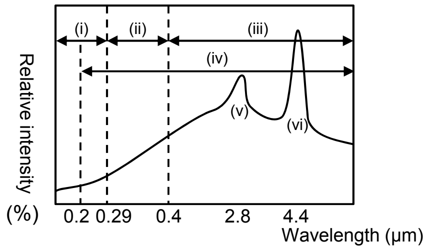
| Detectable objects |
|---|
| [Flame]<br>Factories, plants, etc. |

## 2. Principles

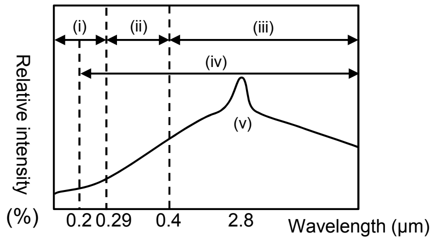
When a substance burns, it generates a substance-specific combination of gases. This combination includes $H_2O$ and $CO_2$, each of which emits light of a wavelength specific to it. The flame emits light in the entire infrared- and visible-light regions that include the above mentioned wavelengths; in particular, it emits intense light in the ultraviolet region. Based on this light, the flame detector senses a flame.
The light to be emitted varies depending on whether the flame is from hydrocarbon or not. The light from $H_2O$ and $CO_2$ each has a peak if the flame is of hydrocarbon and the light from $H_2O$ has a peak if the flame is not of hydrocarbon. The peak of the light from $CO_2$ is observed only for a hydrocarbon flame, which allows the detector to recognize only hydrocarbon flames. The peak of the light from $H_2O$ is observed irrespective of whether the flame is of hydrocarbon or not, allowing the detector to sense both of hydrocarbon and non-hydrocarbon flames.
In addition, the flame-emitted light seen in the ultraviolet region is observed irrespective of whether the flame is of hydrocarbon or not, allowing the detector to sense both of hydrocarbon and non-hydrocarbon flames.

[Legends] (i): UV light (ii): Visible light (iii): IR light (iv): Sunlight that reaches the earth's surface (v): $H_2O$ peak (vi): $CO_2$ peak

For a hydrocarbon flame




For a non-hydrocarbon flame

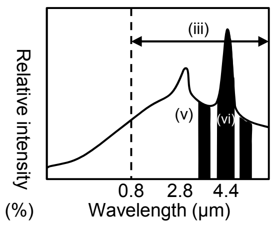



## 3. Features

[Legends] (i): UV light (ii): Visible light (iii): IR light (iv): Sunlight that reaches the earth's surface (v): $H_2O$ peak (vi): $CO_2$ peak

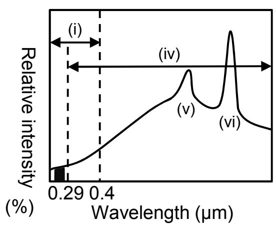
### ○ Three infrared wavelength method

This system monitors the light of the peak wavelength range from $CO_2$ along with two wavelength ranges before and after the peak range. By monitoring three wavelength ranges, it minimizes incorrect detection.
It is characterized by that it provides a high sensitivity and a long detection distance because it detects intense light.



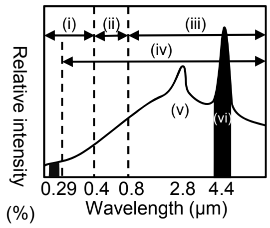

### ○ Ultraviolet method

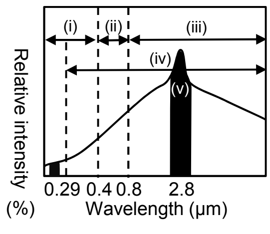
This method monitors the ultraviolet region, which is low in radiation intensity. It monitors the wavelength range in which sunlight is normally absorbed in the atmosphere before reaching the earth's surface and therefore prevents false alarms caused by sunlight.
It is characterized by that it quickly detects flames with a very high sensitivity.




### ○ Combined use of ultraviolet and infrared light

This method monitors intense light in the infrared region along with light in the ultraviolet region.
This prevents false alarms caused by sunlight or any other factor that is not a flame. As the figure on the right shows, this method includes a two-wavelength system that monitors one wavelength range each in the infrared and ultraviolet regions and three-wavelength system that two wavelength ranges in the infrared region and one wavelength range in the ultraviolet region.
The detectable flame varies depending on whether the wavelength range in the infrared region includes the peak of $CO_2$ (upper right figure) or not (lower right figure).




## 4. Principles and detectable flames (examples)

| Principles | Detectable flame |
|---|---|
| Three infrared wavelength method | Hydrocarbon flame |
| Ultraviolet method | Hydrocarbon flame, non-hydrocarbon flame (including welding and other sparks) |
| Combined use of ultraviolet and infrared light<br>UV + IR ($H_2O$ peak) | Hydrocarbon flame, non-hydrocarbon flame*<br>* Hydrogen flame, silane flame, ammonia flame |
| Combined use of ultraviolet and infrared light<br>UV + IR ($CO_2$ peak) | Hydrocarbon flame |

## 5. Products of this type (examples)

### ○ Stationary products

... Three infrared wavelength method: 40/40 I
... Ultraviolet method: BFL-3WW, FL-3W, FL-3B
... Combined use of ultraviolet and infrared light: 40/40 LB, 40/40 L4B, 40/40 UFL

40/40 series

# Ion-Selective Electrode Method Sensor

| Detectable objects |
| --- |
| [Salt in solutions]<br>Fresh concrete |

## 1. Brief description

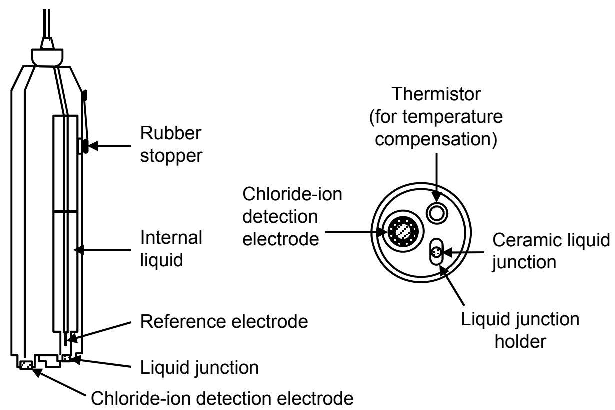
Using a chloride-ion detection electrode that selectively detects ions in solutions, this sensor determines the concentration of salt dissolved in fresh concreate, solutions, etc.

## 2. Structure and principles

**[Structure]**
The sensor consists of a chloride-ion detection electrode, reference electrode, liquid junction, internal liquid, thermistor (for temperature compensation), and other components.

**[Principles]**
The chloride-ion detection electrode generates a voltage that depends on the concentration of ions in the solution. For example, a voltage that depends on the concentration of the chloride-ion detection electrode is generated a voltage at the reference and chloride-ion detection electrode. The sensor measures the generated voltage to determine the concentration of chloride ions.

**[Structure]**




# Ionization Tendency Electrode Method Sensor

| Detectable objects |
| --- |
| [Oily water in the sea]<br>Oil tanker, etc. |

## 1. Brief description

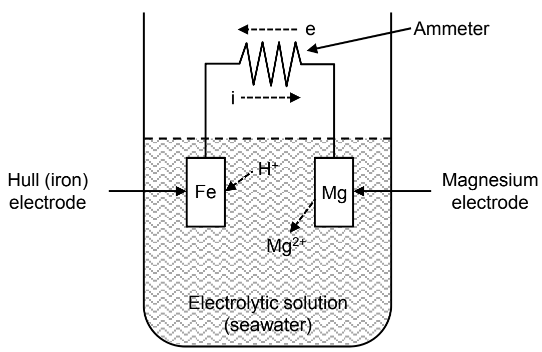
This is an oil-water boundary surface sensor that uses as electrodes two different metals with different ionization tendencies. It is used in a tank of an oil tanker as an instrument to detect the boundary surface between sea water and oil.

## 2. Structure and principles

**[Structure]**
This sensor consists of a magnesium electrode, a conductor that connects this electrode with the hull (iron) electrode, an ammeter, and other components.

**[Principles]**
Two different metals (magnesium (Mg) and iron (Fe)) are soaked in an electrolytic solution (seawater). The metal (magnesium) that is more likely to ionize starts to dissolve as ions, emitting electrons. These electrons flow through the conductor to the metal (Fe) that is less likely to ionize. This electron flow depends on the electrolytic solution. Based on this nature, the sensor detects the boundary surface between seawater (electrolyte) and oil (non-electrolyte).

**[Structure]**



# Photo Elasticity Method Sensor

| Detectable objects |
|---|
| [Internal stress of a transparency model]<br>Design of machinery and civil engineering and construction |

## 1. Brief description

A transparent object that allows light to pass through it, if receiving external force, changes its refractive index. This nature is called *photoelasticity*. This is a stress sensor that recognizes based on photoelasticity the degrees and directions of force (stress) acting on an object as striped patterns and analyzes them to determine the stress distribution in a structure.

## 2. Structure and principles

**[Structure]**

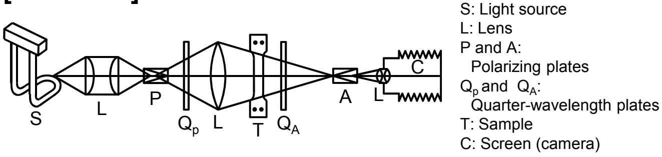
The sensor consists of two quarter-wavelength plates, which are used to sandwich a sample made of a transparent material, and two polarizing plates. Before and after the optical system placed is a light source for emitting light and a screen (camera) for receiving light.

**[Principles]**

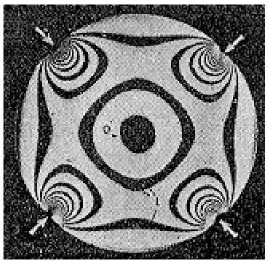
If force is externally applied to a transparent sample, the light incident on the sample as plane-polarized light separates into two plane-polarized rays with different phases that oscillate in the direction of the principal stress. The phase difference between these two rays is proportional to the difference between the principle stresses, which appears as light and dark (polarization) stripes on the screen.
The relationship between the quenching order, N, and the principle stress difference, p - q (kg/mm$^2$), of polarization stripes is expressed as follows. The sensor detects these polarization stripes and analyzes them to determine the stress distribution.

$N = \alpha d (p - q)$ α: Photoelastic sensitivity (kg/mm$^2$)
d: Thickness of the sample (mm)

**[Structure]**




**[Polarization stripes]**



# Geiger - Muller Counter

| Detectable objects |
|---|
| [β, γ, and χ rays]<br>Measurement of surface contamination caused by radiation |

## 1. Brief description

This sensor detects radiation (such as β, γ, and χ rays) incident on it as discharge pulses. It is a radiation sensor used mainly for high-sensitivity measurement of air dose rates.

## 2. Structure and principles

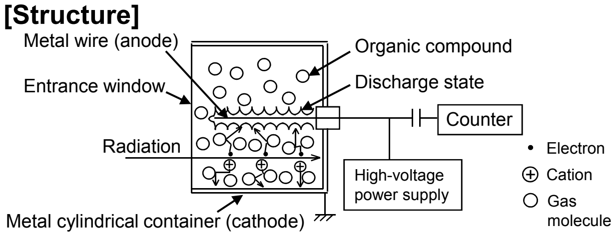
**[Structure]**

The sensor consists of a metal cylindrical container (cathode) with a metal wire (anode) installed in the center of if and with an organic or halogen gas contained in it. The GM counter for β-ray measurement has a β-ray entrance window arranged on the cylindrical container, which is partially made of mica or a similar material.

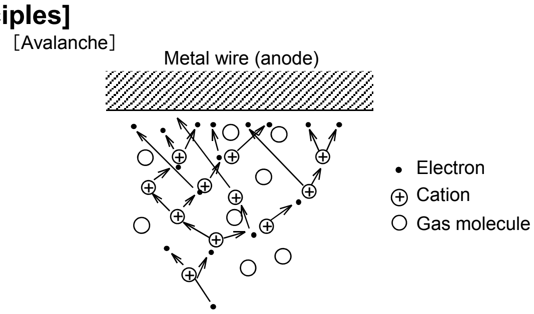
**[Principles]**

When radiation enters the GM counter, the gas inside the counter is ionized to generate cations and electrons.
Inside the GM counter, the electric field is kept intense with a high voltage applied between the cathode and anode. The electrons generated by radiation start to move in the electric field. Since the electric field is intense, this electron movement is accelerated, causing the electrons to have higher energy and inducing ionization; this process is repeated, causing electron avalanches. These avalanches cause discharge between the electrodes with discharge pulses from the GM counter. The sensor measures these pulses to determine the quantity of incident radiation.

**[Structure]**




**[Principles]**



# Ionization Method Sensor

| Detectable objects |
|---|
| [γ and χ rays]<br>Exposure measurement in hospitals and laboratories |

## 1. Brief description

This sensor collects primary ion pairs generated through radiation ionization to measure radiation based on the current, electric charge, or pulse shape according to the amount of radiation that has entered the ion chamber.

## 2. Structure and principles

**[Structure]**
The ionization chamber is made of plastic or metal with a rod-like collector placed in the center of it and with air or inert gas such as argon contained in it. The inner wall of the ionization chamber and collector are made of a conducting material and between the electrodes, the potential in the ionization chamber region is applied. Some have an ionization chamber equipped with an entrance window for measuring α and β rays.

**[Structure and principles]**

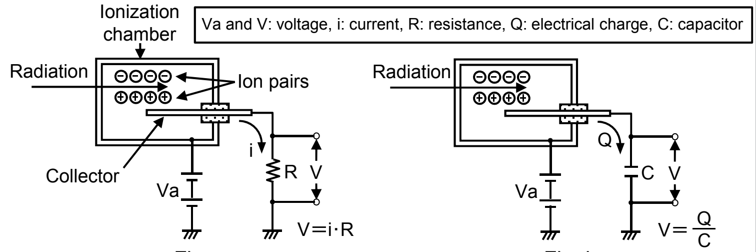
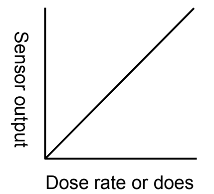



Fig. a　　Fig. b

**[Principles]**
When radiation enters the ionization chamber, the gas inside the chamber is ionized to generate ion pairs (electrons and cations). Inside the chamber, with a potential applied between the electrodes, an electric field is formed, which causes the ions to move to the electrodes, generating a current (Fig. a). This ionization chamber is typically used to measure dose rates. On the other hand, the ionization chamber as shown in Fig. b is of a charge-storage type that stores ions generated inside the chamber in a capacitor; this type of ionization chamber is used for dose measurement. This type includes a portable direct-reading dosimeter that indicates the electric charge accumulated in the capacitor as repulsion of a crystal string and recognizes the location of the crystal string using a built-in microscope.

**[Output characteristics]**




# Stress Detection Method Sensor

| Detectable objects |
|---|
| [Imbalance in wheels]<br>Automobiles and autobicycles |

## 1. Brief description

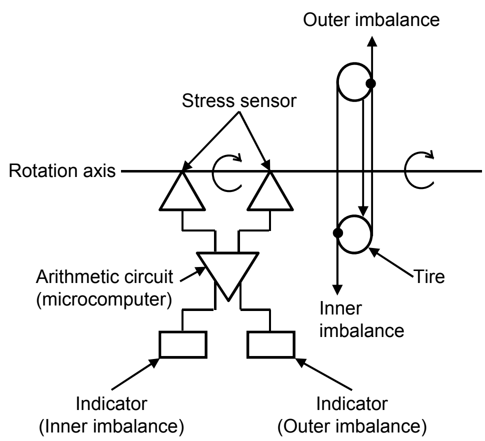
This is a stress sensor that makes use of the nature of a special crystal, which becomes charged if compressed or stretched; in other words, it is a sensor that converts stress into electric signals. It can be used to detect weight imbalance of automobile tires.

## 2. Structure and principles

**[Structure]**
The sensor consists of a rotation axis, two stress detectors, an arithmetic circuit (microcomputer), an indicator, and other components.

**[Principles]**
If a vehicle keeps running with some weight imbalance around the axle shaft, it may cause vibration and/or wheel shaking. With an axle shaft attached to the axis and being rotated, the sensor captures the stress applied to the axis due to weight imbalance using a piezoelectric element and converts into electric signals to determine the location and degree of the imbalance.

**[Structure]**



# Test Paper Type Photo-Electric Photometry Method Sensor (for Black Smoke)

| Detectable objects |
|---|
| [Black smoke from diesel engines]<br>Diesel engine vehicles |

## 1. Brief description

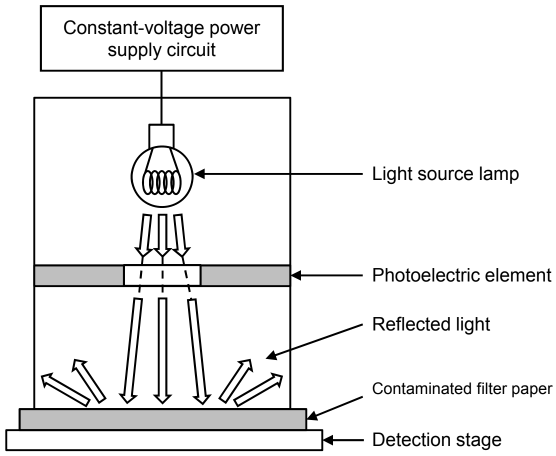
This sensor measures the concentration of black smoke by combining filter paper for collecting black smoke and electrophotometry for measuring the quantity of black smoke. It can be used to measure the amount of black smoke in exhaust from diesel engine vehicles and the level of contamination of exhaust gas from incinerators.

## 2. Structure and principles

**[Structure]**
The sensor consists of filter paper for absorbing solid particles and other substances contained in black smoke in exhaust, a detection stage for holding the filter paper, a light source lamp, a photoelectric element for detecting light reflected from the filter paper, and other components.

**[Principles]**
The sensor is used to aspirate a certain amount of exhaust from a diesel engine for a certain duration. In this process, filter paper is contaminated. With the filter paper placed on the detection stage, light is applied from the light source lamp. The paper reflects the light while absorbing a certain quantity depending on the contamination level of it, meaning that it reflects less light than it has received. The sensor measures the light loss using the photoelectric element to determine the contamination level (%).

**[Structure]**




# Opacimeter (Light - transmission Smoke Meter)

| Detectable objects |
|---|
| [Exhaust gas pollution]<br>Vehicle emission |

## 1. Brief description

Light is passed through vehicle exhaust gas. Based on a change in light transmission, this sensor determines the level (as an optical-absorption coefficient of 0.01 $m^{-1}$) of exhaust gas contamination due to particulate matter (PM).

## 2. Structure and principles

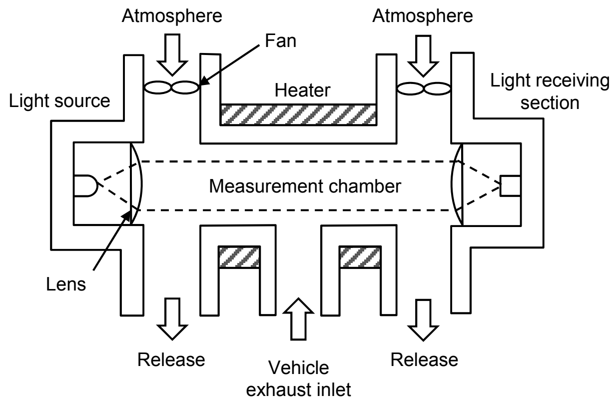
**[Structure]**
The sensor consists of a light source, a lens for paralleling the rays from the light source, a measurement chamber for letting in exhaust gas, a light receiving section for sensing the parallel rays from the light source, and other components.

**[Principles]**
If exhaust gas collected from a vehicle exhaust pipe enters the measurement chamber, smoke in the gas reduces amount of light that passes through the gas. The light receiving section senses the light attenuation, allowing the sensor to determine the optical-absorption coefficient (m-1) of the exhaust gas. The optical-absorption coefficient is given by the equation below:

$$k = \frac{-1}{L_A} \times \ln\left(\frac{\tau}{100}\right)$$

$k$ : Optical-absorption coefficient ($m^{-1}$)
$L_A$: Effective optical path length (m)
$\tau$ : Light transmission (%) for the exhaust gas

**[Structure]**



Appendix

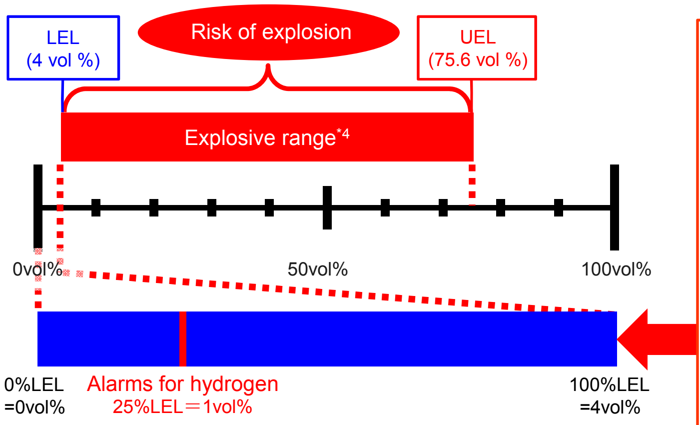
# Understanding Combustible and Toxic Gases

## Combustible gas

Under Article 2, Clause 1 of the Security Regulation for General High-Pressure Gas (JAPAN), a combustible gas is defined as:

- A gas where the lower explosive limit*1 is not more than 10% (the explosive limits mentioned here are for mixture with air and the same applies to the following), or
- A gas where the difference between the upper and lower explosive limits is not less than 20%.

Examples of settings for the lower explosive limit*2 (LEL), upper explosive limit*3 (UEL), and alarms for hydrogen ($H_2$)




**Alarm setting for combustible gas**

It is too late to warn after the concentration of combustible gas has reached its upper explosive limit.

In monitoring gas concentrations, it is required to know the existence of a combustible gas before the lower explosive limit of it is reached.

Under Relation Exemplifying Requirement 23-1-1.2 of the Security Regulation for General High-Pressure Gas, it is defined that the gas concentrations below lower explosive limits should be controlled to ensure that for any combustible gas, the concentration is not more than a quarter the lower explosive limit of it.

*1 Explosive limits are the range of concentrations of a combustible gas in a mixture with oxygen (air) in which the mixture can be caused to explode in the presence of an ignition source. The range has the lower and upper limits, namely the highest and lowest concentrations of the combustible gas.
*2 The lower explosive limit (LEL) of a combustible gas is the lowest concentration of that gas in the range of explosive limits for it.
*3 The upper explosive limit (UEL) of a combustible gas is the highest concentration of that gas in the range of explosive limits for it.
*4 The explosive range of a combustible gas is the range between the upper and lower explosive limits where that gas can be caused to explode.

## Toxic gas

Under Article 2, Clause 2, of the Security Regulation for General High-Pressure Gas (JAPAN), a toxic gas is defined as:

-A gas where the threshold limit value is not more than 200 ppm
(= the permissible concentration is not more than 200 ppm)

Under Exemplifying Requirement 23-1-1.2 of the Security Regulation for General High-Pressure Gas (JAPAN), it is required that the alarm setting for toxic gas should be as follows:

-For toxic gas, the setting must not be higher than the permissible concentration (or not higher than the value twice the permissible concentration for a standard gas for testing that is difficult to examine).

**Definition of permissible concentration (threshold limit value: TLV)**

Even if workers are exposed to a toxic substance at a worksite, that substance has no adverse health effect on almost all workers so long as the concentration of it is not higher than a specific value. This value is the permissible concentration of that substance.

Permissible concentrations are recommended by American Conference of Governmental Industrial Hygienists (ACGIH) and the Japan Society for Occupational Health. We use those recommended by ACGIH.

Permissible concentrations (TLVs) recommended by ACGIH

| Term | Meaning |
|---|---|
| TWA (Time-weighted average) | If a worker is repeatedly exposed to a toxic gas during normal operations for the TWA (eight hours a day, or 40 hours a week), the gas does not contribute to a health problem. |
| STEL (Short-term exposure limit) | If a worker is exposed to a toxic gas for not longer than the STEL (15 minutes) with intervals of longer than one hour, the gas does not contribute to a health problem so long as the worker is not exposed to the gas more than four times a day. |
| C (Ceiling) | Upper limit that must not be exceeded |

Appendix

# Understanding Particular High-pressure Gases, Oxygen, and Hydrogen Sulfide

## Particular high-pressure gases

Particular high-pressure gases are the seven different gases shown below as defined under Article 2, Clause 3 of the Security Regulation for General High-Pressure Gas (JAPAN).

Seven particular high-pressure gases

| Particular high-pressure gases | Arsine | Disilane | Diborane | Hydrogen selenide | Phosphine | Monogermane | Mono-silane |
|---|---|---|---|---|---|---|---|
| Molecular formula | $AsH_3$ | $Si_2H_6$ | $B_2H_6$ | $H_2Se$ | $PH_3$ | $GeH_4$ | $SiH_4$ |

## Oxygen and hydrogen sulfide

The symptom caused by inhalation of oxygen or hydrogen sulfide is defined as follows in Article 2 of the Ordinance on Prevention of Anoxia: (JAPAN)

- Anoxia: A state that exhibits a symptom caused by inhalation of air with an oxygen concentration of less than 18%

- Hydrogen sulfide poisoning: A state that exhibits a symptom caused by inhalation of air with a hydrogen sulfide concentration of more than 10 ppm

### Definition of permissible concentrations

Symptoms of anoxia

Safe ↓ Dangerous

| Oxygen concentration (%) | Symptom |
|---|---|
| 20.93 | Atmospheric concentration of oxygen |
| 18 | Although this concentration is above the lower safety limit, it is required to continuously ventilate the worksite, monitor the oxygen concentration, and make available safety belts and respiratory protective devices.  |
| 16-12 | Symptoms appear such as increased pulse/respiratory rate, loss of concentration, simple miscalculation, degraded precision muscle work, muscle weakness, headache, ear ringing, sickness, and nausea.  |
| 14-9 | Defective judgment, exaltation, emotional lability, frequent sighing, extraordinary exhaustion, inebriation state, headache, nausea, vomiting, loss of memory, Insensitiveness to pain from an injury, generalized weakness, increased body temperature, cyanosis, stupor, and risk of death by falling from a stairway or ladder and drowning  |
| 10-6 | Nausea, vomiting, inability to act at will, inability to move or shout even under a dangerous situation, collapse, hallucination, cyanosis, loss of consciousness, falling unconscious, central nervous system disorder, generalized convulsion, and risk of death  |
| 6 or less | Fainting or falling after several gasping respirations, bradypnea, respiratory arrest, convulsion, cardiac arrest, and death |

* Reference: New Guidebook for Chief Workers Involved in Operations Accompanied with a Risk of oxygen deficit [third impression on October 26, 2007]

Symptoms of hydrogen sulfide poisoning

Safe ↓ Dangerous

| Hydrogen sulfide concentration (ppm) | Symptom |
|---|---|
| 0.025 | Limit of sense of smell |
| 0.2 | Anyone can sense an odor |
| 3-5 | Disagreeable odor of medium degree |
| 10 | Lower limit of irritation to the eye mucous membranes |
| 20-30 | Workers become used to odors, resulting in the inability to sense a higher concentration. Lower limit of irritation to the lungs |
| 100-300 | In two to 15 minutes, the olfactory nerve is paralyzed, causing you to feel that the disagreeable odor has rather weakened. Keratitis (conjunctivitis), itchy eyes, eye pain, feeling that there is sand in the eye, dazzling, congestion and swelling, corneal opacification, corneal destruction/separation, distorted/ hazy vision, pain increased by light, bronchitis caused by continuous exposure of eight to 48 hours, pneumonia, death from suffocation due to pulmonary edema Burning pain in the respiratory mucosa If the exposure duration is not longer than an hour, no severe symptom is produced.  |
| 350-600 | Risk of death if exposure lasts 30 minutes to one hour |
| 700-1000 | Respiratory paralysis, loss of consciousness, falling unconscious, respiratory arrest, and/or death immediately after short-time hyperventilation |
| 5,000 | Instant death  |

Appendix

# List of Risks of Dangers of Combustible and Toxic Gases

| Gas | Chemical formula | Flash point*1 (°C) | Ignition temperature*1 (°C) | Explosive limits*1 (vol%) | | Gas specific gravity*1 | ACGIH recommended values Permissible concentrations (TLV)*2 | | | Japan Society for Occupational Health recommended values*3 |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Lower limit | Upper limit | | TWA | STEL | C | Permissible concentration |
| Arsine | $AsH_3$ | - | - | 4.5 | 78 | 2.7 | 5 ppb | - | - | 10 ppb |
| Phosphine | $PH_3$ | - | 38 | 1.8 | - | 1.2 | 0.3 ppm (0.1 ppm)*4 | 1 ppm | (0.5 ppm)*4 | 0.3 ppm |
| Diborane | $B_2H_6$ | gas | 40-50 | 0.8 | 88 | 0.95 | 0.1 ppm | - | - | 0.01 ppm |
| Silane | $SiH_4$ | - | - | 1.37 | 100 | 1.1 | 5 ppm | - | - | 100 ppm |
| Disilane | $Si_2H_6$ | - | - | 1.0 | 100 | 2.3 | 5 ppm (permissible silane concentration) | - | - | 100 ppm (max. permissible concentration) |
| Germane | $GeH_4$ | gas | 173 | 2.8 | 98 | 2.6 | 0.2 ppm | - | - | - |
| Hydrogen selenide | $H_2Se$ | gas | - | - | - | 2.1 | 0.05 ppm | - | - | 0.05 ppm |
| Nitrogen trifluoride | $NF_3$ | - | - | - | - | 2.5 (20°C) | 10 ppm | - | - | - |
| Boron tribromide | $BBr_3$ | - | - | - | - | 2.7 | - | - | 1 ppm | - |
| Phosphorus trichloride | $PCl_3$ | - | - | - | - | 1.6 | 0.2 ppm | 0.5 ppm | - | 0.2 ppm |
| Phosphorus pentachloride | $PCl_5$ | - | - | - | - | 2.1 | 0.1 ppm | - | - | 0.1 ppm |
| Phosphorus oxychloride | $POCl_5$ | - | - | - | - | 1.7 (20°C) | 0.1 ppm | - | - | - |
| Boron trifluoride | $BF_3$ | - | - | - | - | 2.4 | - | - | 1 ppm | 0.3 ppm |
| Sulfur tetrafluoride | $SF_4$ | - | - | - | - | 3.8 | - | - | 0.1 ppm | - |
| Hydrogen chloride | $HCl$ | - | - | - | - | 1.3 | - | - | 2 ppm | 2 ppm (max. permissible concentration) |
| Hydrogen fluoride | $HF$ | - | - | - | - | 1.0 | 0.5 ppm | - | 2 ppm | 3 ppm (max. permissible concentration) |
| Hydrogen bromide | $HBr$ | - | - | - | - | 3.6 | - | - | 2 ppm | - |
| Chlorine | $Cl_2$ | - | - | - | - | 2.5 | 0.5 ppm | 1 ppm | - | 0.5 ppm (max. permissible concentration) |
| Fluorine | $F_2$ | - | - | - | - | 1.3 | 1 ppm | 2 ppm | - | - |
| Bromine | $Br_2$ | - | - | - | - | 3.1 | 0.1 ppm | 0.2 ppm | - | 0.1 ppm |
| Chlorine trifluoride | $ClF_3$ | - | - | - | - | 3.2 | - | - | 0.1 ppm | - |
| Ozone | $O_3$ | - | - | - | - | 1.6 | 0.10 ppm | - | - | 0.1 ppm |
| Nitrogen monoxide | $NO$ | - | - | - | - | 1.04 | 25 ppm | - | - | - |
| Nitrogen dioxide | $NO_2$ | - | - | - | - | 1.45 (liquid) | 0.2 ppm | - | - | In review |
| Sulfur dioxide | $SO_2$ | - | - | - | - | 2.3 | - | 0.25 ppm | - | In review |
| Hydrogen sulfide | $H_2S$ | gas | 260 | 4.0 | 44.0 | 1.2 | 1 ppm | 5 ppm | - | 5 ppm |
| Carbon monoxide | $CO$ | gas | 609 | 12.5 | 74 | 1.0 | 25 ppm | - | - | 50 ppm |
| Ammonia | $NH_3$ | gas | 651 | 16 | 25 | 0.6 | 25 ppm | 35 ppm | - | 25 ppm |
| Monomethylamine | $CH_5N$ | gas | 430 | 4.2 | 20.7 | 1.0 | 5 ppm | 15 ppm | - | 10 ppm |
| Dimethylamine | $C_2H_7N$ | gas | 400 | 2.8 | 14.4 | 1.6 | 5 ppm | 15 ppm | - | 10 ppm |
| Trimethylamine | $C_3H_9N$ | gas | 190 | 2.0 | 12.0 | 2.0 | 5 ppm | 15 ppm | - | - |
| Diethylamine | $C_4H_{11}N$ | -23 | 312 | 1.7 | 10.1 | 2.5 | 5 ppm | 15 ppm | - | 10 ppm |
| Hydrogen cyanide | $HCN$ | <-20 | 538 | 5.4 | 46 | 0.9 | - | - | 4.7 ppm | 5 ppm |
| Hydrogen peroxide | $H_2O_2$ | - | - | - | - | 1.13 (specific gravity for 35% concentration) | 1 ppm | - | - | - |
| Phosgene | $COCl_2$ | - | - | - | - | 1.4 | 0.1 ppm | - | - | 0.1 ppm |
| Acetylene | $C_2H_2$ | gas | 305 | 2.3 | 100 | 0.9 | - | - | - | - |
| Acetone | $C_3H_6O$ | -20 | 539 | 2.5 | 14.3 (100°C) | 2.0 | 500 ppm (250 ppm)*4 | 750 ppm (500 ppm)*4 | - | 200 ppm |
| Isobutane | $C_4H_{10}$ | gas | 460 | 1.3 | 9.8 | 2.0 | - | 1000 ppm | - | - |
| Ethanol | $C_2H_6O$ | 12 | 400 | 3.1 | 19 | 1.6 | - | 1000 ppm | - | - |
| Ethane | $C_2H_6$ | gas | 515 | 2.4 | 15.5 | 1.0 | - | - | - | - |
| Ethylene | $C_2H_4$ | gas | 440 | 2.3 | 36.0 | 1.0 | 200 ppm | - | - | - |
| Xylene | $C_8H_{10}$ | 25 | 465 | 1.0 | 7.0 | 3.7 | 100 ppm | 150 ppm | - | 50 ppm |
| Ethyl acetate | $C_4H_8O_2$ | -4.0 | 470 | 2.0 | 12.8 | 3.0 | 400 ppm | - | - | 200 ppm |
| Cyclohexane | $C_6H_{12}$ | -17 | 245 | 1.3 | 8.3 | 2.9 | 100 ppm | - | - | 150 ppm |
| Cyclopentane | $C_5H_{10}$ | -37 | 320 | 1.4 | 8.7 | 2.4 | 600 ppm | - | - | - |
| Dimethyl ether | $C_2H_6O$ | gas | 240 | 2.7 | 32 | 1.6 | - | - | - | - |
| Hydrogen | $H_2$ | gas | 560 | 4.0 | 75 | 0.1 | - | - | - | - |
| Styrene | $C_8H_8$ | 30 | 490 | 1.0 | 8.0 | 3.6 | 20 ppm | 40 ppm | - | 20 ppm |
| Tetrahydrofuran | $C_4H_8O$ | -14 | 230 | 1.5 | 12.4 | 2.5 | 50 ppm | 100 ppm | - | 200 ppm |
| Toluene | $C_7H_8$ | 4 | 530 | 1.0 | 7.8 | 3.1 | 20 ppm | - | - | 50 ppm |
| 1,3-butadiene | $C_4H_6$ | gas | 420 | 1.4 | 16.3 | 1.9 | 2 ppm | - | - | - |
| Propane | $C_3H_8$ | gas | 450 | 1.7 | 10.9 | 1.6 | - | - | - | - |
| Propylene | $C_3H_6$ | gas | 455 | 2.0 | 11.1 | 1.5 | 500 ppm | - | - | - |
| n-hexane | $C_6H_{14}$ | -22 | 223 | 1.1 | 7.5 | 3.0 | 50 ppm | - | - | 40 ppm |
| n-heptane | $C_7H_{16}$ | -7 | 204 | 1.1 | 6.7 | 3.5 | 400 ppm | 500 ppm | - | 200 ppm |
| Benzene | $C_6H_6$ | -11 | 498 | 1.2 | 8.6 | 2.7 | 0.5 ppm | 2.5 ppm | - | 1 ppm (excessive carcinogenesis disorder risk level 10-3) |
| Methyl methacrylate | $C_5H_8O_2$ | 10 | 430 | 1.7 | 12.5 | 3.6 | 50 ppm | 100 ppm | - | 2 ppm |
| Methanol | $CH_4O$ | 9 | 440 | 6.0 | 36 | 1.1 | 200 ppm | 250 ppm | - | 200 ppm |
| Methane | $CH_4$ | gas | 600 | 5.0 | 15.0 | 0.6 | - | - | - | - |
| Methyl isobutyl ketone | $C_6H_{12}O$ | 16 | 475 | 1.2 (90°C) | 8.0 (90°C) | 3.5 | 20 ppm | 75 ppm | - | 50 ppm |
| Dichloro-silane | $SiH_2Cl_2$ | -28 | 58±5 | 4.1 | 99 | 3.5 | - | - | - | - |

*1 For the flash point to gas specific gravity, we used data from the Technical Guidelines from the National Institute of Occupational Safety and Health, Japan (Guide to JNIOSH-TR-No.44 (2012): Explosionproof Factory Equipment for Users) (hereafter referred to as the "Guide"); *Handbook of Hazardous and Harmful Effects of Chemical Substances* (hereafter referred to as the "*Handbook*") or International Chemical Safety Cards (hereafter referred to as the "Cards"); and Material Safety Data Sheets from Japan Advanced Information Center of Safety and Health, Japan Industrial Safety and Health Association.

*2 For Permissible Concentration (TLV) of the ACGIH-recommended values, we used data form 2014 TLVs R and BEIs R.

*3 For Japan Society for Occupational Health recommended values, we used data from *Journal of Occupational Health* Vol. 56, #5 issued in September 2014.

*4 The figures in parentheses are preliminary noticed permissible concentrations indicated in 2014 TLVs R and BEIs R.

Memo

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