

Surface Contamination Under Ambient Pressure

We learned in today's class that surface science experiments often require ultra-high vacuum (UHV) conditions to ensure that the surface under study remains clean and uncontaminated. Let's do some problems to understand why UHV is essential for obtaining clean surfaces.

Useful equations:

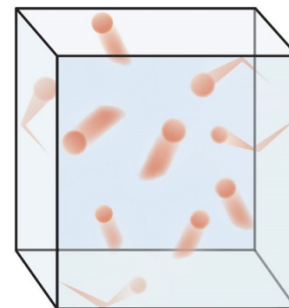
Average molecular velocity of gas molecules, v :

$$v = \sqrt{\frac{8k_B T}{\pi m}}$$

k_B is the Boltzmann constant = 1.38×10^{-23} J/K

T is the temperature in Kelvin = 25°C

m is the molecular mass (for $\text{N}_2 = 28$ g/mol, main component)



Ideal gas law:

$$PV = Nk_B T$$

P is the pressure = $1 \text{ atm} = 1.01 \times 10^5 \text{ Pa}$

V is the volume

N is the total number of molecules

Molecular flux:

$$\Phi = \frac{1}{4} n v$$

n is the number density of molecules

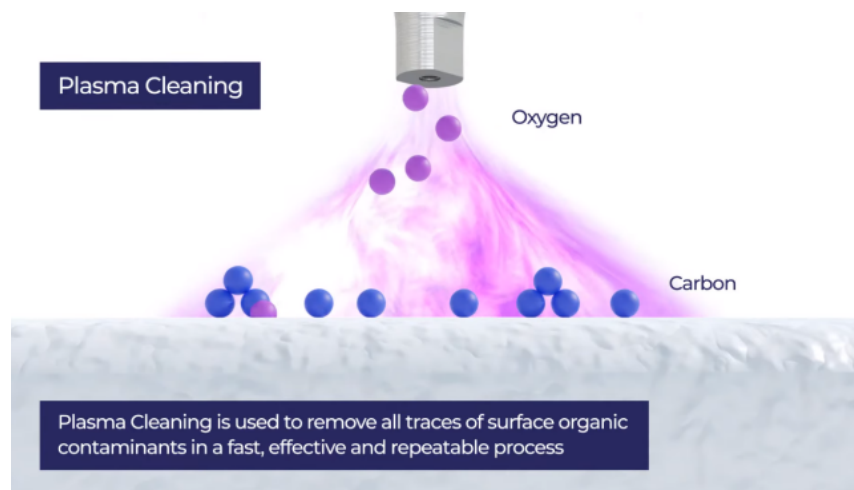
v is the average molecular velocity of gas molecules

1. Assume a surface in a laboratory environment at standard atmospheric pressure (1 atm) and room temperature (25°C). The laboratory air contains nitrogen (78%), oxygen (21%), and trace amounts of water vapor and other gases. Using the kinetic theory of gases, calculate the number of gas molecules that strike a 1 cm^2 surface each second under these conditions.

2. If each molecule (we can assume N_2 again as the main component) occupies an area of 0.1 nm^2 , estimate how long it would take for a monolayer of contaminants to form on this 1 cm^2 surface?

3. Now consider the same scenario under UHV conditions ($10^{-10} \text{ Torr} = 1.33 \times 10^{-8} \text{ Pa}$) and repeat the calculation of the monolayer formation time. Compare the results – can you see why UHV is critical for surface studies?

A solution to clean dirty surfaces is by using plasma cleaning, a surface treatment process that removes contaminants like dirt, oils, and organic residues using a low-pressure, high-energy plasma environment. Plasma, an ionized gas, consists of a mix of ions, radicals, electrons, and neutral species that interact with and break down contaminants on a surface.



A surface contaminated with hydrocarbon molecules C_xH_y is cleaned using an oxygen plasma. The plasma generates reactive oxygen species (ROS) such as O_2^+ , O^+ , and O (atomic oxygen), which react with the hydrocarbon molecules, converting them into gaseous CO_2 and H_2O , which are removed under vacuum.

4. Assume the surface area is 1cm^2 and the plasma density is $1 \times 10^{16} \text{ ions m}^{-3}$. The plasma bombards the surface at a rate of $1 \times 10^{18} \text{ ions m}^{-2} \text{ s}^{-1}$. How long does it take for the plasma to bombard every hydrocarbon molecule on the surface if it is covered by a monolayer of contaminants?

Here are some assumptions:

- Contaminants form a uniform monolayer on the surface.
- Plasma ions react perfectly with no loss or inefficiencies.
- Area of one molecule: $0.1 \text{ nm}^2 = 1 \times 10^{-20} \text{ m}^2$

5. How would this time required to remove the layer of contaminants change if the plasma density was increased by a factor of 10?

Key Takeaways from this Exercise:

- The importance of cleaning surfaces for experiments
- Contaminants in the air can form monolayers immediately on surfaces
- The role of UHV in significantly reducing contamination rates
- Plasma cleaning is an efficient method to ensure clean surfaces