“The Classification of Face Masks and their Distinct Functions”
by

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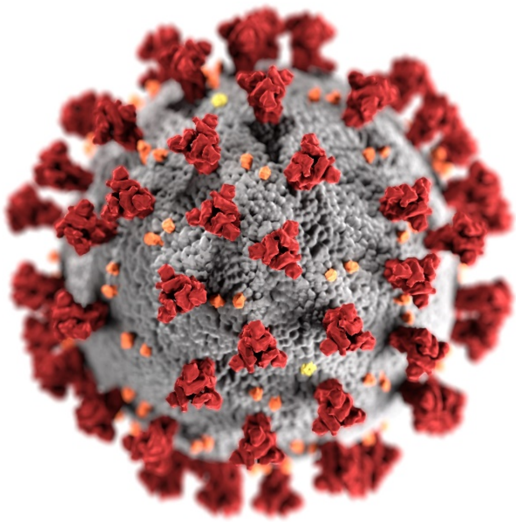
Introduction

The influenza pandemic that kills more than 20 million people worldwide in 1918 is a huge disaster in human history. Air has been proven to be the media to spread out the terrible influenza. The spread of the coronavirus which causes the recent global COVID-19 pandemic is also mainly through the patients’ droplets into the air; therefore, wearing a face mask is the most effective way to avoid inhaling such viruses, bacteria or other harmful substances transmitted through the air or droplets.



▲ Electron microscope photo of coronavirus
(https://scitechvista.nat.gov.tw/c/sTy1.htm)

Face mask firstly appeared in the sixth century BC. It was invented by the Persians who believed in Zoroastrianism (known as Bai Huo Jiao in ancient China), and was used to prevent the uncleaned breath from the mouth and nose when worshipped the so-called "Holy Fire". During the Northern and Southern Dynasties, face masks were introduced to China, and soon became popular throughout the country. According to《Marco Polo's Travels》by Italian traveler Marco Polo, back in the Yuan Dynasty, the emperor would ask the serving waiters to cover their noses with scarves so that their breath would not contaminated the food. The function of the scarves is similar to the face mask nowdays.

1. The classification of face masks:

People gradually realize and accept the idea of wearing face masks in medical cares, thus, face masks have become a daily necessity. To meet different needs, face masks can be classified into various types, which will be briefly introduced as follows:

1.1. General mask

General mask is the kind of face mask to be the obtained in retail stores most easily. Since general mask does not undergo additional treatments and the pores of its fiber structure are quite large (about 1 micrometer), it cannot effectively prevent pathogen transmitted through air. In addition, general mask has no protective effect against dust that is most likely to enter the human respiratory system, but still can isolate dust with large particles. This kind of mask can still be used to keep warm and avoid dirty face and nostrils, but it cannot be used to prevent the invasion of germ. Nevertheless, evidences show that general mask still have a certain resistance effect on the viruses with particle size less than 100 nanometers (nm).

1.2. Activated carbon mask

Activated carbon has a porous structure and the main function of its filter layer is to adsorb organic gases, odorous molecules and toxic dusts, not to filter these substances; therefore it has no sterilization function. In addition, activated carbon masks will lose its effectiveness when all the pores are filled by the absorbed substances. When it happens, the activated mask must be replaced. However, it is not easy to evaluate when the pores will reach absorption saturation. Activated carbon mask will attract virus particles to its surface but has no capability to kill the viruses. As a result, accidental contact with the surface of active carbon masks through hands, eyes, nose or mouth will still cause disease transmission.

▲ Activated carbon mask has no sterilization function.
(http://www.tsetech.com.tw/tw/goods.php?act=view&no=65)

1.3. Surgical mask

The purpose of surgical masks is originally to avoid influence of doctors' droplets on patients. Its design is not to avoid the inhalation of harmful particles. Although its effectiveness is better than that of cotton yarn masks and cloth printing masks, it only shows 70% of effectiveness at most. The effectiveness of surgical mask on preventing infection from viruses is very limited. A standard surgical mask has three layers: the outer layer is dust- and water-proof and can prevent droplets from penetrating the mask; the middle layer exhibits filtering effect and can block more than 90% of particles with ≧ 5 microns; and the inner layer has hygroscopic function.

▲Surgical mask is designed to mainly avoid the doctors' droplets from affecting the patients, so its antibacterial effect is limited.
(https://yasco.com.tw/tw/productDetail.asp?id=82324)

Charged filter mask

According to 3M, a major manufacturer of charged filter masks, the function of such masks is mainly to facilitate breathing, not to filter particles. This filtering function of filtering of charged filter masks comes from the layer of activated carbon under the charged filter material. The filtering mechanism may be the same as the activated carbon mask, which means that it has the same limitations as for the activated carbon mask. There is a layer of adhesive resistance filter material, used to enhance its lifespan and increase its comfort.

Although different masks have distinct filtering effects, their efficiency to filter impurities with various particle sizes in the air all shows a U-shaped curve. It indicates that impurities can be filtered out by different kinds of face mask, regardless of particle sizes.

2. How face masks filter out dusts:

There are five mechanisms for filtering dusts:

2.1. Brownian Motion

When Robert Brown, a British botanist, used a general microscope to observe the pollen grains suspended on the water surface, he found that these pollen grains would make continuous, rapid and irregular random movements, which are called “Brownian motion”.

Small particles in the air will be hit by the air and make intense twists and turns, such kind effect becomes more obvious for particles with even smaller sizes. Because all the particles in the surrounding air (about 10^{19} gas molecules or particles per cubic centimeter) are moving at a fairly fast rate, the chance of collision between the particles is increased. Their movement trajectories is irregular, which significantly increases the chance of contact between the particles and the filter material. Such kind of effect is getting more obvious when the particle sizes is getting smaller.

2.2. Interception

The basic principle of interception is to make effective separation according to the particle size of the intercepted particles, so this effect basically varies with the size of the pores of the filter material. If the particle size is larger than the pores of the filter material, it will be blocked on the surface of the filter material. Theredore, the larger the particles, the better the filtering effect.

2.3. Inertial impact

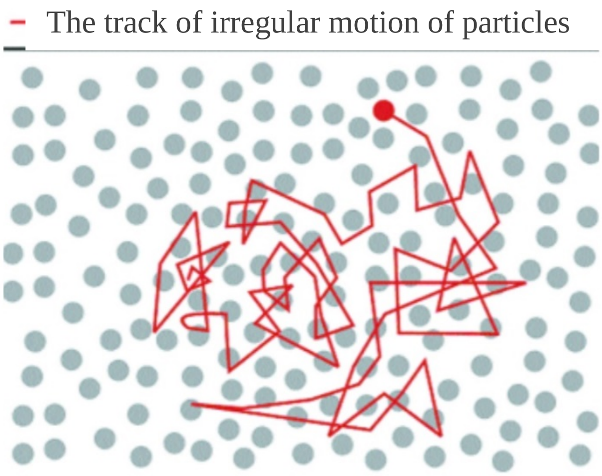
Inertia is the continuous nature of the moving particles themselves. If the gas and the suspended particles hit the filter cloth or filter material at the same speed, the gas will change its moving direction, while the suspended particles will still maintain the original moving direction due to inertia, so they will be captured by the filter material. For this effect, the larger the particles is, the better is the filtering effect.

2.4. Gravitational attraction

The gravitational attraction effect of particles is the same as universal gravitation; thus the larger the particles is, the better is the filtering effect.

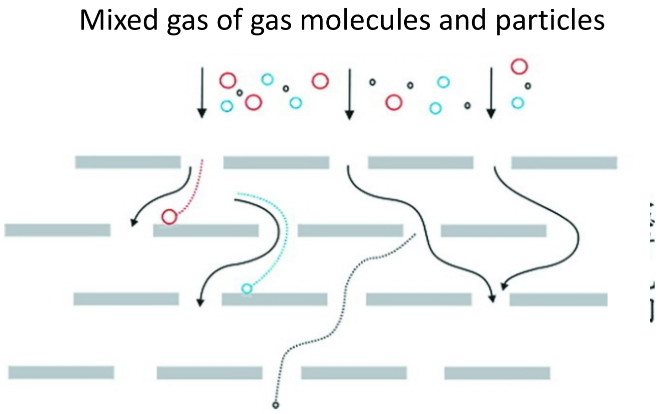
2.5. Electrostatic attraction

The electrostatic attraction between the particles in the gas and the filter fiber is more significant for the particles with smaller sizes. This phenomenon is similar to the electrostatic dust collection technology (device), and the collection effect of fine particles (90%) is the same. Basically, the movement of the particles in the gas is affected by the flow direction of the gas and the surrounding electric field.



▲ The continuous and irregular random movement of particles in the air increases the chance of collision between particles. The irregular moving trajectories significantly increases the chance of particles in contact with the filter material.

It can be seen that if you want to collect particles in a flowing gas with electrostatic force, you must overcome the above-mentioned inertial force. However, since the particles with larger sizes can get rid of the flow of gas due to the effect of inertial force, it is of course less affected by the electrostatic attraction; thus the electrostatic dust collection is more efficient for particles with smaller sizes. In addition, extremely small particles in the gas do not even need to rely on Brownian motion to increase the chance of hitting the filter material, so they can be attracted by electrostatic force, which also increases the ability to filter fine particles.



▲ Schematic diagram of inertial impact of particles of different sizes. Larger particles will maintain their original flow direction due to inertia, and thus impinge on the filter material to achieve the purpose of filtration.

3. Mask classification standards

After elucidating the above five effects of filtering dust, we will have better understanding of the efficiency of various types of masks in filtering particulates. When the particle size is larger than one micron, the effects of mask interception, inertial impact and gravitational attraction will be enhanced. Therefore, higher filtering and blocking efficiency can be achieved regardless the materials or grades of the face mask.

On the other hand, particles with the size less than 0.6 microns are more susceptible to Brownian motion and electrostatic attraction, so the collected effect will be increased. Since the filtering efficiency of various types of masks all shows a U-shaped curve, the lowest point in the curve is the particle size which is the most difficult to be filtered, referred to as MPPS (most penetrating particle size). The size of MPPS is generally about 0.3 microns. MPPS is used as the standard for testing masks both for European standard EN149 or the American standard NIOSH.

There are various standards for the classification and labeling of face masks; however, the most common one is to grade for NIOSH verification in the United States and FFP Series in the European Union.

Series classification	Filtration efficiency			Particle properties
	95%	99%	99.97%	
N- series	N95	N99	N100	non-oily suspended particles
R- series	R95	R99	R100	oily and non-oily suspended particles
P- series	P95	P99	P100	oily and non-oily suspended particles(eight hours)

▲ The classification standard of NIOSH protective mask in the United States and of FFP protective mask in the European Union

4. American NIOSH verification

The National Institute for Occupational Safety and Health, NOISH) divides protective masks into three categories. In addition to the N , there are P and R series, each containing three types of 95, 99, and 100, which indicates that they can block 95, 99, and 99,7% of germs, respectively.

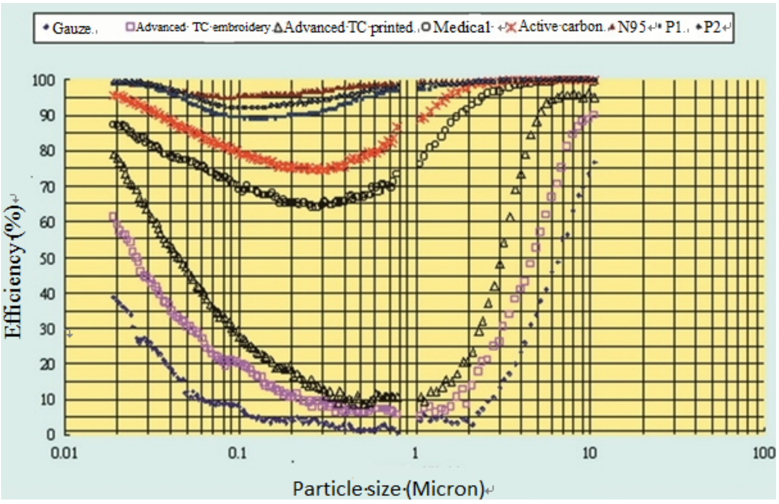
According to the test standard published by NOISH on June 8, 1995, all N series masks are used to filter non-oily suspended particles in the air and can be used repeatedly. Unless otherwise indicated, there is usually no time limit. The P series masks are used to filter oily and non-oily suspended particles in the air and the time limit for use is eight hours. R series masks are used to filter oily and non-oily suspended particles in the air. Unless otherwise indicated, there is usually no time limit for use and can be used repeatedly.

During the SARS epidemic, the N95 mask, which is designated in the United States to prevent tuberculosis bacteria, can effectively filter tuberculosis bacteria (diameter of about 0.3 to 0.6 microns, length of 1 to 4 microns), to prevent infection through the air. The inspection standard is to use 0.3-micron sodium chloride particles to test, the blocking efficiency must be more than 95%, and the attached test shows that when the mask is closely attached to the edge of the face, the air can only enter and exit through the mask.

5. EU FFP series classification

Base on the validation of respiratory protective equipment in EU, the dust masks are divided into P1, P2 and P3 levels, while simple masks are divided into FFP1, FFP2 and FFP3. According to a press release issued by the Labor Safety and Health Research Institute on March 17, 2003, the EU industrial standard FFP2 and FFP1 masks are slightly less effective than the N95. Although the surface filtration effect of the mask with activated carbon is close to (or slightly better than) the surgical mask, the actual effect is far less than that of the surgical mask because it cannot be close to the face.

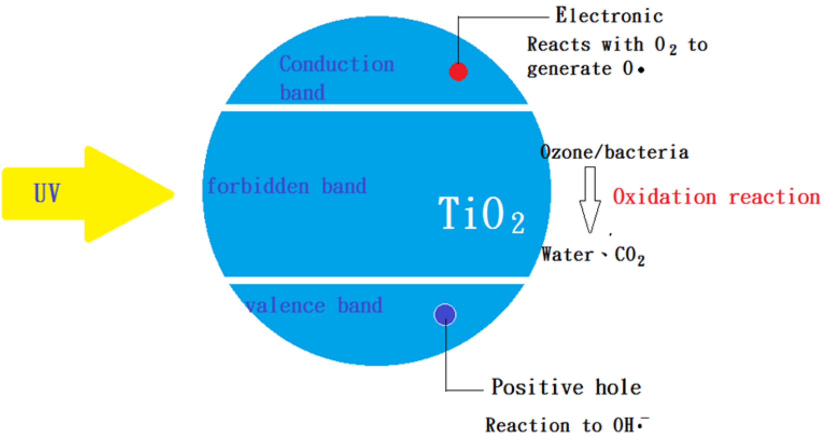
The minimum pore size of general masks is about 0.3 microns, while the size of SARS coronavirus is about 0.08-0.14 microns, so the general idea is that masks can not effectively filter SARS coronavirus. However, the World Health Organization (WHO) has determined that SARS is spread by droplets, which means that the virus is not scattered in the air individually, but mainly hidden in the droplets from the mouth or nose (its size is about one hundred times larger than the virus, more than 0.3 microns). In the case of medical masks, it has a droplet blocking efficiency of more than 65%. Therefore, the mask still has a certain effect on the prevention of "droplet infection" disease.



▲ Comparison chart of the filtration efficiency of different masks for particulate matter. Both large and small particles are easier to be filtered, but different types of masks have a particle size value that is the most difficult to filter.

6. Mask with both filtering and sterilizing effects

Recently, a nano-photocatalyst mask with a considerable sterilization function has been developed. Its principle is to use photocatalysis reaction to decompose harmful substances and kill bacteria. Photocatalytic reaction uses a semiconductor photoelectric ceramic as a catalyst to oxidize or reduce the adsorbed substances. Many semiconductor optoelectronic ceramics can be used as photocatalysts, such as titanium dioxide (TiO_2), zinc oxide (ZnO), cadmium sulfide (CdS), etc. At present, the most used photocatalyst is titanium dioxide. Besides its strong oxidation and reduction ability, it also has the advantages of chemical stability, harmless to the environment and low price.



▲ The reaction mechanism of titanium dioxide. Titanium dioxide uses the oxidation force of the electric hole and the reduction of electrons to contact with the surface of water and oxygen. The production of free radicals with high oxidation power has the capability of sterilization, deodorization, decomposition of organic matters. It can also break down hydrocarbons into carbon dioxide and water; thus exhibits a relatively high bactericidal capacity.

When the photocatalyst is irradiated with ultraviolet rays with a wavelength of below 400 nanometers, the electrons of the valence electron band are excited by the energy of three electron volts of ultraviolet rays and jump to the conduction band. At this time, the valence electron band will generate holes with positive electricity, forming a group of electron-hole pairs. Titanium dioxide uses the oxidizing power of electron holes and the reducing power of electrons to interact with water and oxygen on the surface to produce free radicals with extremely strong oxidizing power. Therefore, it exhibit the capibility of sterilization, deodorization, and decomposition of organic matters. Hydrogen compounds decompose into carbon dioxide and water; thus also have a relatively high sterilization ability.

▲ Photocatalyst antibacterial performance test

Bacteria	Coated material	Before test	After 3 hours	Sterilization rate
Escherichia col	wallpaper	3.5×10^5	< 10	99.9% or more
	carpet	3.5×10^5	< 10	99% or more

	Uncoated materia	3.5×10^5	2×10^7	
Staphylococcus aureus	wallpaper	1.9×10^5	< 10	99.9% or more
	carpet	1.9×10^5	< 10	99.9% or more
	Uncoated materia	1.9×10^5	9×10^4	

Conclusions

The invention of face the mask is to prevent human beings from contaminated by droplets and unnecessary pollutants from entering the human body. With the development of science and technology and different needs, face masks with different functions have also emerged. Choosing the right face mask on different occasions can not only protect yourself, but also protect others from disease pandemic.