# A WHITE PAPER:
# Air Ionization

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## Introduction

The purpose of this White Paper is to provide an overview of air purification by cold plasma ion generators (also known as non-thermal plasmas) with particular reference to products manufactured by Top Products Innovations. Areas covered include the chemistry and physics of cold plasma generators, their benefits and applications in air purification, and disinfection, including the removal of odors, volatile organic compounds (VOCs), pathogens and particulates. Recognizing that some readers will not have a strong scientific background, technical issues are simplified as much as possible.

## Background

The air we breathe outside typically contains 2000 – 3000 ions per cubic centimeter (cc). Ions, in the context used here, are negatively or positively charged gas molecules. They are generated naturally in many ways, such as by lightning, flowing water such as waterfalls, cosmic rays that continuously bombard the earth from space, UV, and even by some plants. Being reactive species, they act as air purifiers, oxidizing and eliminating pollutants, deactivating pathogens, and aggregating particulates so they can be easily filtered out. Indoor air, unless otherwise supplemented, typically contains just 10% of the outside air level of ions leading to sick building syndrome. More on these various points later.

## What is Plasma?

In the sense we are using the word here, plasma is one of the four states of matter in addition to solids, liquids, and gases and consists of a gas of ions and (initially) free electrons. The positive ions are gas molecules with one or more of their orbital electrons removed, and the negative ions are molecules that have gained one or more electrons. Overall, plasmas are essentially electrically neutral. Plasmas can be artificially generated by putting sufficiently high energy into a neutral gas, subjecting it to a strong electromagnetic field or a sufficiently high temperature. In everyday life, we typically meet partially ionized plasmas containing a mixture of neutral gases and ionized gases. Examples include neon signs, hot flames such as oxyacetylene torches, plasma TVs, and air purification devices.

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The air we breathe on average consists of 78% nitrogen, 21% oxygen, 0.04% carbon dioxide, and the balance consists of water vapor and the so-called inert gases, including helium, argon, neon, and xenon. The amount of energy required to ionize a gas is known as ionization energy (sometimes called its ionization potential) and is measured in electron volts (eV). Different gases require (typically) different energy levels to cause ionization, as is illustrated in the table below.

| Gas | Ionization Energy (eV) |
|---|---|
| Dioxygen ($O_2$) | 12.1 |
| Water vapor ($H_2O$) | 12.6 |
| Atomic Oxygen (O) | 13.6 |
| Carbon Dioxide ($CO_2$) | 13.8 |
| Nitrogen ($N_2$) | 14.5 |

Bipolar air ionizers create charged air molecules. By either adding or removing an electron, air molecules are given a negative or positive charge. The types of ionic species generated by a cold plasma air ionization unit depend on the input energy. As is used by TPI, limiting the input energy level to 12.7 eV is sufficient to directly ionize water vapor and molecular oxygen but not atomic oxygen.

$$O_2(g)+\Delta\rightarrow O_2^{+}(g)+e^{-}$$

$$H_2O(g)+\Delta\rightarrow H_2O^{+}(g)+e^{-}$$

The liberated electrons, e-, then attach themselves in varying degrees and ways to the other air molecules giving a host of other negative air ions, including several oxygen anions such as the superoxide radical anion [2].

$$O_2 + e^{-} \rightarrow O_2\cdot^{-}$$

The superoxide radical anion is especially useful in reacting with airborne VOCs and particulate matter, as is discussed later. The reaction also generates hydroxyl radicals (OH.), which play a significant role in deactivating pathogens.

The amount of energy used to generate the plasma in a mixture of gases such as air will control its composition, and the composition is all-important in determining its properties. With reference to the table above, a potential of 13.6 eV or greater is sufficiently high to ionize atomic oxygen directly. Higher potentials generate a number of additional reactive oxygen species (ROS) [3], including those that can lead to the generation of ozone. Ozone is a neutral molecule, naturally present in outside air, but in very low concentrations, ranging from typically 5 to 30 parts per billion (ppb).

Ozone is a highly reactive and toxic gas that causes damage to mucous and respiratory tissue in animals, as well as tissues in plants, above concentrations of about 100 ppb. (However, like many things, a little might be even good for you while more is bad. Low dose ozone treatment is used medically for several conditions such as in diabetic angiopathia, diabetic foot, chronic hepatitis, and chronic intestinal disorders [4] ). Ozone can be produced by a number of electrically operated machines, including electric motors, medical equipment, laser printers, photocopiers, and automobiles. Industrially, the exposure level is regulated by the EPA to no more than 50 ppm averaged over 8 hours.

Reactive oxygen species show a spectrum of reactivity before they recombine or interact with something else, such as a pathogen or pollutant. The lifetime of air ions depends on their type and concentration. Highly reactive air ions or free radicals such as the hydroxyl radical HO. can have lifetimes measured in microseconds ranging up to about sixty seconds or more for poorly reacting ones such as water ion clusters. Lifetimes of ions are shorter, the higher their concentrations (or conversely, lifetimes are longer, the lower their concentrations as there is less chance of them hitting something and interacting with it).

To summarize, the types of ionic species that can be generated by a cold plasma unit depend on the input energy. Limiting the input energy level to 12.7 eV, as is used by TPI, virtually eliminates the production of ozone down to 5 ppb, which, as noted above, is around the lower limit of what is naturally present in outside air.

Cold plasma air ionization devices have a long history going back a hundred years and have been used in the US for residential and commercial air purification since the 1970s. During this time, the technology has continued to evolve.

## Volatile Organic Compounds

We meet VOCs in various ways, such as paints, varnishes, adhesives, nail polish, cleaners, cooking odors, and body odors, to name but some. As gases, they too can be ionized in plasma, and by interacting with the air, ions are converted in the main to water vapor and carbon dioxide. Many VOCs have ionization energies below 12.7 [5], as is illustrated by a partial listing below.

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| Compound | eV | Compound | eV | Compound | eV | Compound | eV |
|---|---|---|---|---|---|---|---|
| Pinene | 8.07 | Tetrachloroethylene | 9.30 | Ethyl acetate | 10.01 | Acetic acid | 10.65 |
| Naphthalene | 8.14 | THF | 9.38 | Ammonia | 10.07 | Methanol | 10.85 |
| Limonene | 8.30 | Diethyl ether | 9.51 | Iso-Propanol | 10.17 | Formaldehyde | 10.88 |
| Xylene | 8.50 | MEK | 9.52 | Glyoxal | 10.20 | Propane | 10.95 |
| Toluene | 8.82 | Acetone | 9.70 | Methyl acetate | 10.25 | Acetylene | 11.40 |
| Furan | 8.88 | Octane | 9.80 | Ethanol | 10.40 | Chloroform | 11.40 |

This assists in their destruction by the air ionization unit as they are oxidized to water and carbon dioxide.

## Particulate Matter PMx

The air we breathe contains particulates of a number of different sizes [6]. The terminology PMx is used to indicate their size, so PM2.5 refers to particles with a size of 2.5 microns (where a micron is one-millionth of a meter). For reference, a typical human hair has a diameter of about 75 microns ( 3 mils). Airborne particles typically have diameters of 10 microns or less (of course, they are not usually exactly spherical, but it is convenient to classify them as such). Some particulates occur naturally, such as from dust storms, volcanoes, forest and grassland fires, others are produced by human activity such as burning of fuels in cars, power plants, home heating, road dust, and various industrial processes including the processing of minerals.

For air pollution purposes, particulates are classified into two main size ranges. PM10 and PM2.5. PM10 consists of particles 10 microns and smaller and PM2.5 of particles 2.5 microns and smaller. The latter are particularly dangerous as they can be inhaled into the lower respiratory system, and with enough exposure, absorbed into the bloodstream. Particulate exposure has been associated with adverse respiratory symptoms ranging from irritation of the airways, aggravated asthma, coughing, and difficulty breathing from acute exposure to symptoms such as irregular heartbeat, lung cancer, kidney disease, chronic bronchitis, and premature death in individuals who suffer from pre-existing cardiovascular or lung diseases due to chronic exposure [7].

Reducing the particulates in the air then has obvious health benefits. The best way to remove them is to use air ionizers to generate positive and negative ions. Airborne particles become oppositely charged, attracted to each other, and consequently become larger, making them much easier to filter out. Should the air filters in the HVAC system be or become ineffective, a heavier build-up of dust may be noticed in the living environment. This can be easily vacuumed up and is a healthy sign as it shows the air ionizer is effective and making large particles out of small ones that would otherwise have been airborne and breathed in, to the detriment of the people within.

## Pathogens

The terms pathogens and microbes cover a number of potentially bad actors, including viruses, bacteria, mold spores, fungi, and others. They may be present on surfaces, where they are easily disinfected, or airborne. Most usually, they attached to airborne liquid droplets or solid particles, which gives them a safe haven and allows their transport and spread over wide areas. Numerous scientific studies have confirmed that lowering the amount of particulate matter, such as dust in the air, protects people from bacterial and viral infections. As noted above, air ionizers are effective in removing airborne pathogens attached to particulates. Air ionizers are also very effective in deactivating pathogens directly both in the air and on surfaces and rendering them harmless, thus providing a double benefit to their use.

Ionized air also contains a small number of short-lived, very reactive free radicals such as hydroxyl radicals (OH). Free radicals are species carrying no charge but are very reactive due to the presence of unpaired electrons. Hydroxy radicals produce chemical reactions on the surface of the viral envelope that inactivates the virus, such as COVID-19 and other similar viruses, by damaging lipids in the envelope.

Oxygen ions and hydroxyl radicals can also damage viral S protein by drastically changing its shape. With the S protein damaged, a virus cannot infect humans. This is like changing the shape of the key, so it no longer matches the lock.

It should be noted that hydroxyl radicals upon the reaction with viruses, or other microbes, as they do with air pollutants, simply revert to water ($H_2O$).

## Operation of Air Ionizers

Bipolar air ionizers create charged air molecules. By either adding or removing an electron, air molecules are given a negative or positive charge. They can be stand-alone devices or, more effectively, incorporated into the heating and ventilating systems (HVAC) of residential, commercial, or other buildings, as illustrated by the schematic below.

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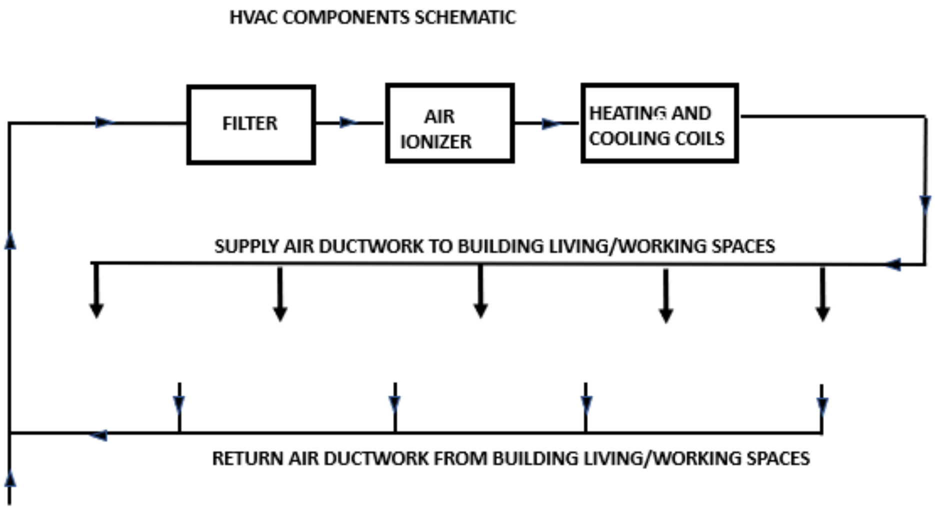


Installation is straightforward as they just need to be inserted into the ductwork and hooked up to a source of power. Their power demands are very low, and they are safe and require minimal maintenance, unlike other air purification devices.

## Benefits of Air Ionizers

As already discussed, air ionizers effectively remove pollutants, particulates, and pathogens from the environment. There have been many studies over the past seventy years as to whether ionized air provides additional health benefits above and beyond these already sterling attributes. Research to date [8] supports that exposure to negative ions reduces symptoms of depression for some people, has an activating influence on some body systems and cognitive performance, and promotes antimicrobial activity. Still, there is insufficient evidence to support that it reduces serotonin to help manage anxiety or lowers blood pressure or improves breathing. Several hours or more exposure to negative ions caused people with chronic depression and seasonal affective disorder (SAD) to record lower scores on surveys of their depression symptoms [9].

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