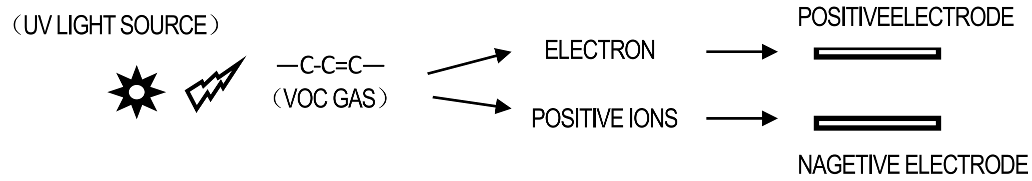
The Application of Photoionization Detector (PID)

1. **Photoionization Detector (PID)**
   The photoionization detector (PID) uses an ultraviolet (UV) light source to break down molecules for measuring the target gas concentration. It is an efficient detector and widely used to measure volatile organic compounds (VOCs) and some inorganic gases in concentrations from 1 ppb (parts per billion) up to 10,000 ppm (parts per million).

2. **Working Principle of PID**



   When UV light is applied to VOC molecules, the VOC will be ionized to produce positively charged ions and electrons. If a pair of collecting electrodes is placed in the ionized region, the electrons will flow to the positive electrode and the positive ions to the negative electrode to create an electric current, which is the signal output of the PID and proportional to the VOC concentration.

3. **Volatile Organic Compounds**
   Volatile organic compounds (VOCs) are organic chemicals that easily evaporate into gases at room temperature. They are generally organic compounds with a low molecular weight or boiling point.

4. **Gases Detectable by PID**
   PID can detect most VOCs and a number of gaseous inorganic substances. Whether a VOC can be detected by PID is dependent on the energy of the UV light and the ionization energy of the VOC. If the UV light energy of a PID is larger than the ionization energy of the VOC molecules, the VOC can be detected by the PID. The light energy of a UV lamp is basically determined by the window material of the UV lamp. The most used UV lamps have three light energies: 9.8 eV, 10.6 eV and 11.7 eV. Among those, the 10.6eV UV lamp is most commonly used for VOC detection. 9.8 eV lamps are used for the detection of benzene or benzene derivatives. Due to the special window material, the service life of 11.7 eV UV lamps is short, and it is mainly used for special VOC detection. The ionization energy of VOC can be found in the "Physical Properties Table of Organic Compounds" in the reference book.

5. **PID Light Source - UV Lamps**
   UV lamp selection is based on what VOCs to measure and the consideration of sensitivity and life time of the lamp. Because of different material and bonding processes used to adhere the UV lamp window, the lamp life time has the order of 10.6 eV > 9.8 eV >11.7 eV. In general, larger lamps have the better long-term stability,

sensitivity and life span. Here are the UV lamp selection rules for the detection of different VOCs:

- **10.6 eV UV lamp:** detecting most 3-carbon hydrocarbons and all VOCs of more than 4 carbons, plus some 2-carbon VOCs.
  1) Except methane, ethane, propane, acetylene, it can detect all alkanes, alkenes and alkynes, and some halogen compounds
  2) Except methanol, formaldehyde and most of fluorine, chlorine and bromine, it can detect all alcohols, aldehydes, ketones and lipid VOCs
  3) It can detect all amines and organic sulfides.
- **9.8 eV UV lamp:** suitable for the detection of aromatic and unsaturated organic compounds with 6 carbon or above, such as benzene, toluene, ethylbenzene and xylene.
- **11.7 eV UV lamp:** detecting all VOCs that 10.6 eV lamp can detect as well as methanol, formaldehyde, acetylene, and most of the organic compounds with fluorine, chlorine and bromine.

6. Calibration

Similar to other gas sensors, PID needs to be calibrated periodically. Using a standard gas prepared for the target VOC at a specific concentration near the expected measurement range is the most precise way to calibrate a PID. In principle, if the PID is perfectly linear, any calibration concentration could be used, and calibration at two points is good enough including zero point and one span point. Zero point should be calibrated by zero air (VOC free) or pure nitrogen gas (N2), and span gas should use air as balance to reduce the systemic error. More practically or close to most applications, zero air and span gas using air balance are recommended for PID calibration. Furthermore, if the target gas and the measurement range are known, it is important to match the span concentration to the maximum measurement concentration, or the higher concentration gas should be chosen for calibration. For example, when 60 ppm benzene in the environment needs to be monitored, the calibration gas for the sensor should be 100 ppm. If the PID linearity is questionable, more span points are highly recommended to ensure the accuracy of the measurement. If the target VOC is unknown, isobutylene (IBE) is the most well-known PID calibration gas due to its low cost, accessibility, intermediate sensitivity, and has exceptionally low toxicity. Using isobutylene calibration typically in the range 100 – 2,000 ppm is a common practice. Because of the good linearity at low concentrations for the low ppm measurements, calibration at 100 ppm is usually used. The issue of using 1 ppm (1,000 ppb) IBE calibration gas for measurements in the 10 - 1,000 ppb range is the accuracy of the calibration gas because it is difficult to be certified to be better than 20% accuracy. It is necessary to notice that linearity may be good for IBE, but different for other VOCs.

The calibration frequency is determined according to the cleanliness of the environment where the PID is used or deployed. Generally, the calibration frequency can be lower in a clean environment. In a relatively dirty environment, higher calibration frequency provides a more accurate measurement. For general conditions, the recommendation for the calibration frequency is once a month.

7. Correction Factors and Correction Coefficients

The PID has high sensitivity and a fast response time to VOCs, but the selectivity is quite low. It responds to almost all VOCs that have ionization energies lower than the energy of the UV lamp. Calibration is usually done by using a known VOC like IBE, but other VOCs are measured. Due to the different sensitivities of various VOCs to the PID, it is necessary to correct the measurement between the VOC to be measured and the calibration VOC like IBE This correction coefficient is called the correction factor. The ratio of the calibration VOC sensitivity with the same concentration to the sensitivity of the VOC to be measured is used to calculate the correction factor. For example, if the PID is calibrated with 100 ppm IBE, the response of 50 ppm benzene on the sensor is 100 ppm, the correction factor relative to IBE is 0.5 in this case. In general, UV lamps and electrodes used in those PID sensors available in the marketplace are very similar. Theoretically the correction factors among those PID sensors should have no significant differences However, it is always recommended to take the data provided by the PID manufacturer for desired accuracy of the measurement.

8. Maintenance of PID

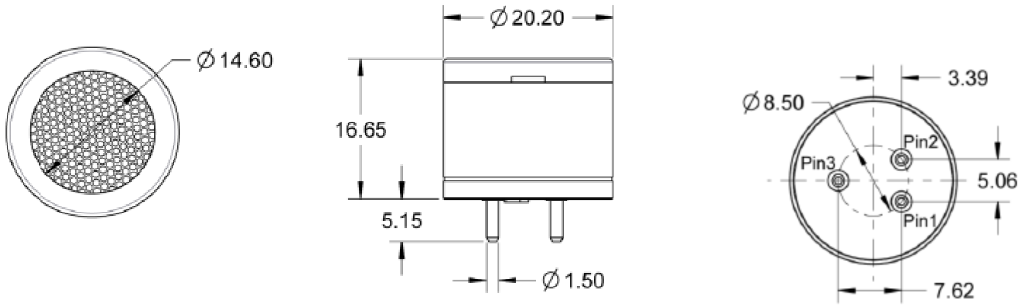
The electronic part of a PID is usually maintenance free, however, the UV lamp and the detection electrodes need to be maintained and cleaned periodically. Depending on the environment where the PID is used, the maintenance frequency can vary. The PID is not recommended to be used continuously in wet and dirty environments for a long time if a filtration of dehumidification and dirt removal is not in place. The maintenance work is mainly to clean the window of the UV lamp and the detection electrodes. Here are the cleaning details:

- Wear gloves or finger cots to grasp the UV lamp and detection electrodes.
- Use a cotton swab to stick some aluminum trioxide powder to rub the window of the UV lamp to remove the contaminants.
- If the contamination is just oil or dust, moisten a cotton swab with reagent-grade methanol or other organic solvent like acetone and isopropyl alcohol to gently clean the window of the UV lamp and the surface of the detection electrodes.
- Wipe the window of the UV lamp and the surface of the detection electrodes with dry cotton swabs to ensure that it is shining and free of any foreign substances.
- Keep the UV lamp and detection electrodes in a clean environment until the solvent is completely volatilized.

After reassembling, calibration is needed before the next use. For the applications in the clean environment like indoor air quality monitoring, it is generally recommended to perform the maintenance once a month. For the applications in the environment with a high concentration of VOC, dust, or other pollutants, the maintenance should be performed frequently and as soon as the decline of the PID sensitivity is observed. If the PID sensor is still not sensitive enough after cleaning, the replacement of the UV lamp should be considered. If the PID sensor is too sensitive to the humidity, or the baseline is unstable after cleaning and calibration, the detection electrodes need to be cleaned again or replaced.

9. Introduction of 4S PID

4S PID is a 4-Series PID sensor with DC voltage outputs and designed for the detection of 0-10,000 ppm VOCs. The resolution can be chosen from 5 to 1,000 ppb (1 ppm) based on the applications. It is powered by 3.3 to 5.5 VDC. The maximum working current is less than 80 mA. The 4S PID is packaged in a stainless-steel enclosure with more details shown below.



Pinout	Pin 1	Vcc	Power supply positive
	Pin 2	GND	Power supply ground
	Pin 3	Vout	Analog signal output

A DC power supply must be used with the voltage output between 3.3 and 5.5 V. If the voltage is lower than 3.3 V, the sensor will have no response and no output to VOCs. If the voltage is higher than 5.5 V, it will damage the internal power integrated circuits and cause the sensor to be damaged permanently. So choosing a DC power supply with the output between 3.6 or 5.0 V is recommended. For high resolution 4S PID, the applied voltage from the DC power supply should be stable and have no ripples within 10 MV, and never exceed 20 MV to prevent fault signal outputs.

Before powering the 4S PID, please carefully read the pinout diagram to ensure the DC power supply is connected correctly. A reversed connection will damage the internal power integrated circuits and cause the sensor to be permanently damaged.

The working current of the 4S PID is less than 80 mA during normal operation. However, it takes a sudden large current about 120 mA and lasts 200 ms to ignite the UV lamp. Therefore, the design of the power supply circuit for the sensor needs a redundant energy to ensure the successful start-up of the sensor when it is powered up.

The output signal of the 4S PID usually does not exceed 2.5 V so that it can be directly connected to ADC, voltage follower or MCU pin. Due to the large internal resistance of Vout (⩾100 K), it is not recommended to directly connect it with an amplifier or directly use the impedance divider circuit to process the signal output.