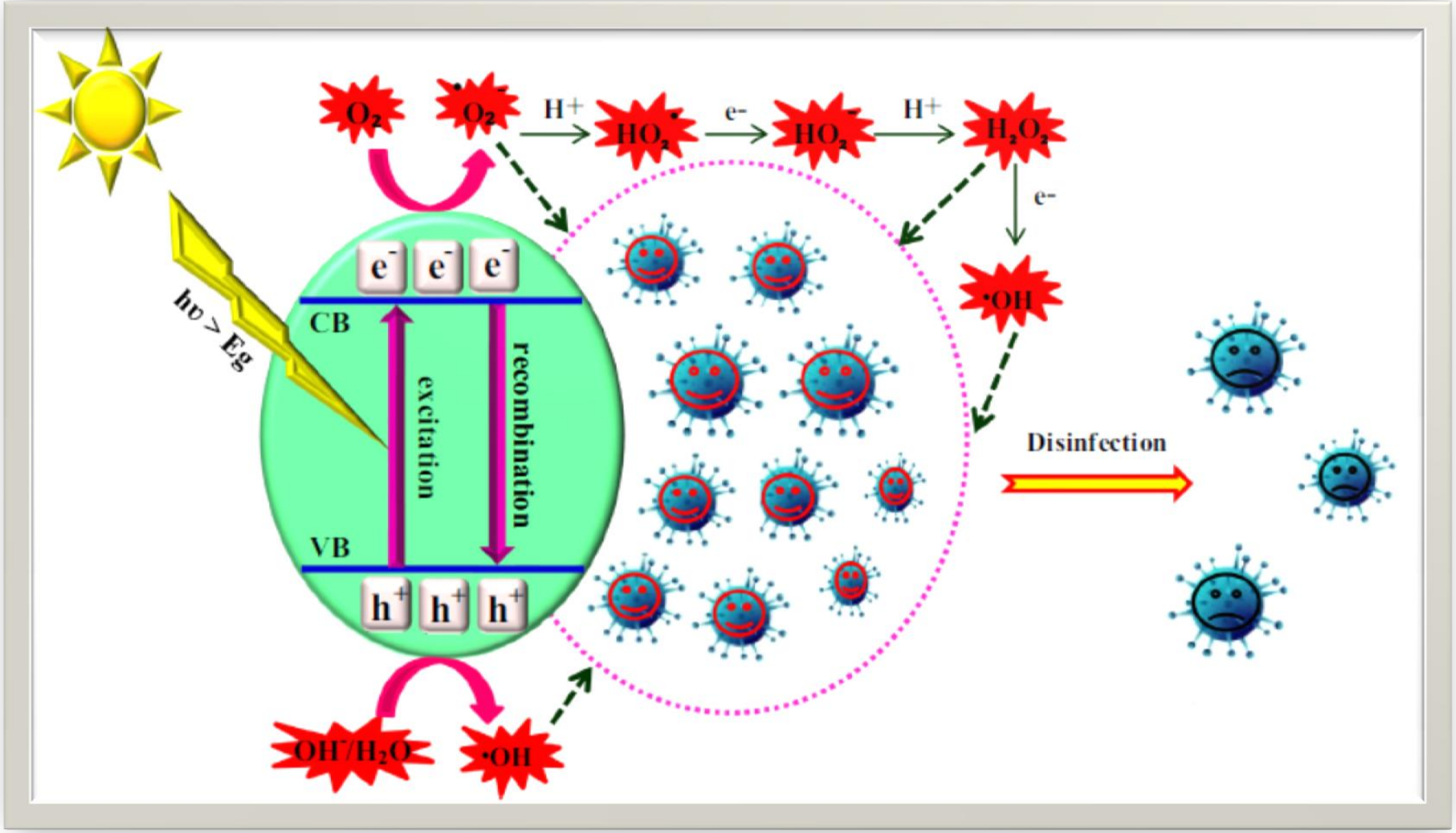
ANTI CORONAVIRUS SOLUTION

"AIRION", both of SPACE STERILIZER & OXYGEN GENERATOR

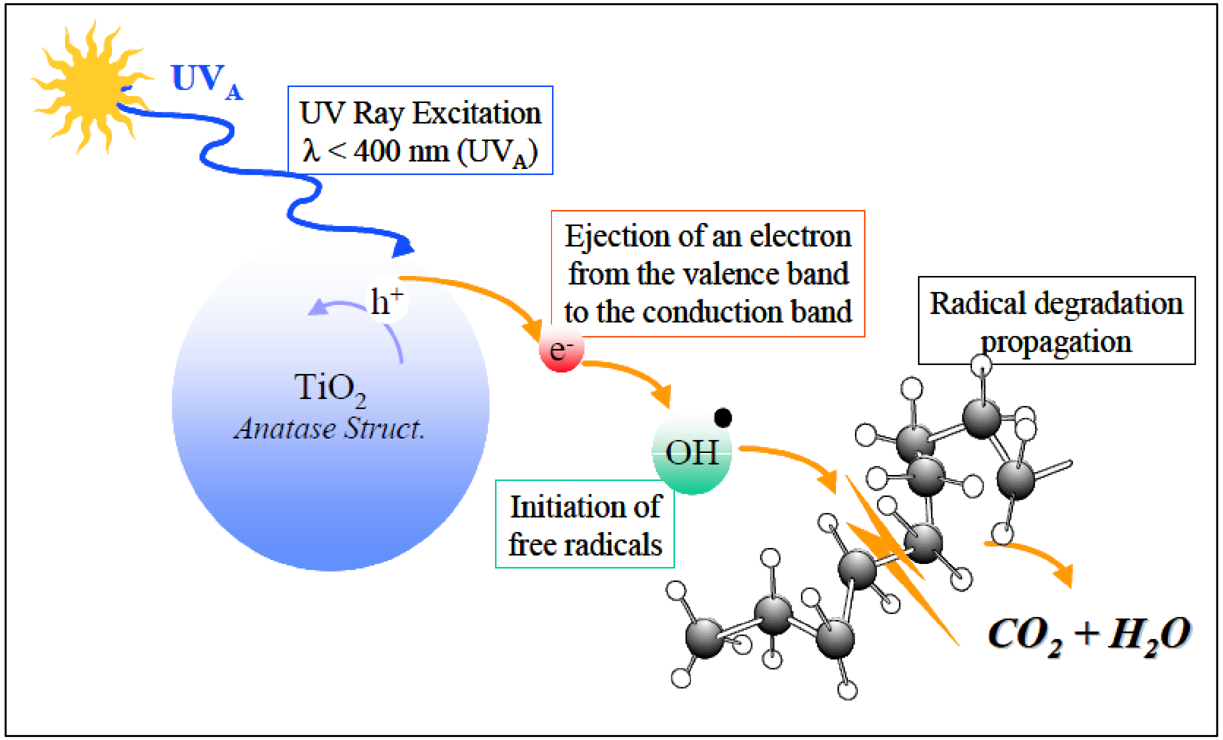
Technical description for questions (UV-Photocatalysis)

Summary : Disinfection of viruses by photocatalysts



The Ultraviolet radiation lighting on the TiO_2 Photocatalysis filter adsorbs the harmful substance and oxidize them → Remove over 20,000 types of chemical impurities and biological noxious particles

Photocatalytic mechanism(1)



Step1 : Exposure to UV causes TiO_2 to release electrons (e-) and positively charged holes (h+).

Step 2: The electrons and positive holes cause generation of super oxide (O_2-) and hydroxy radicals (·OH) from water and air.

Step 3: These radicals may induce the conversion of present organic compounds, setting of a chain-reaction of radical formation and oxidation.

Step 4: If total oxidation takes place, the end-products are carbon dioxide (CO_2) and water (H_2O).

Photocatalytic mechanism(2)

Step 1: $TiO_2 + h\nu \rightarrow e_{cb}^- + h_{vb}^+$

Step 2: $O_2 + e_{cb}^- \rightarrow O_2^-\cdot$

$h_{vb}^+ + H_2O \rightarrow \cdot OH + H^+_{aq}$

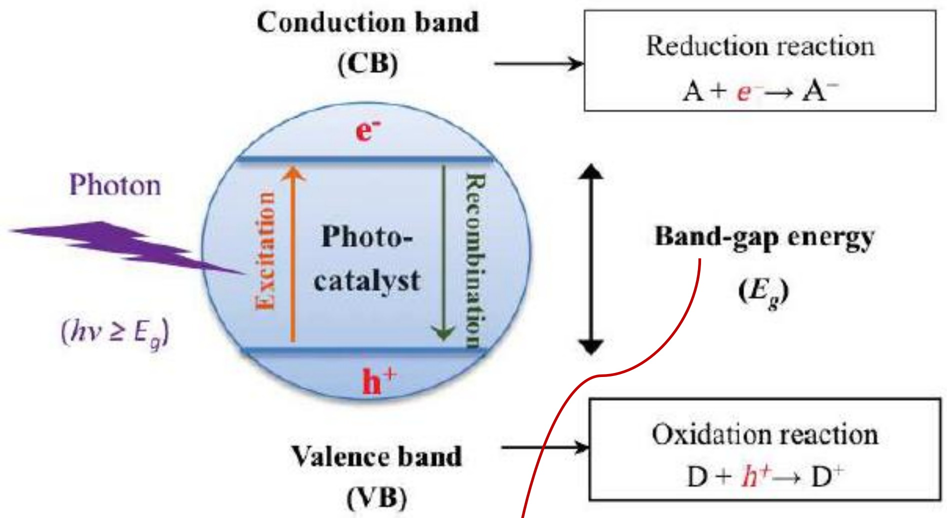
$\cdot OH + \cdot OH \rightarrow H_2O_2$

$O_2^-\cdot + H_2O_2 \rightarrow \cdot OH + OH^- + O_2$

$O_2^-\cdot + H^+ \rightarrow \cdot OOH$

Step 3:
Step 4: $\cdot OH + \text{Organic} + O_2 \rightarrow CO_2, H_2O$

Organisms including bacteria, including endospores, fungi, algae, protozoa and viruses



The band gap energy (energy required to promote an electron) of TiO_2 anatase is approx. **3.2 eV**, which effectively means that photocatalysis can be activated by photons with **a wavelength of below approximately 385 nm (i.e. UVA).**

Howard A. Foster & Iram B. Ditta & Sajnu Varghese & Alex Steele, "Photocatalytic disinfection using titanium dioxide: spectrum and mechanism of antimicrobial activity", Appl Microbiol Biotechnol (2011) 90:1847–1868, DOI 10.1007/s00253-011-3213-7

Hydroxyl radical (OH radical)

What is an Hydroxyl radical (OH radical, OH•) ?

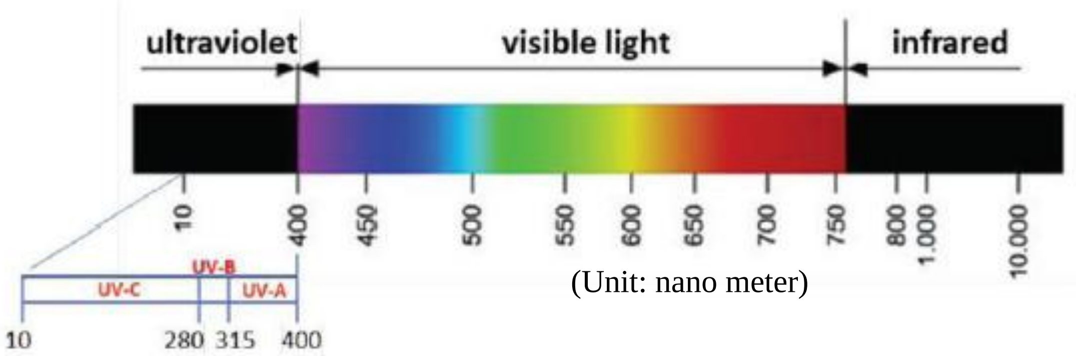
- Hydroxyl radicals are highly reactive species that attack most of the organic molecules. They are highly oxidizing in nature which is attributed to their oxidation potential.
- In addition, owing to their nonselective nature, many susceptible organic molecules can easily be removed or degraded using hydroxyl radical (e.g., acids, alcohols, aldehyde, aromatics, amines, ethers, ketone, etc.).

<Oxidation Potentials od Various Chemical Species>

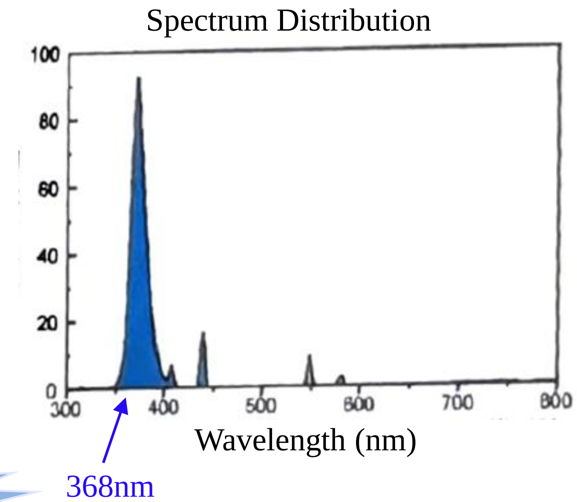
Species	Oxidation Potential (V)
Fluorine (F_2)	-3.03
Hydroxyl radical (OH •)	-2.80
Atomic oxygen (O_2)	-2.42
Ozone (O_3)	-2.07
Hydrogen peroxide (H_2O_2)	-1.78
Perhydroxyl radical (HO_2•)	-1.70
Permanganate (MnO_4^-)	-1.68
Hypobromous acid (HOBr)	-1.59
Chlorine dioxide (ClO_2)	-1.57
Hypochlorous acid (HOCl)	-1.49
Hypoiodous acid (HOI)	-1.45
Chlorine (Cl_2)	-1.36
Bromine (Br_2)	-1.09
Iodine (I_2)	-0.54

OH radical has the most powerful oxidation power in nature except for fluorine. OH radical is more powerful than Ozone, Hydrogen peroxide and Cl_2 , that are well-known as the oxidation materials, in terms of oxidation power.

UV Light



(Unit: nano meter)



Energy Intensity:	UV-C	>>	UV-B	>>	UV-A
(Electron Volt) :	(4.43 - 12.4 eV)	:	(3.94 - 4.43 eV)	:	(3.1 - 3.94 eV)

AIRION'S UV light source

(Good)
Currently, by direct irradiation, UV-C light is commonly used in water and air disinfection at a wavelength of 254 nm, which inactivates pathogens through efficient absorption by their DNA or RNA.

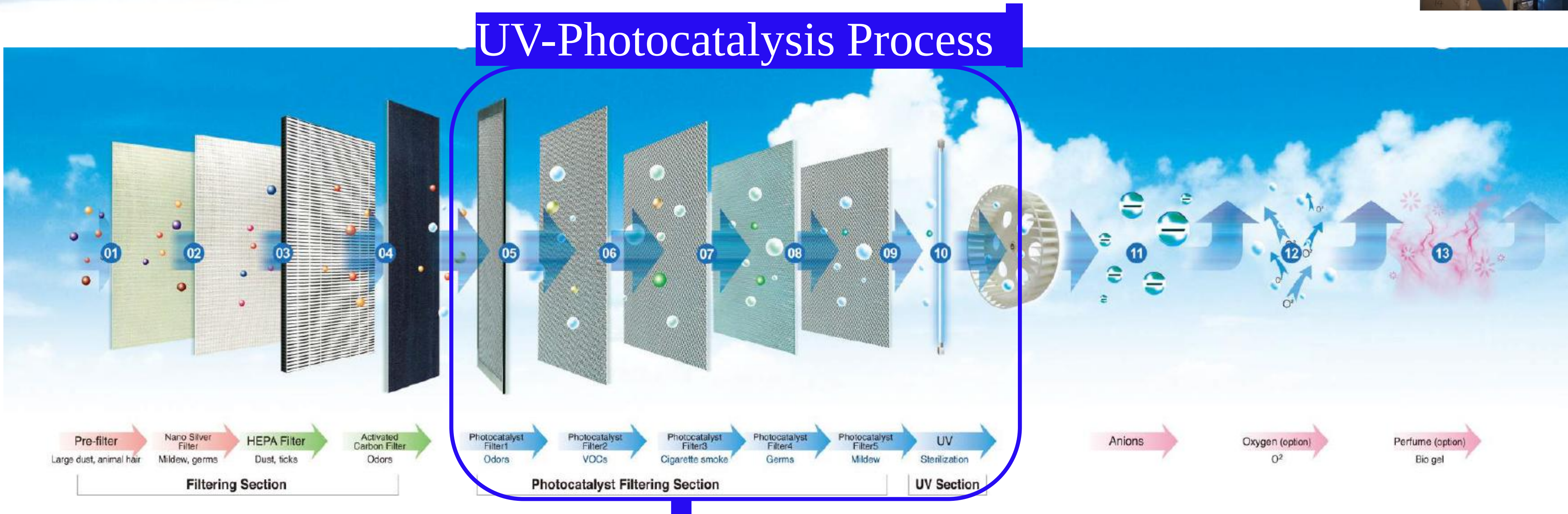
(Dangerous)
- ✓ UV-C light can produce **eye damage** when exceeding the recommended and experimentally validated limit of ~60 J/m2 fluence exposure over several hours.
- ✓ The lower the wavelength of UV-C light, the more effective it is at generating **harmful ozone**.

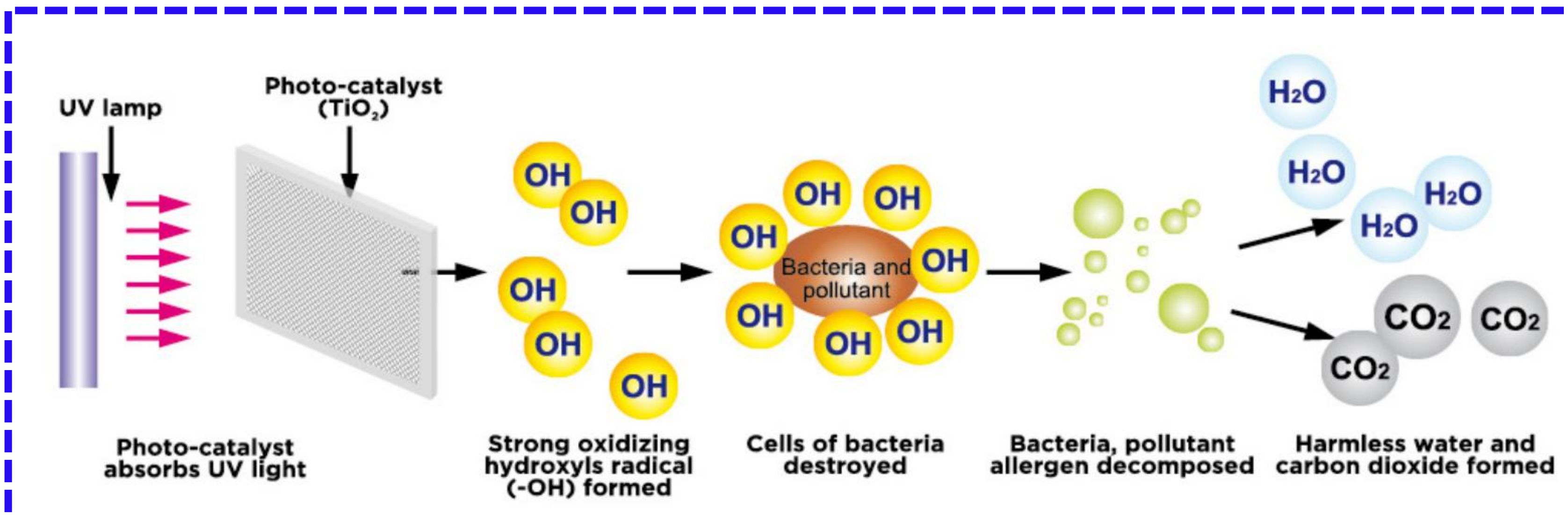
(Good)
UVA irradiation provides sufficient photonic activation energy to TiO2 catalyst. Photocatalysis is capable of killing a wide range of organisms including bacteria, including endospores, fungi, algae, protozoa and viruses. UV-A light is not harmful to human eyes or skin.

(Bad)
Not so much effective to disinfect virus by just direct irradiation of UV-A light.

F. Javier García de Abajo and others, "Back to Normal: An Old Physics Route to Reduce SARS-CoV-2 Transmission in Indoor Spaces", ACS Nano, https://dx.doi.org/10.1021/acsnano.0c04596

UV-Photocatalysis Process in Air Sterilizer





Scientific Papers

UV-Photocatalytic effects on by viruses

	Paper title
Scientific Paper 1	Photocatalytic disinfection using titanium dioxide: spectrum and mechanism of antimicrobial activity
Scientific Paper 2	Decomposition of Organic Chemicals in the Air and Inactivation of Aerosol-Associated Influenza Infectivity by Photocatalysis
Scientific Paper 3	Review on heterogeneous photocatalytic disinfection of waterborne, airborne, and foodborne viruses: Can we win against pathogenic viruses?
Scientific Paper 4	Inactivation of airborne viruses using vacuum ultraviolet photocatalysis for a flow-through indoor air purifier with short irradiation time

Scientific Paper 1 (UV-Photocatalytic effects on microorganisms(1))

Howard A. Foster & Iram B. Ditta & Sajnu Varghese & Alex Steele, "Photocatalytic disinfection using titanium dioxide: spectrum and mechanism of antimicrobial activity", Appl Microbiol Biotechnol (2011) 90:1847–1868, DOI 10.1007/s00253-011-3213-7

The test results for microorganisms to be killed by Photocatalytic disinfection

Organisms	Detailed organisms names	Results (References)
Gram-negative bacteria	• Escherichia coli • Acinetobacter • Coliforms • Others	Table 2 Table 3
Gram-positive bacteria	• Actinobacillus actinomycetemcomitans • Bacillus cereus • Clavibacter micheganensis • Others	Table 4
Fungi, algae and protozoa	• Aspergillus niger AS3315 • Amphidinium corterae • Acanthamoeba castellanii • Others	Table 5 (Fungi) Table 6 (Algae and protozoa)
Viruses	• Influenza A/H1N1 • Norovirus • SARS coronavirus • Others	**Table 7**
Bacterial toxins	• Brevetoxins • Cylindrospermopsin • Lipopolysaccharide endotoxin • Others	Table 8

Scientific Paper 1 (UV-Photocatalytic effects on microorganisms(2))

Howard A. Foster & Iram B. Ditta & Sajnu Varghese & Alex Steele, “Photocatalytic disinfection using titanium dioxide: spectrum and mechanism of antimicrobial activity”, Appl Microbiol Biotechnol (2011) 90:1847–1868, DOI 10.1007/s00253-011-3213-7

Viruses shown to be killed by photocatalytic disinfection

Host	Virus	Reference
Bacteroides fragilis	Not specified	Armon et al. (1998)
Birds	Influenza (avian) A/H5N2	Guillard et al. (2008)
E. coli	Coliphage	Guimarães and Barretto (2003)
E. coli	*fr*	Gerrity et al. (2008)
E. coli	T4	Ditta et al. (2008), Sheel et al. (2008)
E. coli	λ vir	Yu et al. (2008)
E. coli	λNM1149	Belhácová et al. (1999)
E. coli	ϕX174	Gerrity et al. (2008)
E. coli	MS2	Sjogren and Sierka (1994), Greist et al. (2002), Cho et al. (2004, 2005), Sato and Taya (2006a, b), Vohra et al. (2006), Gerrity et al. (2008)
E. coli	Qβ	Lee et al. (1997), Otaki et al. (2000)
Human	Hepatitis B virus surface antigen HBsAg	Zan et al. (2007)
Human	Influenza A/H1N1	Lin et al. (2006)
Human	Influenza A/H3N2	Kozlova et al. (2010)
Human	Norovirus	Kato et al. (2005)
Human	*Poliovirus* type 1 (ATCC VFR-192)	Watts et al. (1995)
Human	SARS coronavirus	Han et al. (2004)
Human	Vaccinia	Kozlova et al. (2010)
Lactobacillus casei	PL-1	Kakita et al. (1997, 20000, Kashige et al. (2001)
Salmonella typhimurium	PRD1	Gerrity et al. (2008)

Table 7. Viruses shown to be killed by photocatalytic disinfection

Scientific Paper 1 (UV-Photocatalytic effects on microorganisms(3))

Howard A. Foster & Iram B. Ditta & Sajnu Varghese & Alex Steele, “Photocatalytic disinfection using titanium dioxide: spectrum and mechanism of antimicrobial activity”, Appl Microbiol Biotechnol (2011) 90:1847–1868, DOI 10.1007/s00253-011-3213-7

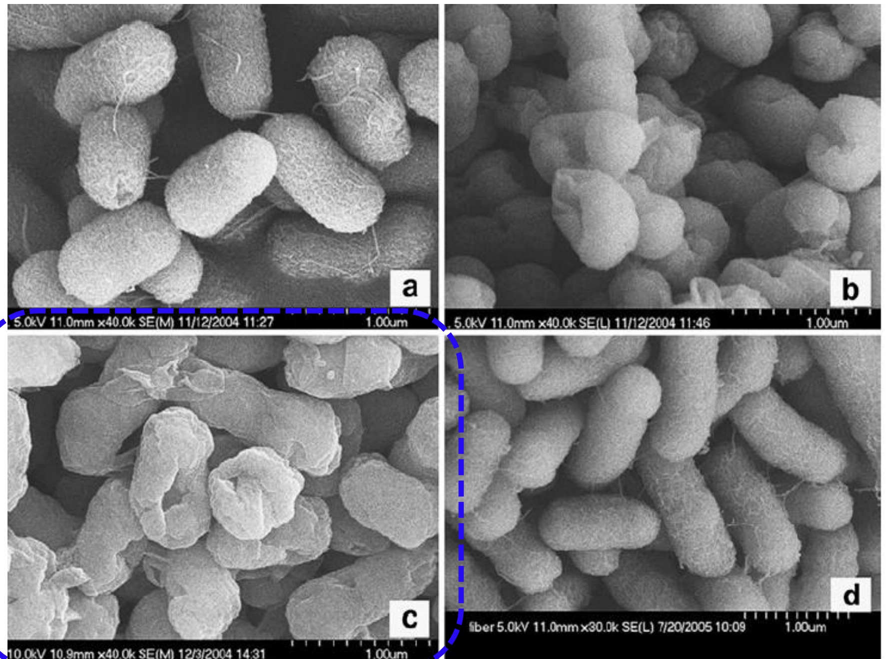


Fig. 2. Scanning electron micrographs of photocatalytically treated E. coli.

(a) Untreated cells.
(b) & (c) Cells after 240 min.
(d) Cells after 30 min.

※ Catalyst TiO_2 thin film.

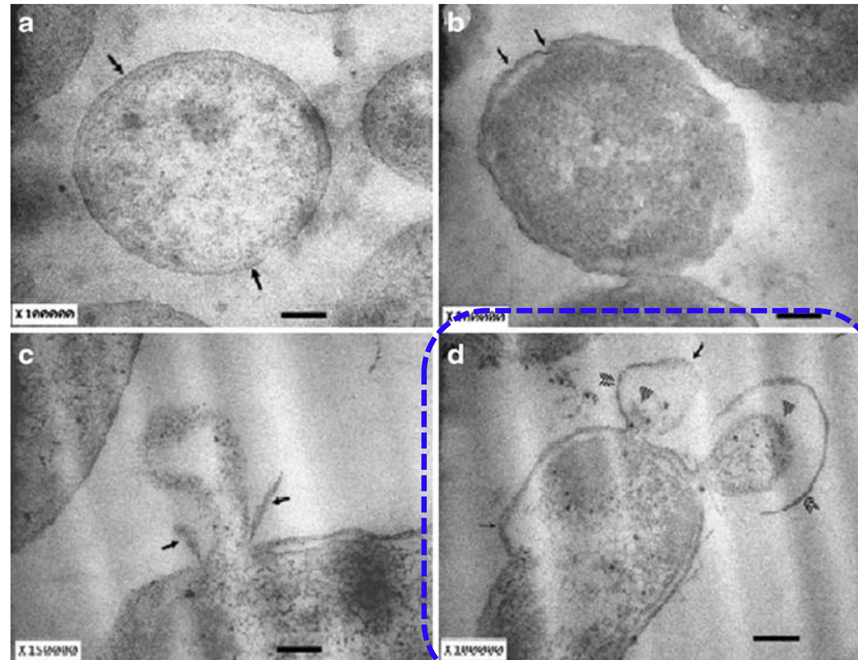


Fig. 3. Transmission electron micrographs of photocatalytically treated P. aeruginosa.

(a) Untreated cells transverse section showing normal thickness and shape cell wall (arrows).
(b) – (d) Cells after 240 min treatment showing abnormal wavy cell wall (arrows)

※ (b) Cytoplasmic material escaping from the cell with damaged cell wall
(c) and (d) Cell showing two “bubbles” of cellular material with cell wall

※ Catalyst TiO_2 thin film.

Scientific Paper 2 (UV-Photocatalytic effects on influenza virus(1))

Tohru Daikoku, and others, “Decomposition of Organic Chemicals in the Air and Inactivation of Aerosol-Associated Influenza Infectivity by Photocatalysis”, Aerosol and Air Quality Research, 15: 1469–1484, 2015

The test result for infectivity of influenza virus under Photocatalytic disinfection

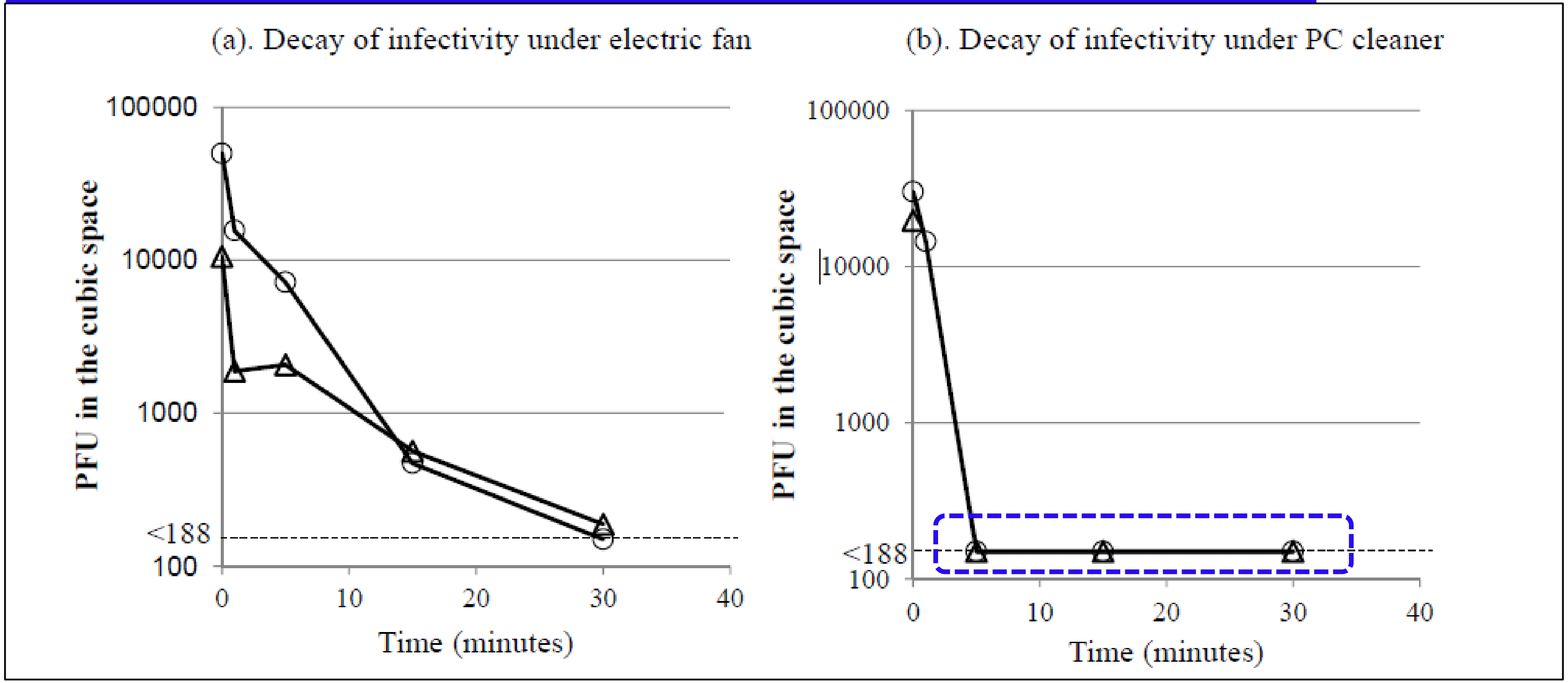


Fig. 4. Stability and decay of aerosol-associated infectivity of influenza virus in the closed space (a) and its inactivation by the photocatalytic air cleaner (b).

※ Decay of infectivity was determined under PC cleaner with and without a UV-A black light.
The aerosol-associated infectivity was quickly inactivated and was undetectable within 5 min by photocatalysis with TiO2 irradiated by UV-A black light (Fig. 4(b)), while 2,072 and 7,159 PFU were detected at 5 min under an electric fan without black light (Fig. 4(a)).
※ PFU = plaque forming unit

Scientific Paper 2 (UV-Photocatalytic effects on influenza virus(2))

Tohru Daikoku, and others, “Decomposition of Organic Chemicals in the Air and Inactivation of Aerosol-Associated Influenza Infectivity by Photocatalysis”, Aerosol and Air Quality Research, 15: 1469–1484, 2015

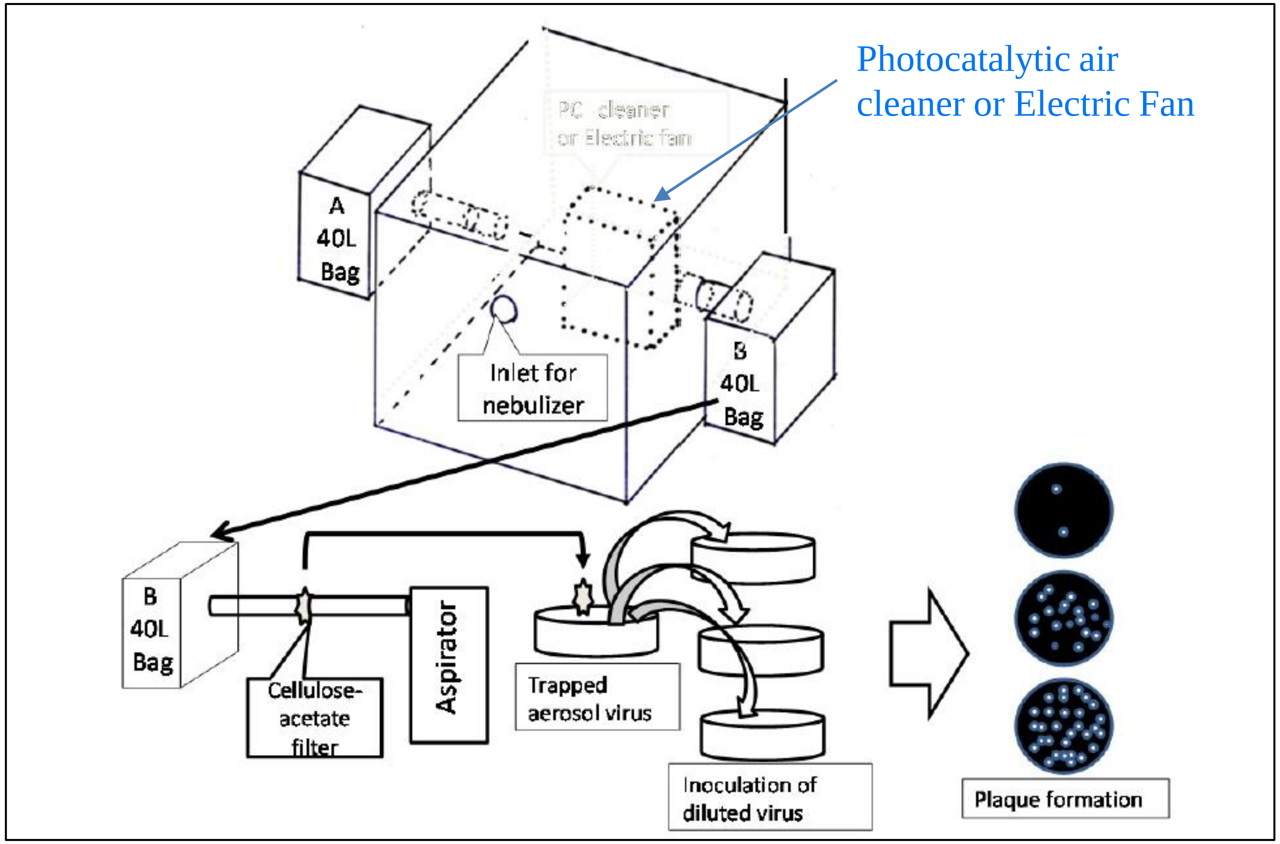


Fig. 2. Diagram of the system to assay aerosol-associated infectivity of influenza virus.

※ Aerosol-associated influenza virus was injected by a nebulizer into a 91 × 91 × 91-cm cubic space (754 Liters (L)), and a 40-L volume of air was slowly blown from bag A to bag B.

Scientific Paper 3 (UV-Photocatalytic effects on pathogenic viruses)

Aziz Habibi-Yangjeh, and others, “Review on heterogeneous photocatalytic disinfection of waterborne, airborne, and foodborne viruses: Can we win against pathogenic viruses?”, Journal of Colloid and Interface Science 580 (2020) 503-514

Summary of utilized photocatalysts for various viral disinfection

Photocatalyst	Virus	Operational condition		Light source	Disinfection efficiency	Type of virus	Ref.
		Catalystloading (mg/L)	Virus level (PFU*/mL)				
TiO_2	Phage MS2	1000	6×10^4	UV	2.8-log in 65 min	waterborne	[41]
TiO_2	Phage MS2	1000	6×10^5	18 W BLB* lamp	1.8-log in 180 min	waterborne	[61]
TiO_2	Bacteriophage Qβ	1000	1×10^6	UV lamp	3.5-log in 2 min	waterborne	[64]
TiO_2	Phage f2	1000	10^{10}–10^{11}	6 W black light lamp	6-log in 15 min	waterborne	[78]
TiO_2	Influenza virus	No data	4.0×10^8	1 mW black light	Eliminated in 5 min	airborne	[83]
TiO_2	Influenza virus	No data	0.0 or 0.1 mg ml^{-1}	20 W black light	4-log in a short irradiation time	airborne	[84]
TiO_2	H1N1	No data	No data	UV-LED lamp	Eliminated in 7 min	airborne	[85]
TiO_2	MNV-1	No data	No data	UV lamp	3.2-log in 10 min	foodborne	[91]
TiO_2	MNV-1	No data	No data	UV lamp	>5.5-log in 15 min	foodborne	[95]
TiO_2	MS-2 bacteriophage	No data	2×10^5	4 W BLB lamp	2-log in 109 min	waterborne	[96]
TiO_2	Phage f2	100	>20	4 W UV-Clamp	5–6-log in 160 min	waterborne	[97]
TiO_2	Murine norovirus	10	1×10^8	UV lamp	3.3-log in 24 h	waterborne	[98]

Table 1. Summary of utilized photocatalysts for various viral disinfection

※ black light : UV-A light
[*]: PFU = plaque forming unit; BLB = black-light-blue

Scientific Paper 4 (UV-Photocatalytic effects on inactivation of airborne viruses)

Jeonghyun Kim and Jaesung Jang, “Inactivation of airborne viruses using vacuum ultraviolet photocatalysis for a flow-through indoor air purifier with short irradiation time”, AEROSOL SCIENCE AND TECHNOLOGY 2018, VOL. 52, NO. 5, 557–566

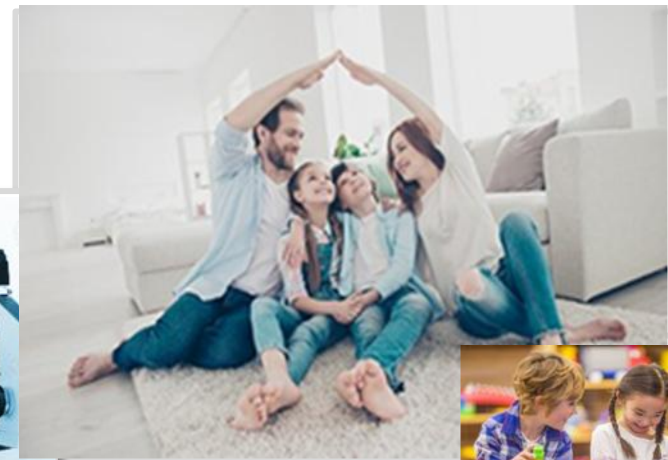
Summary of studies on UV photocatalytic oxidation systems for disinfecting bioaerosols

Light source	Target bioaerosols	Photoreactors	Irradiation time (flow rate)	Disinfection efficiency	Reference
UVA[a]	*Escherichia coli*	TiO_2-coated Pyrex tubular reactor	9–35 s (1.5–6l/min)	99.1–99.8%	(Keller et al. 2005)
UVA[a]	*Escherichia coli*	Continuous annual reactor with TiO_2-coated glass fiber filter	1.1 min (1l/min)	100%	(Pal et al. 2008)
UVA[a]	*Legionella pneumophila*	Three-dimensional solid foam structured reactor	1.5 s (21.6l/min)	94%	(Josset et al. 2010)
UVA[a]	Influenza virus H1N1	TiO_2-coated porous ceramic substrate	5 min (6–24l/min)	100%	(Daikoku et al. 2015)
UVA[a]	*Pseudomonas aeruginosa, Staphylococcus aureus,* Methicillin-resistant *Staphylococcus aureus, Aspergillus fumigatus*	Honeycomb structure made of P25 dip-coated cellulose acetate monoliths	15 min	74–98%	(Rodrigues-Silva et al. 2017)
UVA[a], UVC[b]	*Escherichia coli*	TiO_2-coated glass fiber substrates	~0.5 s (20l/min)	95%	(Lin et al. 2010)
UVA[a], UVC[b]	*Escherichia coli*	TiO_2-coated filter	2–6 h	100%	(Pigeot-Remy et al. 2014)
VUV[c]	MS2 phage	Spiral and pleated Pd-deposited TiO_2 flow-through reactor	0.004–0.125 s (33l/min)	47.8–100%	Present study

Table 1. Summary of studies on UV photocatalytic oxidation systems for disinfecting bioaerosols.

※ a. UVA: 365 nm wavelength ultraviolet light.
b. UVC: 254 nm wavelength ultraviolet light.
c. VUV: 185 nm wavelength ultraviolet light.

End of Document



For further contacts:

Email: info@airion.es

Phones: 91 664 53 50, Jorge 625 607 941, Carlos 609 25 93 77

www.airion.es

Madrid, Spain