Sensor Technologies used in Portable Gas Monitors

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Honeywell

Multi-gas & Single-gas Monitors

Honeywell

Today's gas monitoring equipment has come a long way from the miner's canary. Workers need to have a personal multi-gas monitor to perform the required atmospheric pre-testing and continuous monitoring. The monitor needs to be easy to use, rugged and reliable to work in some of the adverse conditions that can exist in these environments. The most important component in these monitors are the sensors.

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Sensor Types for Portable gas monitoring

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Fuel Cell Oxygen Sensors

- Oxygen sensor performance
  - Sensor generates electrical current proportional to the O2 concentration
  - Sensor used up over time (last approximately two years)

Fuel Cell Oxygen Sensors

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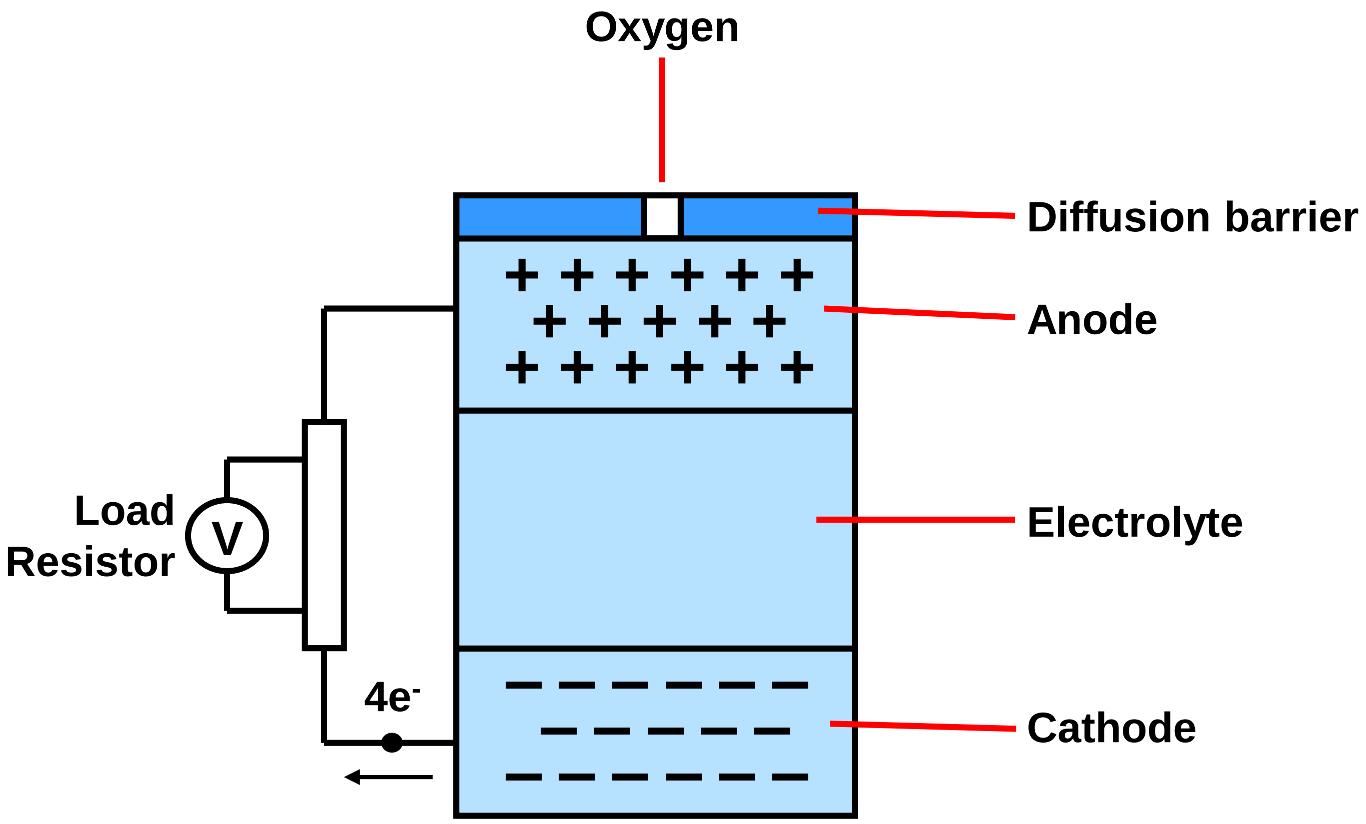
- Oxygen enters the sensor through a capillary pore



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Oxygen Sensor

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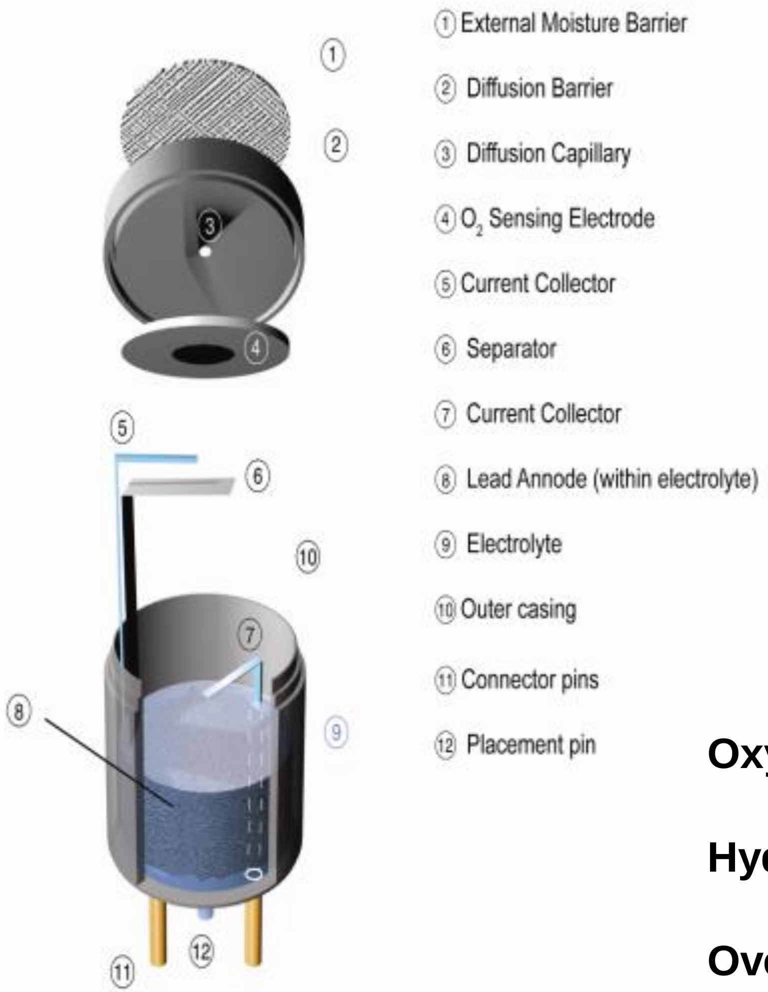

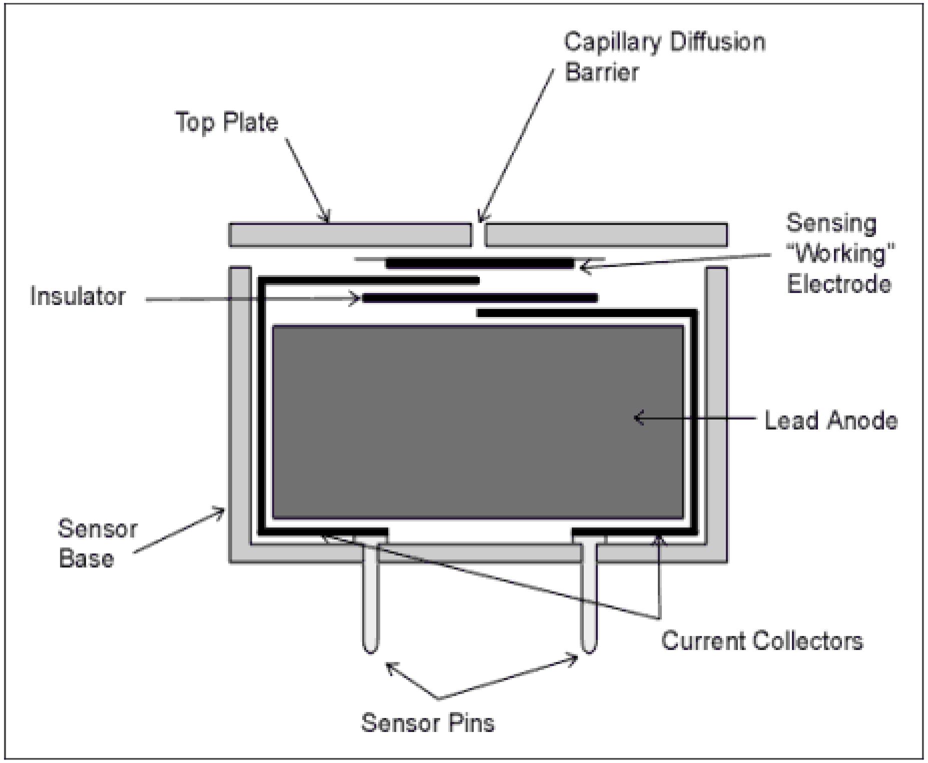

Oxygen is reduced to hydroxyl ions at the cathode:

$$O_2 + 2H_2O + 4e^- \longrightarrow 4OH^-$$

Hydroxyl ions oxidize the (lead) anode:

$$2Pb + 4OH^- \longrightarrow 2PbO + 2H_2O + 4e^-$$

Overall cell reaction:

$$2Pb + O_2 \longrightarrow 2PbO$$

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Oxygen Sensor Operation

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Capillary Pore Benefits

- True percent by volume sensor
- Not influenced by changes in pressure less that +/- 10% of ambient due to:
  - Barometric pressure
  - Pressurized buildings
  - Altitude

O2 Sensor Failure Mechanisms

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- Failure modes that lead to lower current output:
  - All available surface area of Pb anode converted to PbO_2
  - Electrolyte poisoned by exposure to contaminants:
    - High concentrations of acid gases - H_2S and CO_2
    - Solvents
  - Electrolyte leakage
  - Desiccation
  - Excessive heat and humidity
  - Blockage of capillary pore

LEL Sensors

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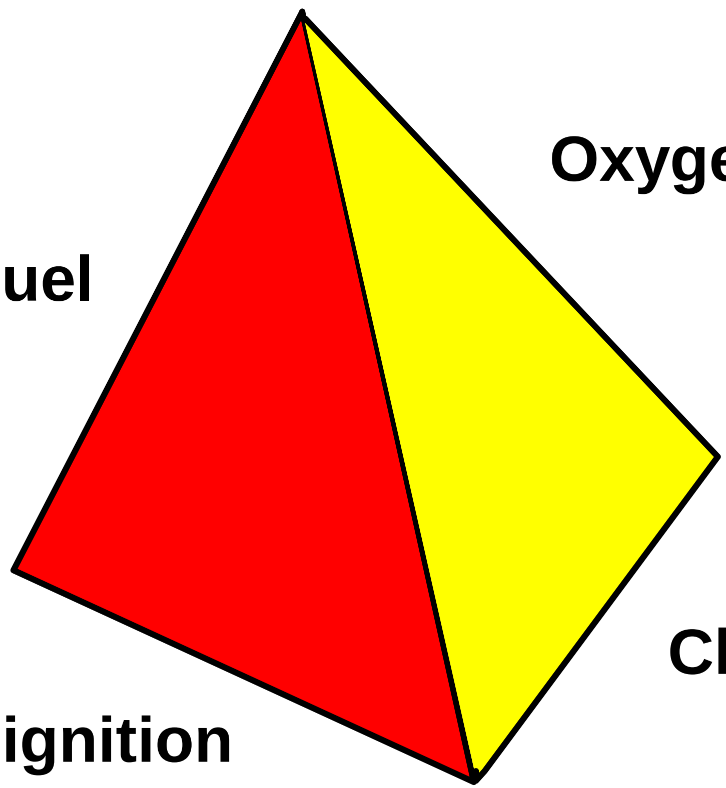

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Lower Explosive Limit (L.E.L.)

Minimum concentration of a combustible gas or vapor in air which will ignite if a source of ignition is present

Upper Explosive Limit (U.E.L.)

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- Most but not all combustible gases have an upper explosive limit
  - Maximum concentration in air which will support combustion
  - Concentrations which are above the U.E.L. are too “rich” to burn

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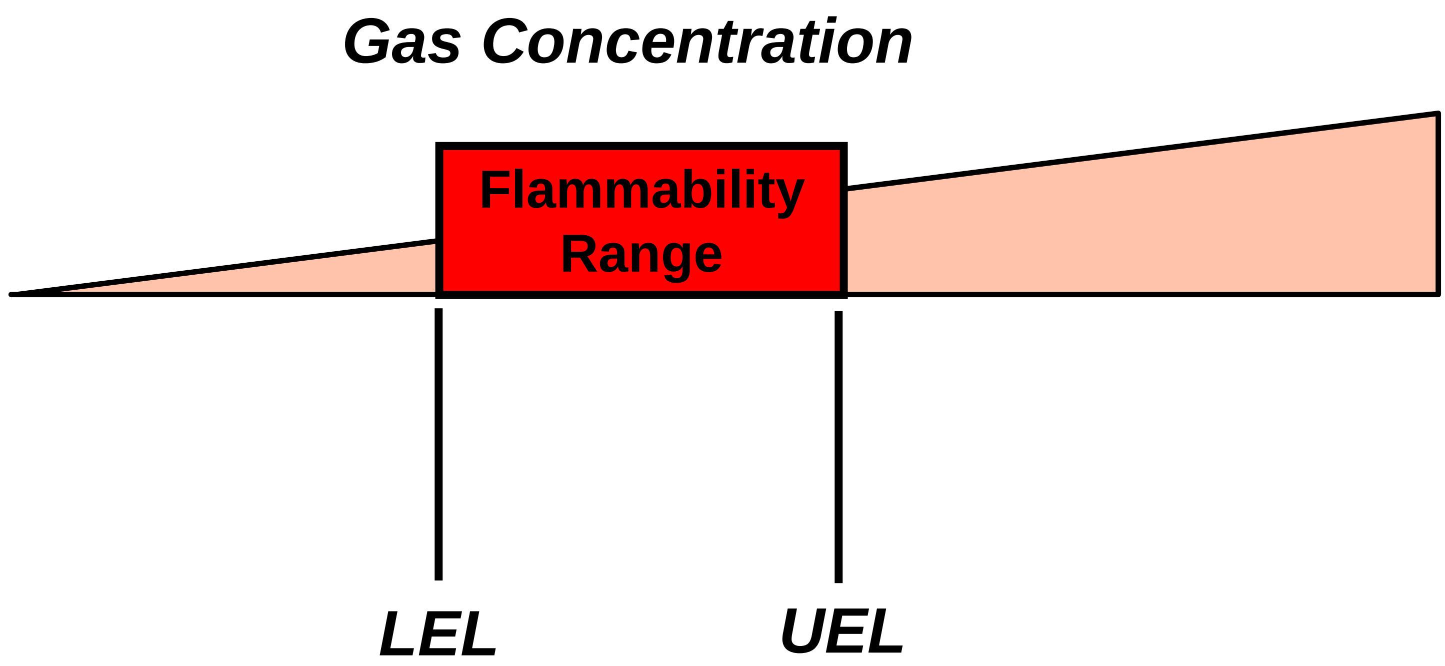
Flammability Range

Honeywell



- The range between the L.E.L. and the U.E.L. of a combustible gas or liquid
- Concentrations within the flammable range will burn or explode if a source of ignition is present

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Common Flammability Ranges

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- Different gases have different flammability ranges

	LEL	UEL
Methane	5.0%	15.0%
Propane	2.2%	9.5%
Hydrogen	4.00%	75.0%
Butane	1.8%	8.4%
Pentane	1.40%	7.8%
Ethylene Oxide	3.0%	100.0%
Hydrogen Sulfide	4.3%	46.0%

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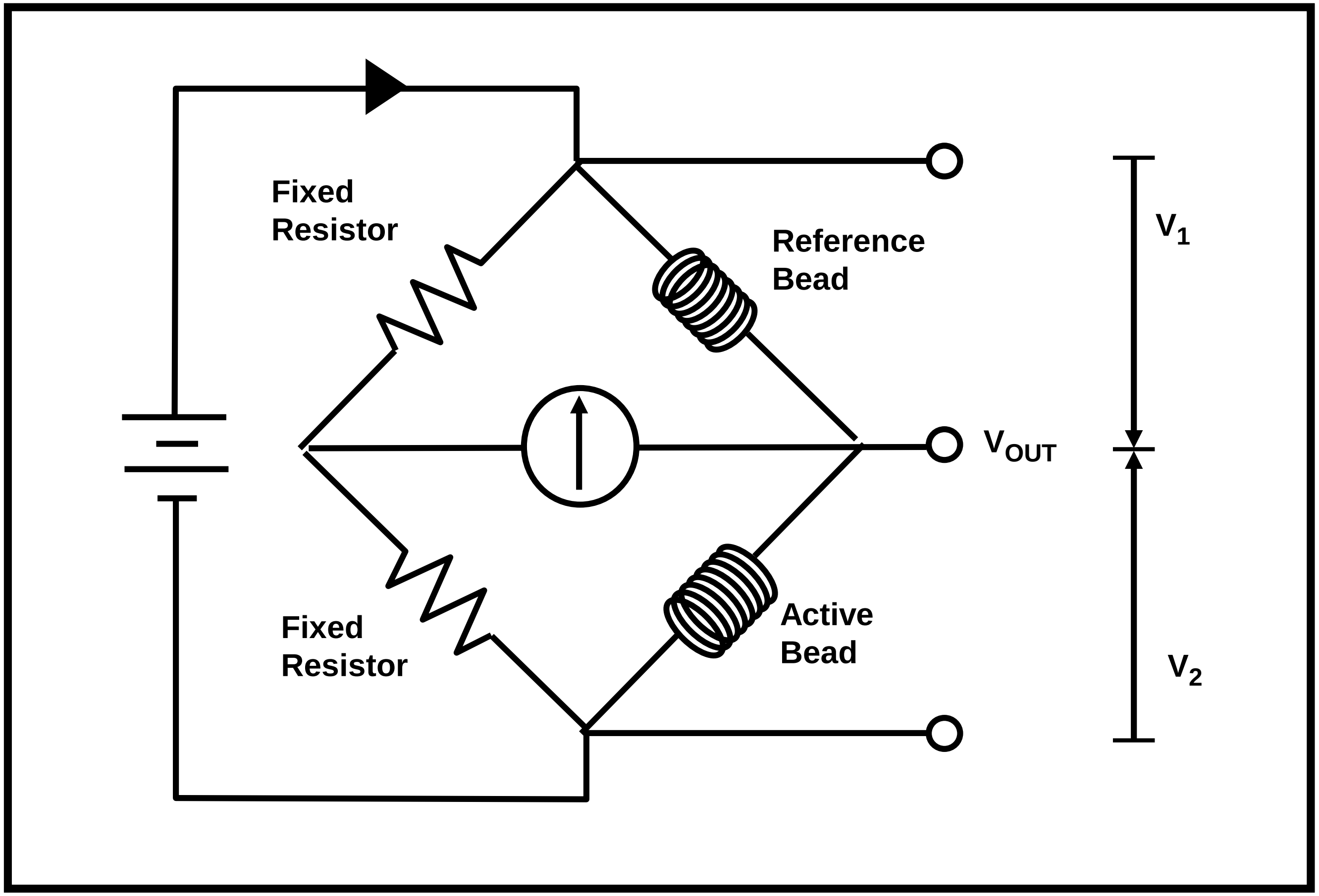
Catalytic “Hot Bead” Combustible Sensor

- Detects combustible gas by catalytic oxidation
- When exposed to gas oxidation reaction causes bead to heat
- Requires oxygen to detect combustible gas!

Balanced Wheatstone Bridge



Combustible Sensors

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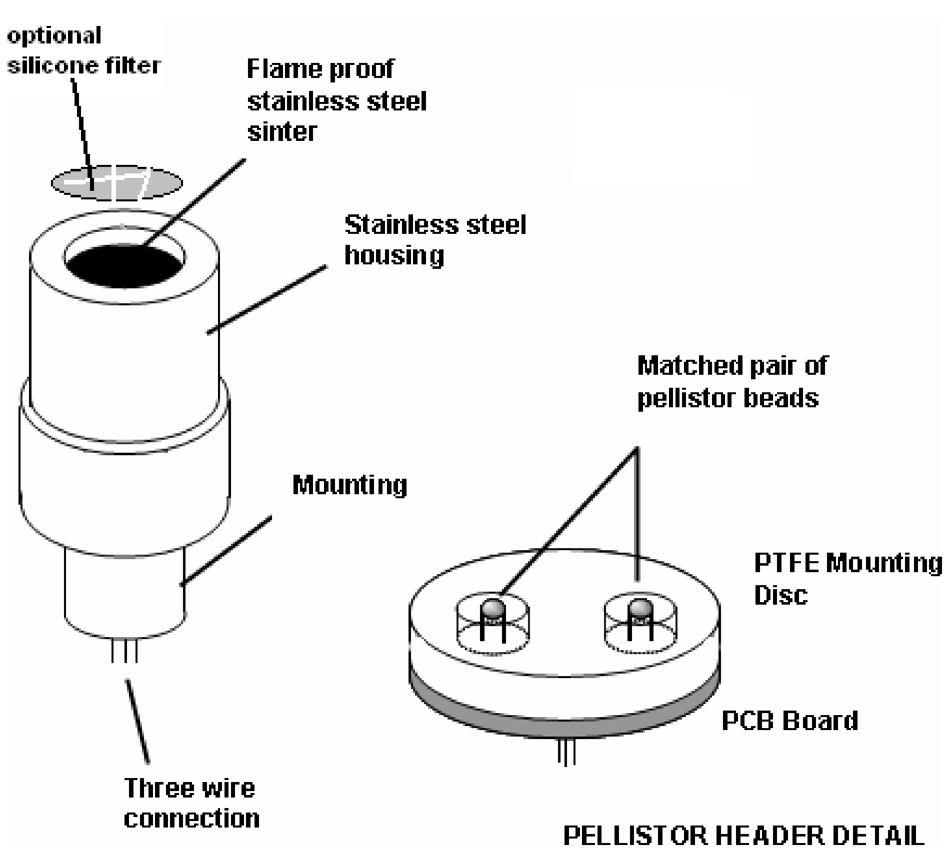

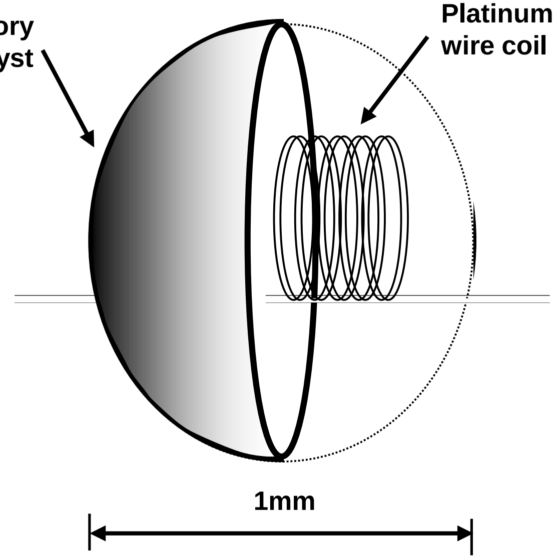

Combustible sensors detect gas by catalytic combustion

Catalytic Sensor Operation

Relative Sensitivity 4P-90C

Honeywell

- Table below shows response variation of 4P-90C CiTipeL on exposure to a range of gases and vapors at the same %LEL concentration
  - Figures are experimentally derived and expressed relative to the Methane signal (=100)

Gas/Vapor	Relative Sensitivity	Gas/Vapor	Relative Sensitivity	Gas/Vapor	Relative Sensitivity
Methane	100	n-Hexane	40	Ammonia	125
Propane	60	Acetylene	80	Cyclohexane	50
n-Butane	60	Carbon Monoxide	105	Ethylene	85
n-Pentane	50	Hydrogen	100	1, 3 Butadiene	55

Each sensitivity has been rounded to nearest 5%

- Note:
  - Results are intended for guidance only
  - For the most accurate measurements an instrument should be calibrated using target gas

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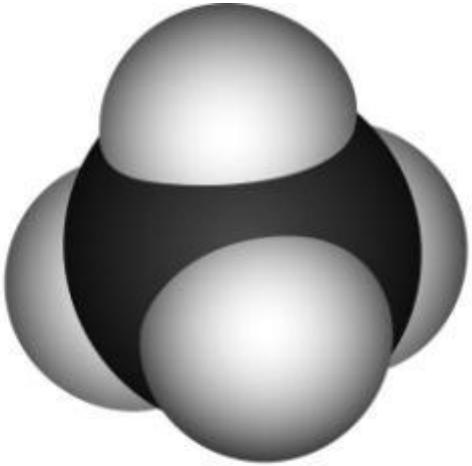
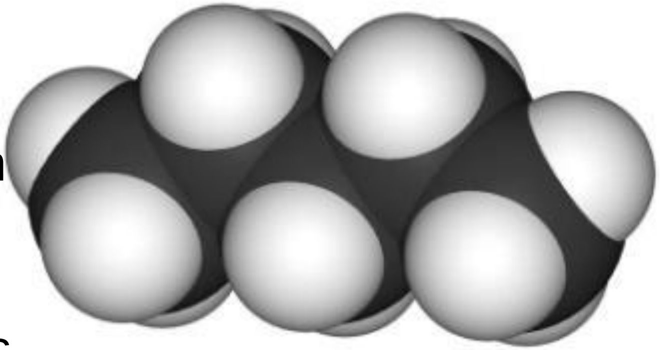
Correction Factors

- Correction factor is reciprocal of relative response
- Consider a detector calibrated on methane, then used to monitor pentane
  - When calibrated on methane, the sensor shows a relative response to pentane of 0.5
  - In other words, the readings will be 50% lower than actual
  - Correction factor would be calculated as: 1 / 0.5 = 2.0

LEL Sensors and Calibration

- BW Technologies by Honeywell chose to calibrate all LEL sensors to Methane
- Methane is a stable tetrahedron and requires more energy to oxidize than other hydrocarbons
- While it is true a monitor calibrated to pentane will alarm on the side of safety in a methane environment, poisoning and over exposure can lead to reduced sensitivity in an LEL sensor.
- An LEL sensor with reduced sensitivity may potentially respond to pentane and not to methane.
- The only way to be certain if an LEL sensor can detect methane is to challenge it with methane
- Alarm levels are set conservatively in order to compensate for the correction factor differences





Combustible Sensor Poisons

- Silicones
  - Lubricants such as WD-40
  - Rust inhibitors
  - Hand moisturizers
  - Hand sanitizers
  - Cleaners such as ARMOR ALL
- Hydrogen sulfide and other sulfur containing compounds
- Phosphates and phosphorus containing substances
- Lead containing compounds (especially tetraethyl lead)
- Over exposure to combustible gases

Monitor Cleaning

Honeywell

- In addition to the use of a soft damp cloth as recommended in the BW User Manual the only approved cleaner is ACL Staticide
- Avoid exposing the sensor screens to moisture – do not use computer keyboard air dusters to clean debris from sensor filters
- BW does not recommend the use of products such as EconoClean, citrus based cleaners or Armor All

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Silicone Filtered vs Unfiltered Response

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- Filter removes silicone vapor – a profound sensor poison
- Filter also reduces response to heavier hydrocarbons such as pentane, hexane, benzene, toluene, xylene, cumene, etc.
- The heavier the compound, the greater the reduction in response. Nonane cannot be detected

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Toxic Gases and Vapors

- Detection technologies:
  - Electrochemical Sensors
  - Photo-ionization detectors (PID)
  - Non-dispersive infrared (NDIR)

Substance Specific Electrochemical Sensors

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- Gas diffusing into sensor reacts at surface of the sensing electrode
- Sensing electrode made to catalyze a specific reaction
- Use of selective external filters further limits cross sensitivity

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Electrochemical Toxic Sensor

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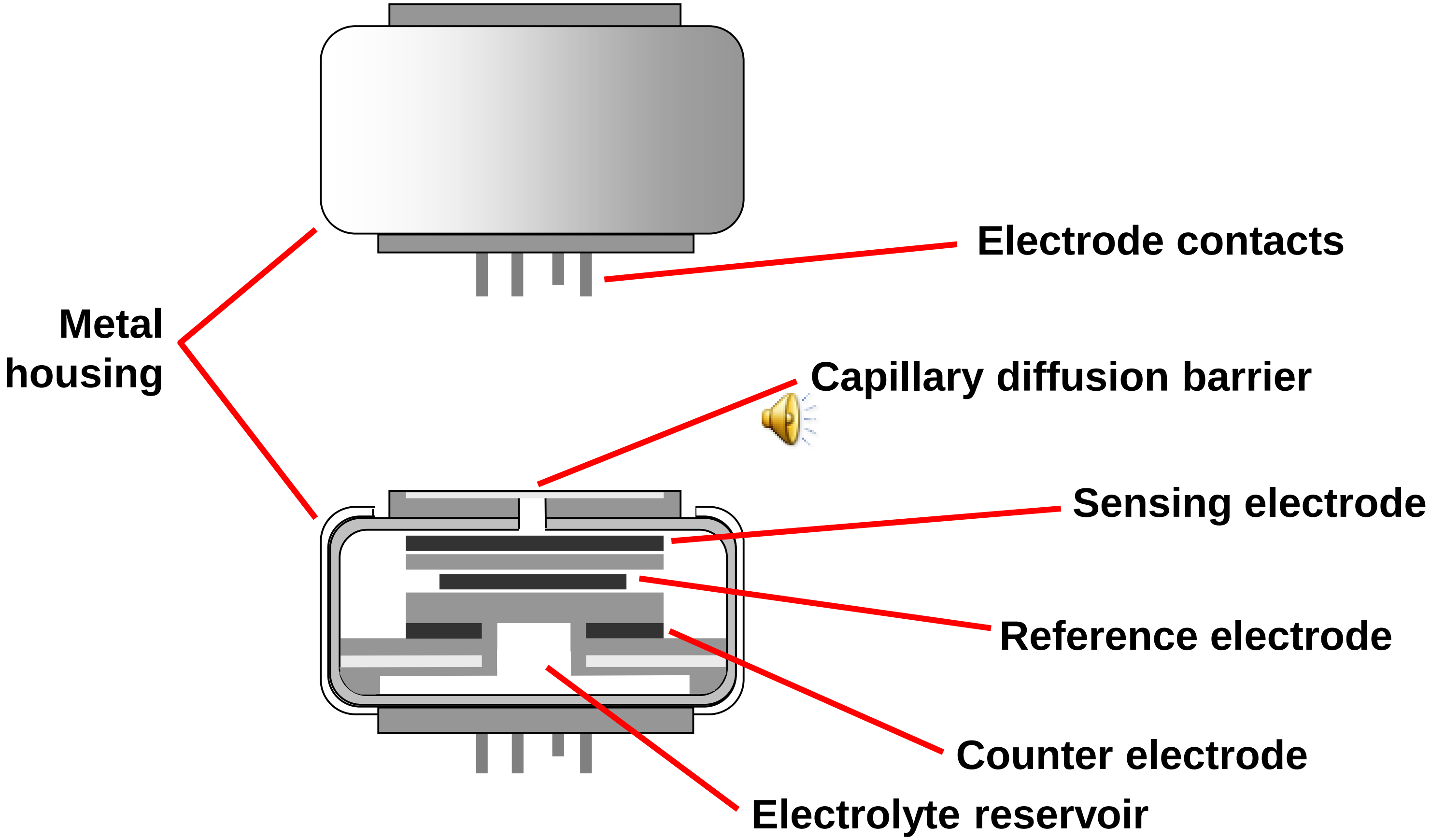

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H2S Sensor Performance

CO and H2S Sensor Detection Mechanism

Honeywell

Carbon monoxide is oxidized at the sensing electrode:

$CO + H_2O \rightarrow CO_2 + 2H^+ + 2e^-$

The counter electrode acts to balance out the reaction at the sensing electrode by reducing oxygen present in the air to water:

$1/2O_2 + 2H^+ + 2e^- \rightarrow H_2O$

And the overall reaction is: $CO + ½O_2 \rightarrow CO_2$

4CF Signal Output: 0.07 μ A / ppm CO

Hydrogen sulfide is oxidized at the sensing electrode:

$H2S + 4H2O \rightarrow H2\,SO4 + 8H+ + 8e-$

The counter electrode acts to balance out the reaction at the sensing electrode by reducing oxygen present in the air to water:

$2O2 + 8H+ + 8e- \rightarrow 4H2O$

And the overall reaction is: $H2S + 2O2 \rightarrow H2\,SO4$

4HS Signal Output: 0.7 μ A / ppm H2S

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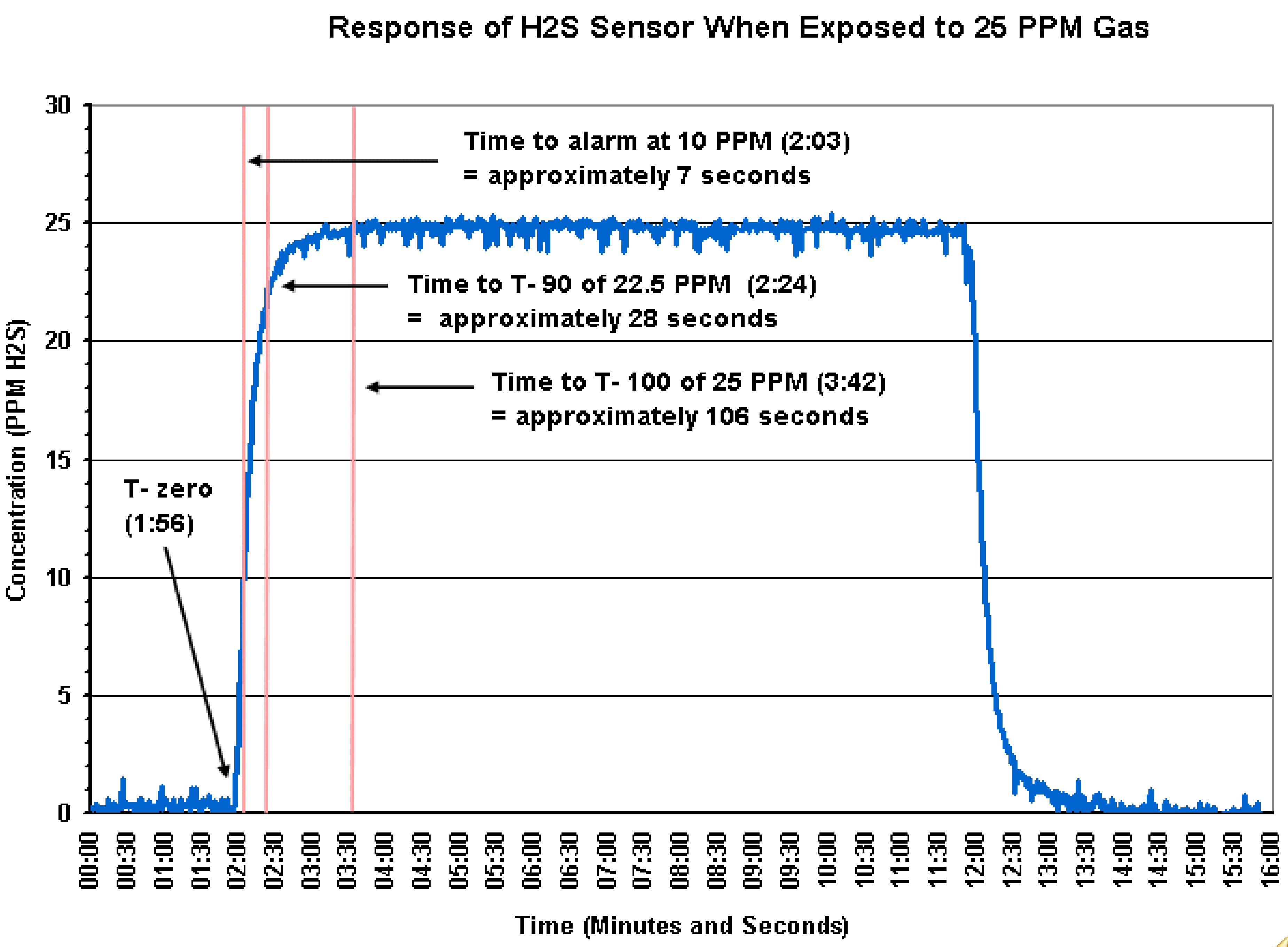

Response of H2S Sensor When Exposed to 25 PPM Gas
Time to alarm at 10 PPM (2:03)
= approximately 7 seconds
Time to T- 90 of 22.5 PPM (2:24)
= approximately 28 seconds
Time to T- 100 of 25 PPM (3:42)
= approximately 106 seconds
T- zero
(1:56)
Concentration (PPM H2S)
0
5
10
15
20
25
30
00:00
00:30
01:00
01:30
02:00
02:30
03:00
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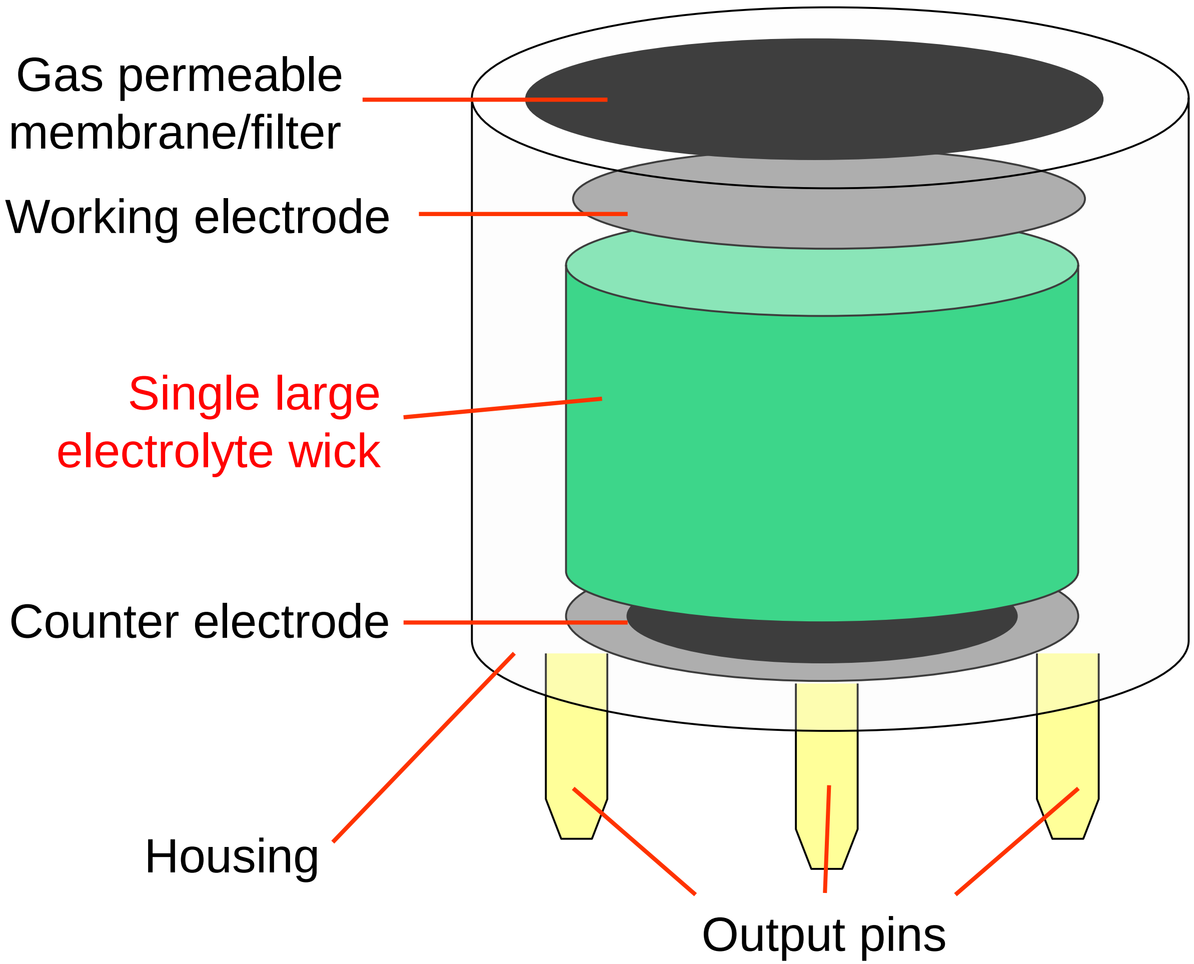
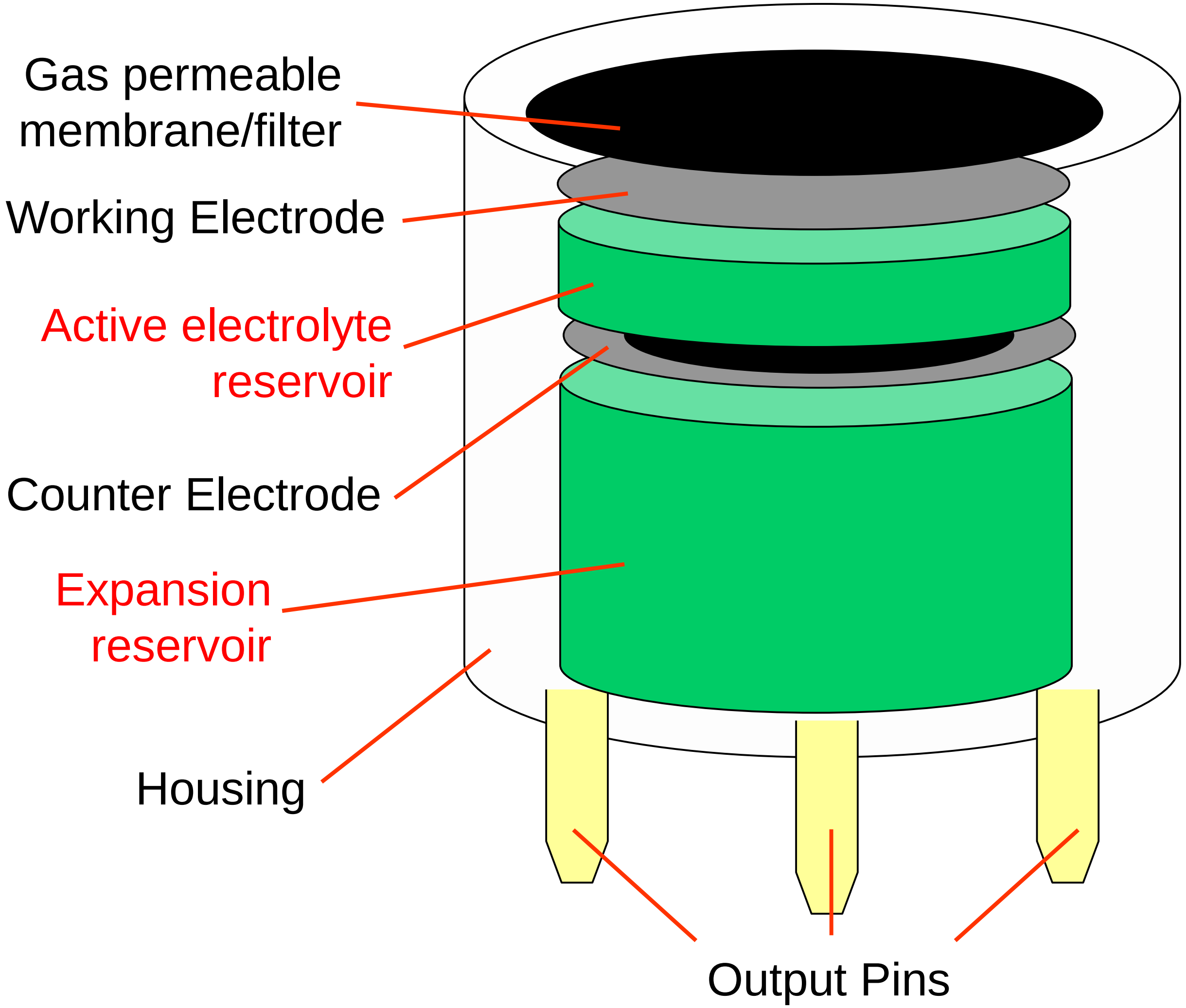
15:30
16:00
Time (Minutes and Seconds)

Standard Electrochemical Sensor Design



- How does it work?
  - Chemical reaction generates electrical current
- Why Do We Use It?
  - No Mechanical Parts
  - Linear response to gas concentrations
  - Generally reliable and economical
- Challenges
  - Sensitive to temp and humidity extremes
  - Speed of response
  - Cross sensitivity
  - CO2 sensor requires constant bias

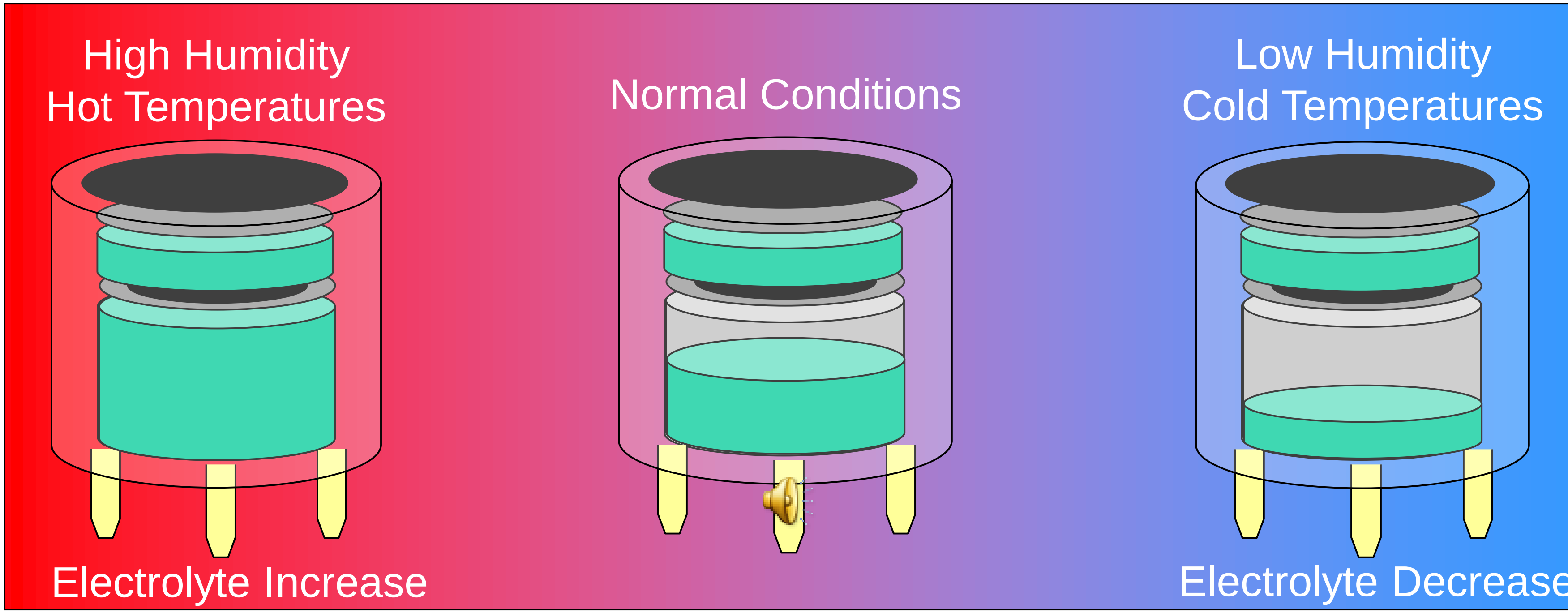
Honeywell SureCell Electrochemical Design



- Advantages
  - Separate electrolyte reservoirs allow for expansion and contraction under extreme conditions
  - Faster speed of response
  - Better linearity
  - Longer calibration intervals

SureCell advantages

Honeywell



- Prevents cell bursting/leakage in high temperature and humidity environments
- Prevents dehydration in low temperature & humidity environments
- Produces faster and more reproducible response times
- Decreases warm-up time
- Reduced cross-interferences to VOCs

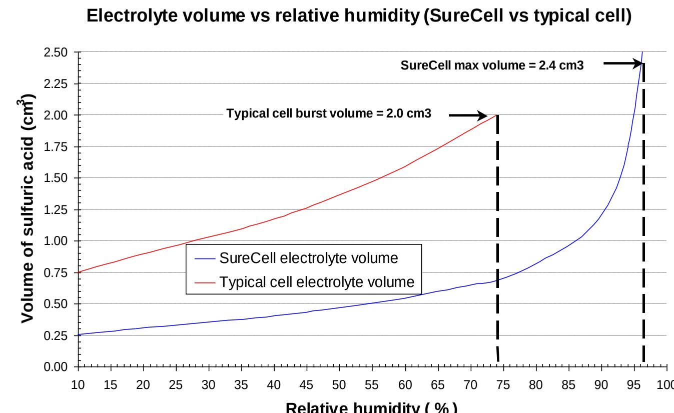


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Photo-ionization Detectors

Honeywell

- Measuring Solvent, Fuel and VOC vapors in the workplace environment

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Volatile Organic Compounds (VOCs)

Honeywell

- VOCs are organic compounds characterized by tendency to evaporate easily at room temperature
- Familiar VOCs include:
  - Solvent, Paint thinner, Nail polish remover, Gasoline, Diesel, Heating oil, Kerosene, Jet fuel, Benzene, Butadiene, Hexane, Toluene, Xylene, many others

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PID Operating Principle

- PIDs use ultraviolet light as source of energy to remove an electron from neutrally charged target molecules creating electrically charged fragments (ions)
  - Produces a flow of electrical current proportional to the concentration of contaminant
- Amount of energy needed to remove an electron from a particular molecule is the ionization potential (or IP)
- Energy must be greater than the IP in order for an ionization detector to be able to detect a particular substance

Ionization Potential

Honeywell

- IP determines if the PID can detect the gas
- If the IP of the gas is less than the eV output of the lamp, the PID can detect the gas
- Ionization Potential (IP) measures the bond strength of a gas and does not correlate with the Correction Factor
- Ionization Potentials are found in the NIOSH Pocket Guide and many chemical texts
- IP is sometimes referred to as IE (ionization energy)

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How does a PID work?

Honeywell

Ultraviolet light used to remove electron from neutrally charged target molecules creating electrically charged fragments (ions)

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Technical Advances in PIDs

- Miniaturization
- Ruggedness
- EMI/RFI resistance
- Lower humidity interference

Critical PID Performance Issues

Honeywell

- Condensation and contamination on lamp window and sensor surfaces can create surface conduction paths between the sensing and counter electrodes
- If present, these currents cause false readings and / or add significant noise that masks intended measurement
- Buildup of even minor contamination provides nucleation points for condensation, leading to surface currents
- Most PID designs are forced to depend on active pumps, “ozone scrubbing”, or frequent cleaning of the lamp and detector to minimize the effects of contaminants and humidity condensation on PID readings

Critical PID Performance Issues: Humidity Effects & Contamination

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PID Performance

Honeywell

- Detector assembly
  - Electrodes:
    - Sensing
    - Counter
    - In some designs - fence
  - Lamp:
    - 10.6 eV
- BW PID
  - 7 Series formatted miniaturized PID
  - Fence electrode: electrostatically collects charged fragments, prevents accumulation on window and collector electrodes
  - Replaceable electrode stack: very inexpensive consumable component
  - Easy to use lamp cleaning kit

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PID as "Broad Range" Sensor

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- VOCs usually detected by means of broad range sensors
- Broad range sensors provide overall reading for general class or group of chemically related contaminants
- Cannot distinguish between different contaminants they are able to detect
- Provide single total reading for all detectable substances present

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Correction Factors

10.6 eV Correction Factors

	RAE	BW	ION		RAE	BW	ION
Acetaldehyde	5.5	4.7	4.9	Jet fuel (JP8)	0.6	0.6	0.7
Acetone	1.1	1.1	0.7	Kerosene	n/a	1.1	0.8
Ammonia	9.7	11.2	8.5	Methylethylketone	0.9	0.9	0.77
Benzene	0.5	0.5	0.5	Naptha (iso-octane)	1.2	1.1	1.1
Butadiene	1	0.9	0.85	Styrene	0.4	0.46	0.45
Diesel fuel	0.8	1	0.75	Toluene	0.5	0.53	0.51
Ethanol	12	13.3	8.7	Turpentine	0.4	0.45	0.45
Ethylene	10	10.1	8	Vinyl chloride	2	2	2.2
Gasoline	0.9	0.7	1.1	Xylene	0.4	0.5	0.43
n-Hexane	4.3	4.3	3.3				

Non-dispersive Infrared Gas Detectors

Honeywell

- Many gases absorb infrared light at a unique wavelength (color)
- In NDIR sensors the amount of IR light absorbed is proportional to the amount of target gas present

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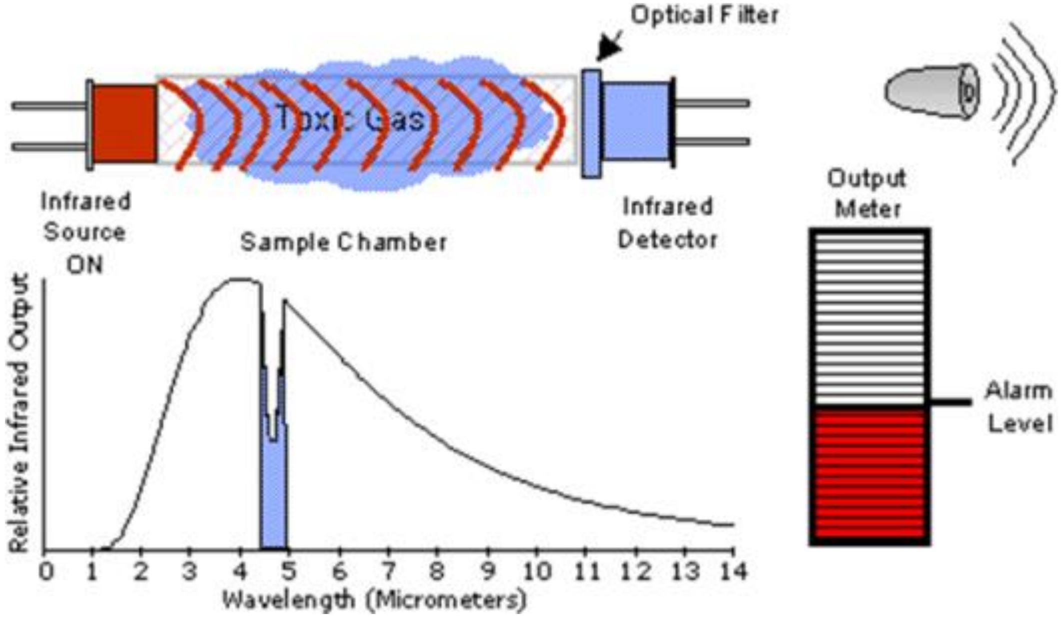
Infrared Detectors

- Chemical bonds absorb infrared radiation
- For infrared energy to be absorbed (that is, for vibrational energy to be transferred to the molecule), the frequency must match the frequency of the mode of vibration
- Thus, specific molecules absorb infrared radiation at precise frequencies

Infrared Detectors

Honeywell

- NDIR detector measures absorbance at specific wavelength to determine concentration of target gas
  - When infra-red radiation passes through a sensing chamber containing a specific contaminant, only those frequencies that match one of the vibration modes are absorbed
  - The rest of the light is transmitted through the chamber without hindrance
  - The presence of a particular chemical group within a molecule thus gives rise to characteristic absorption bands



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QUESTIONS?