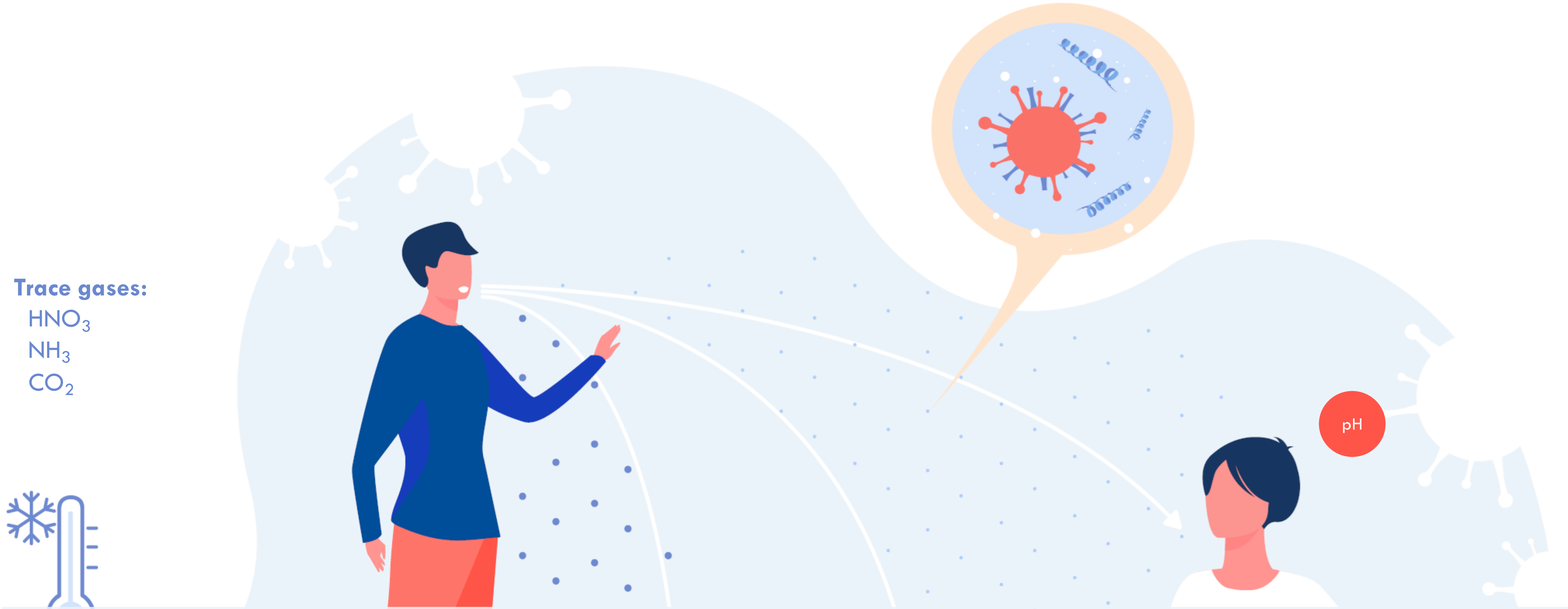


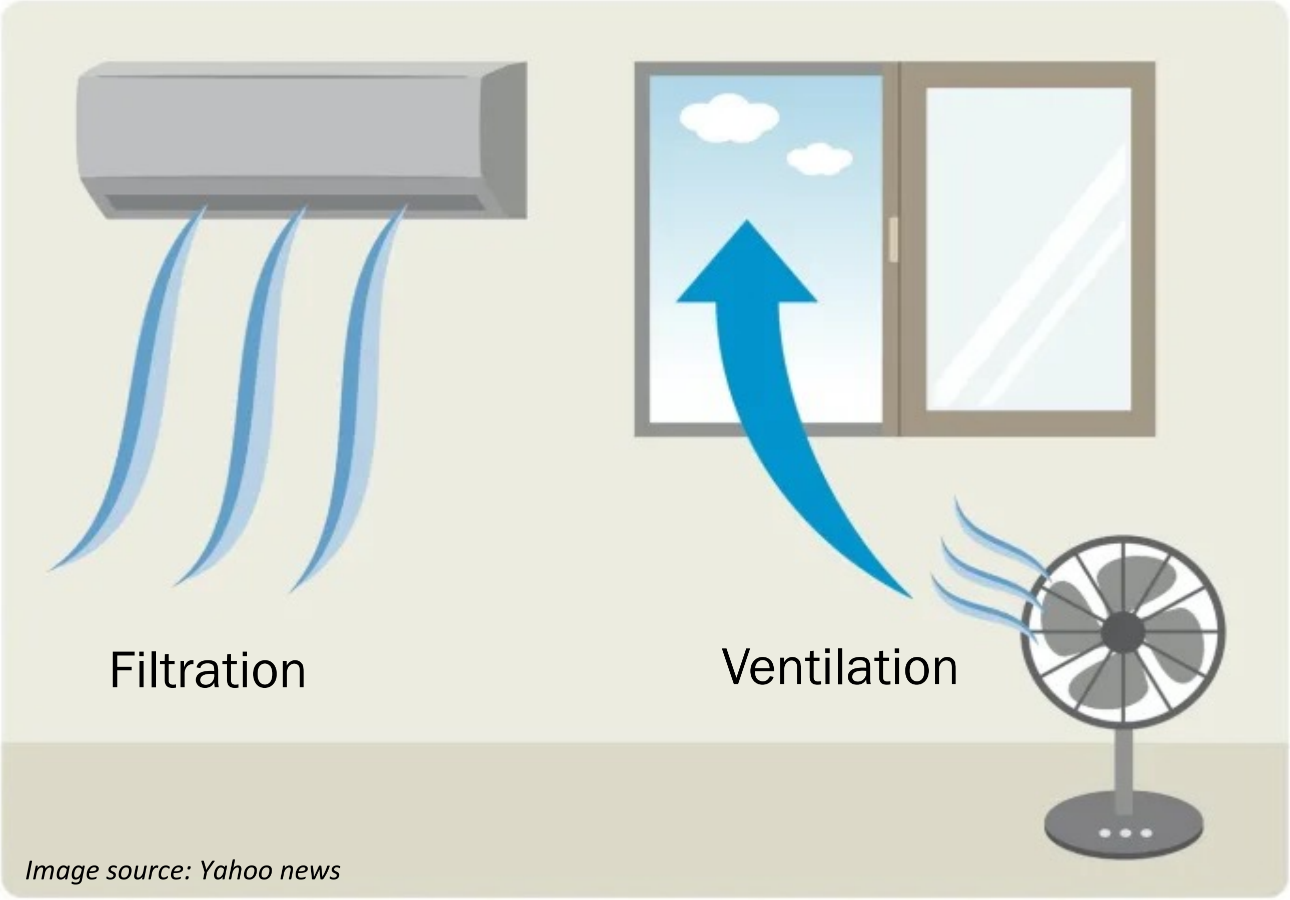
Aerosol pH is an overlooked driver of airborne influenza and coronavirus inactivation

Tamar Kohn

EPFL

Illustration by Ramona Klein

Recommended methods to prevent airborne transmission



Masking

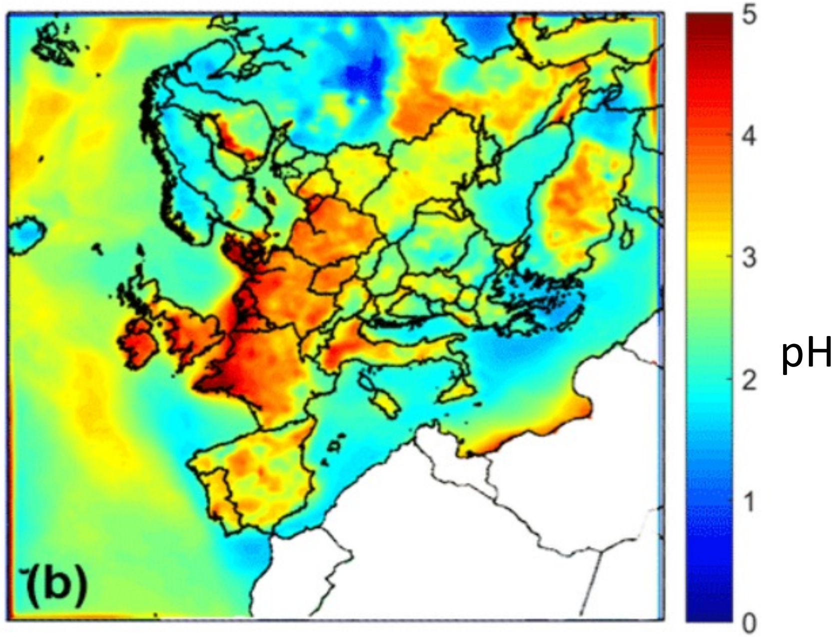
Physical barriers

Can we achieve better health protection by **inactivating** viruses while airborne? How?

Some hints

Atmospheric sciences

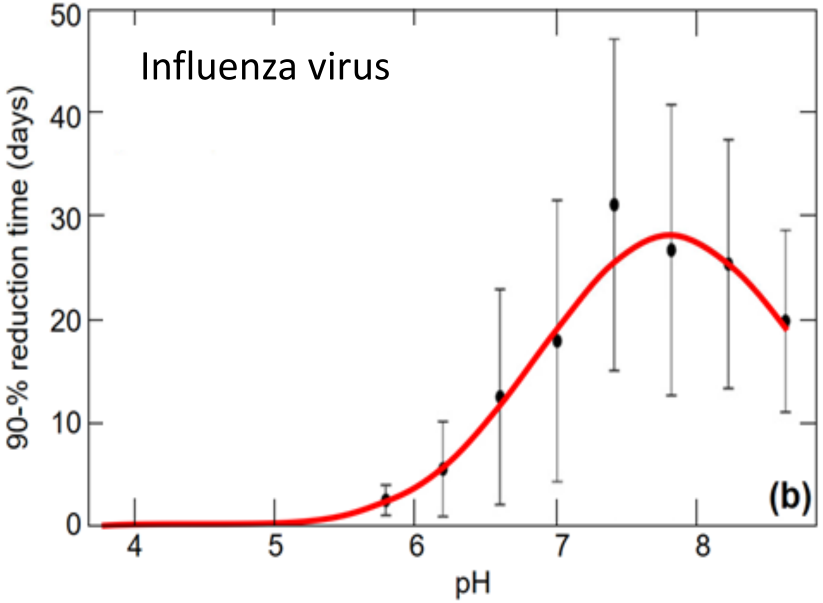
Ambient aerosol particles can be acidic



Kakavas et al. (2021)

Virology

Some respiratory viruses are inactivated at acidic pH



Brown et al. (2009)

1. What is the pH of exhaled aerosol particles?
2. What are the inactivation kinetics of respiratory viruse … rosol pH?
3. Can the inactivation time be modified by modulating … pH?

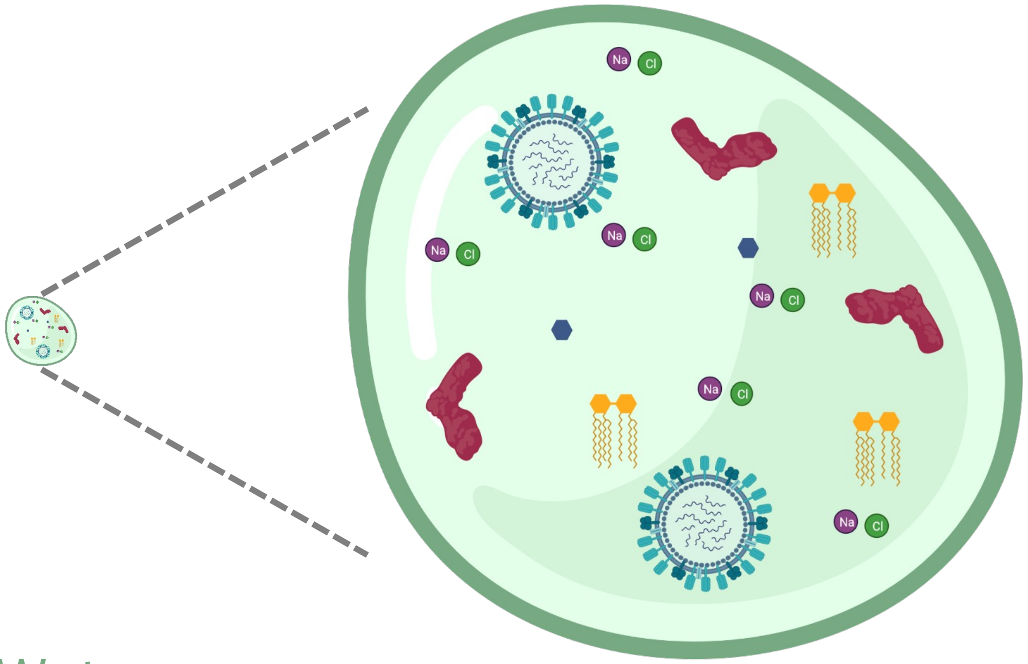
Is aerosol pH a driver of airborne virus inactivation?

Q1: What is the pH of an exhaled aerosol particle?

Illustration by Ramona Klein

Expiratory aerosol particles are dynamic and complex

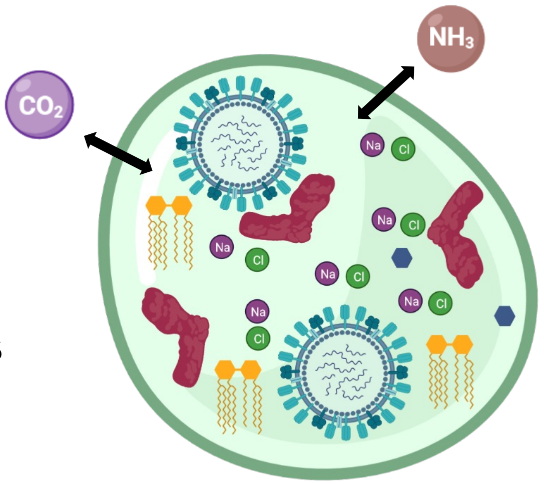
Relative humidity in the **body**:
~100% (37 °C)



Relative humidity in **indoor air**:
~20-70% (20 °C)

Water evaporation

Concentration of solutes
Gas exchange



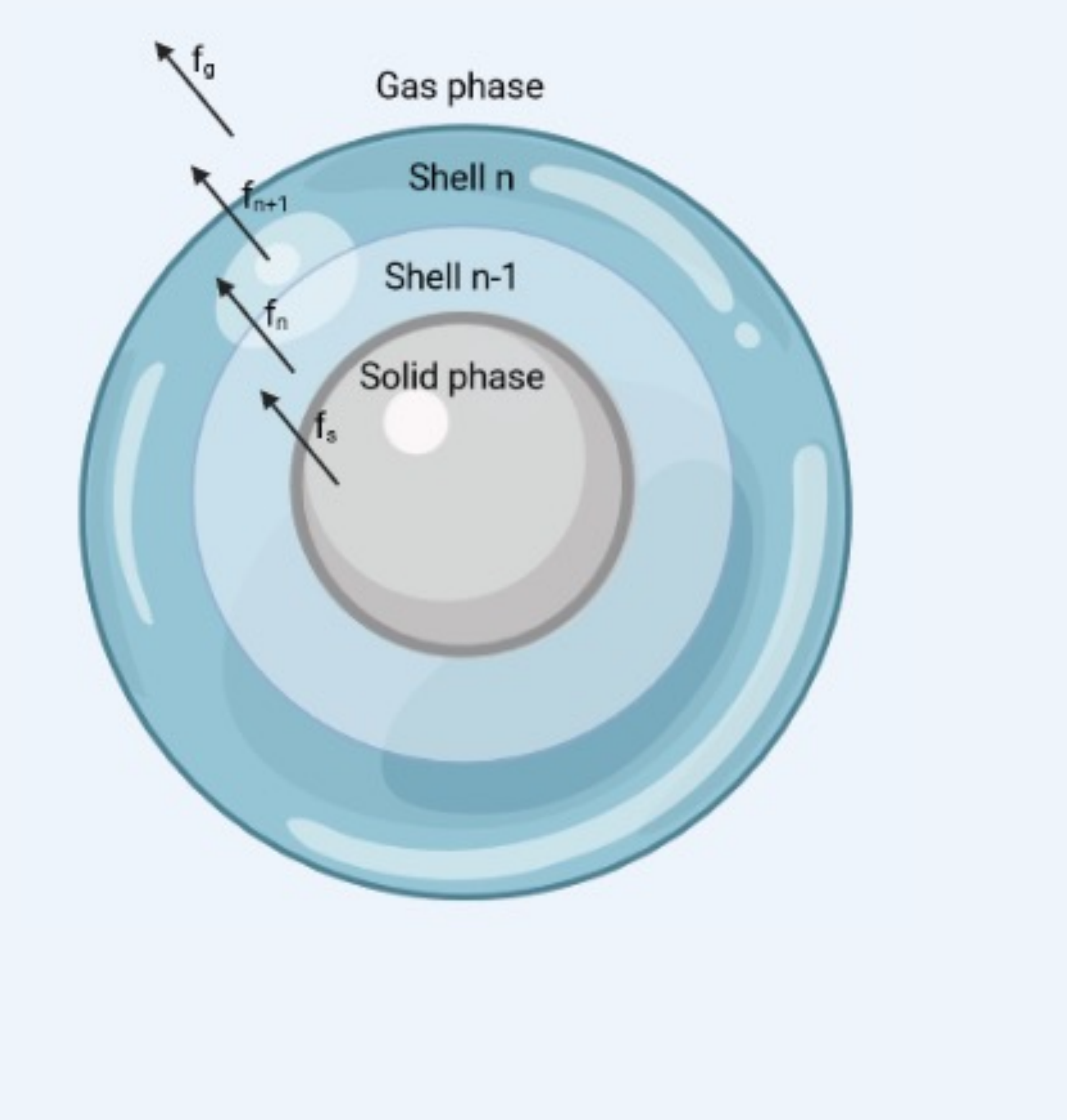
Water
Salts
Organics
Infectious virus

Properties depend on

- RH
- Matrix composition
- Time since exhalation
- Surrounding air composition
- ...

Respiratory aerosol model

1. Mass transfer
2. Heat transfer

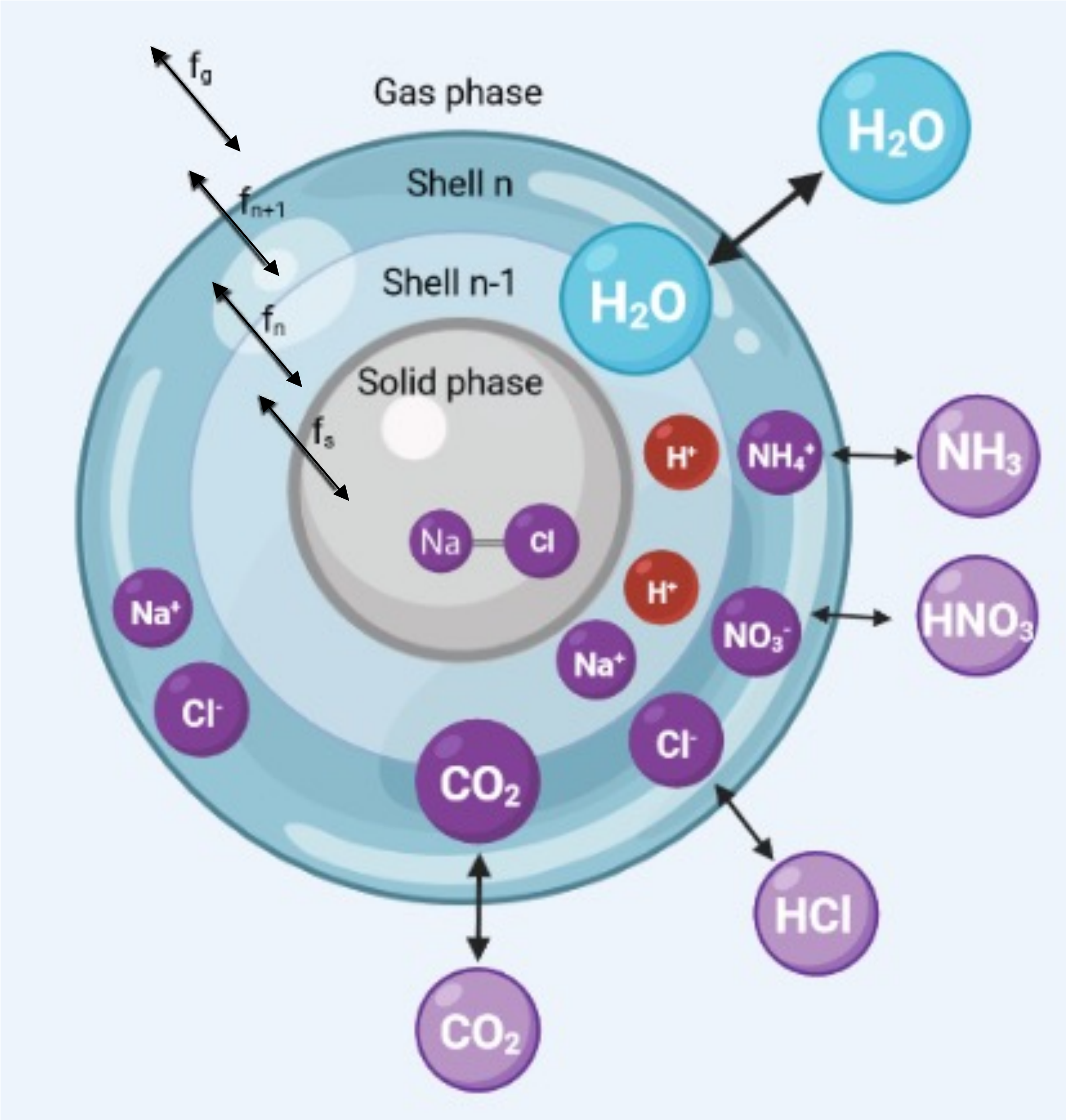


Respiratory aerosol model

1. Mass transfer
2. Heat transfer
3. Chemistry
4. Kinetics (diffusion of H_2O and ions)
5. Deliquescence and efflorescence
6. Charge neutrality

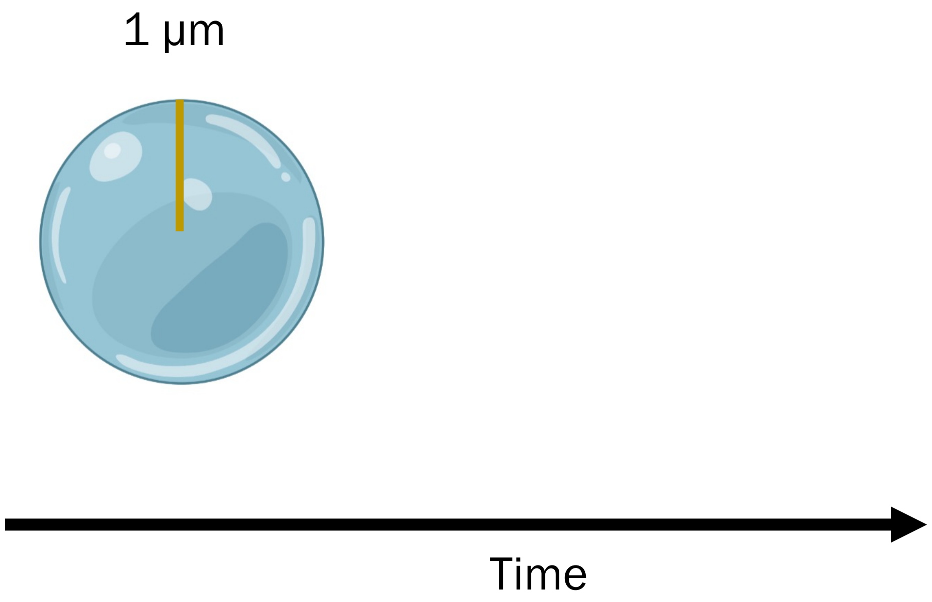
Hassoun et. al (2018)

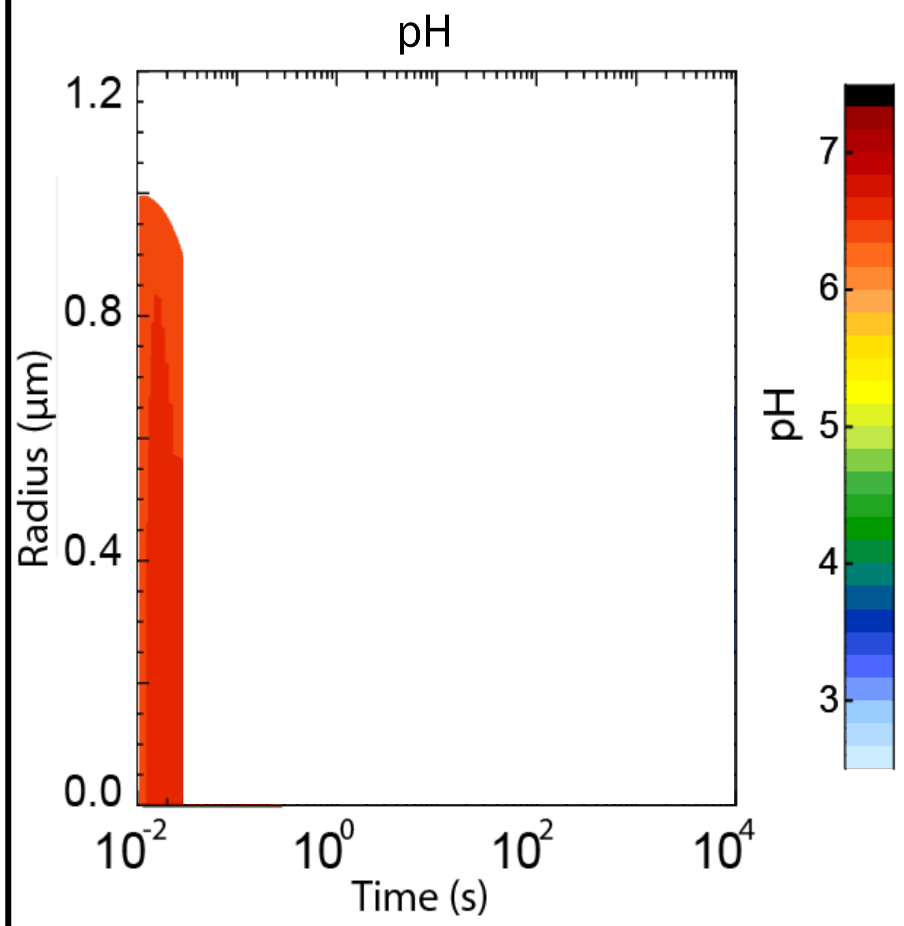
Synthetic Lung Fluid (SLF)



Aerosol pH in typical indoor air

Exhaled air:
RH = 91%
T = 313 K
x_{CO_2} ≈ 50,000 ppm
x_{HNO_3} = 0 ppb
x_{NH_3} ≈ 200 ppb





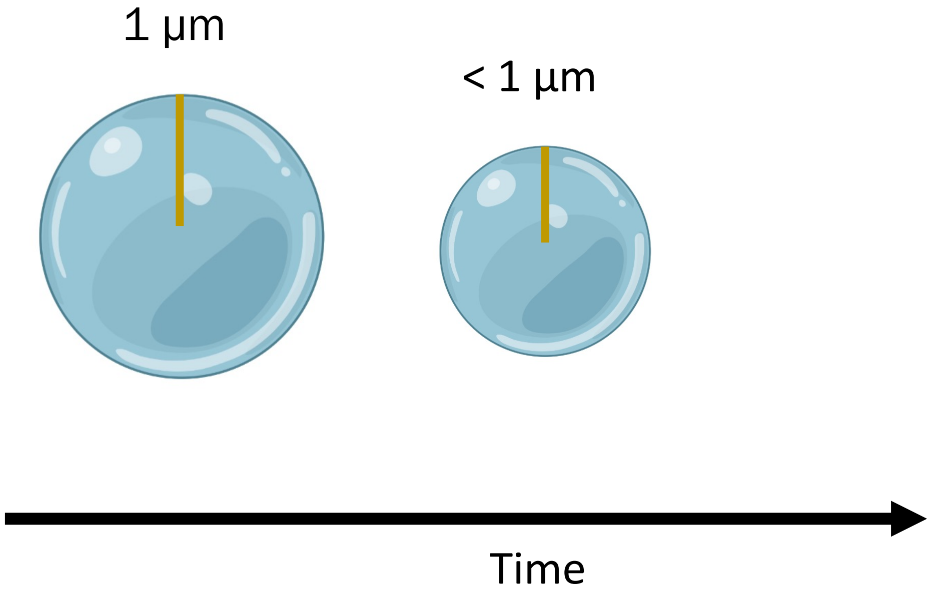
Aerosol pH in typical indoor air

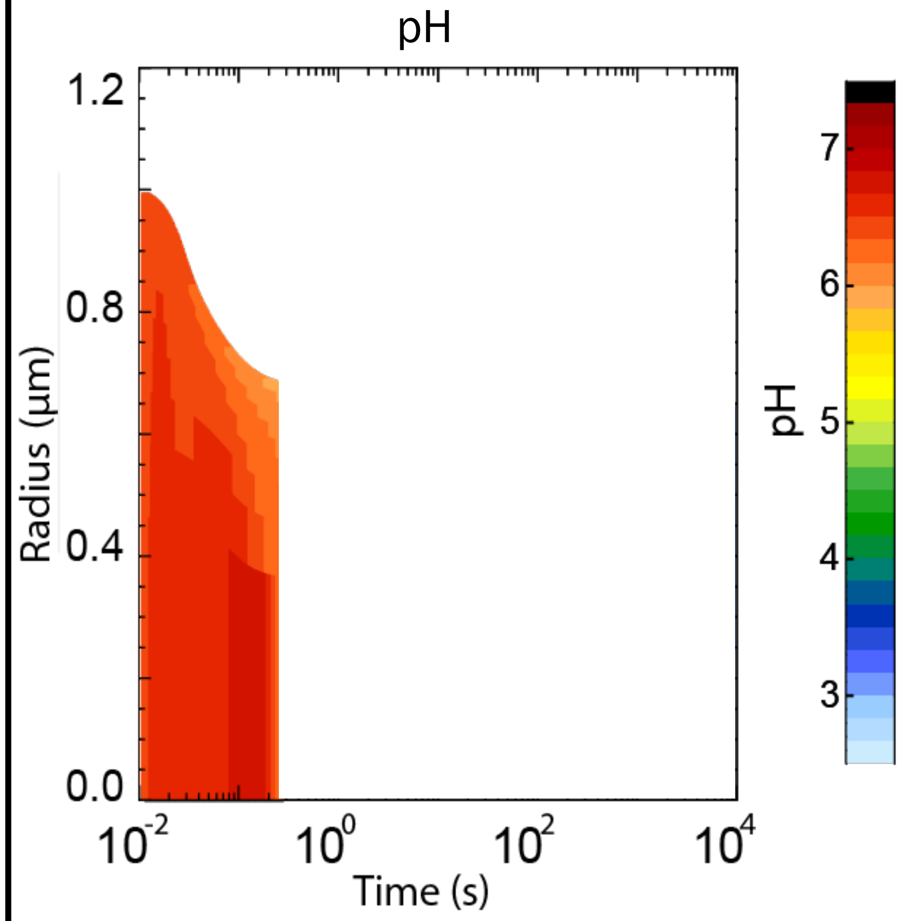
<u>Exhaled air:</u>

RH = 91%
T = 313 K
x_{CO_2} ≈ 50,000 ppm
x_{HNO_3} = 0 ppb
x_{NH_3} ≈ 200 ppb

<u>Indoor air:</u>

RH = 50%
T = 293 K
x_{CO_2} = 600 ppm
x_{HNO_3} ≈ 0.3 ppb
x_{NH_3} ≈ 40 ppb

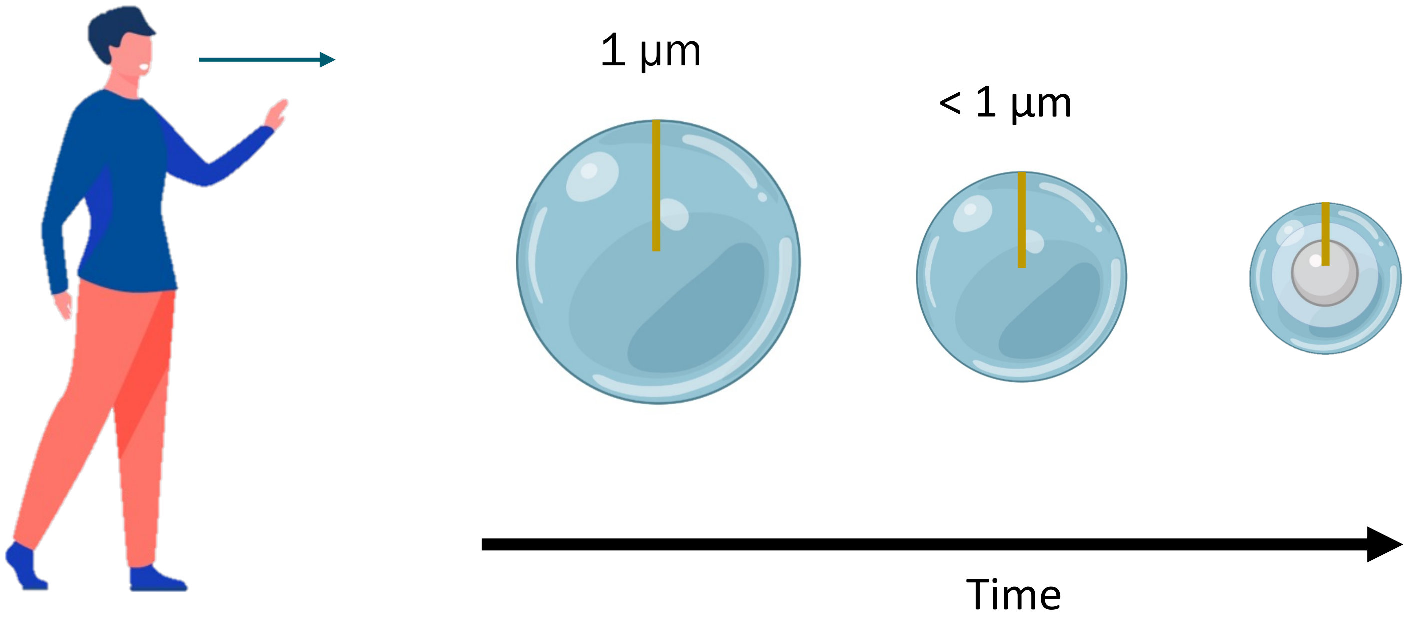


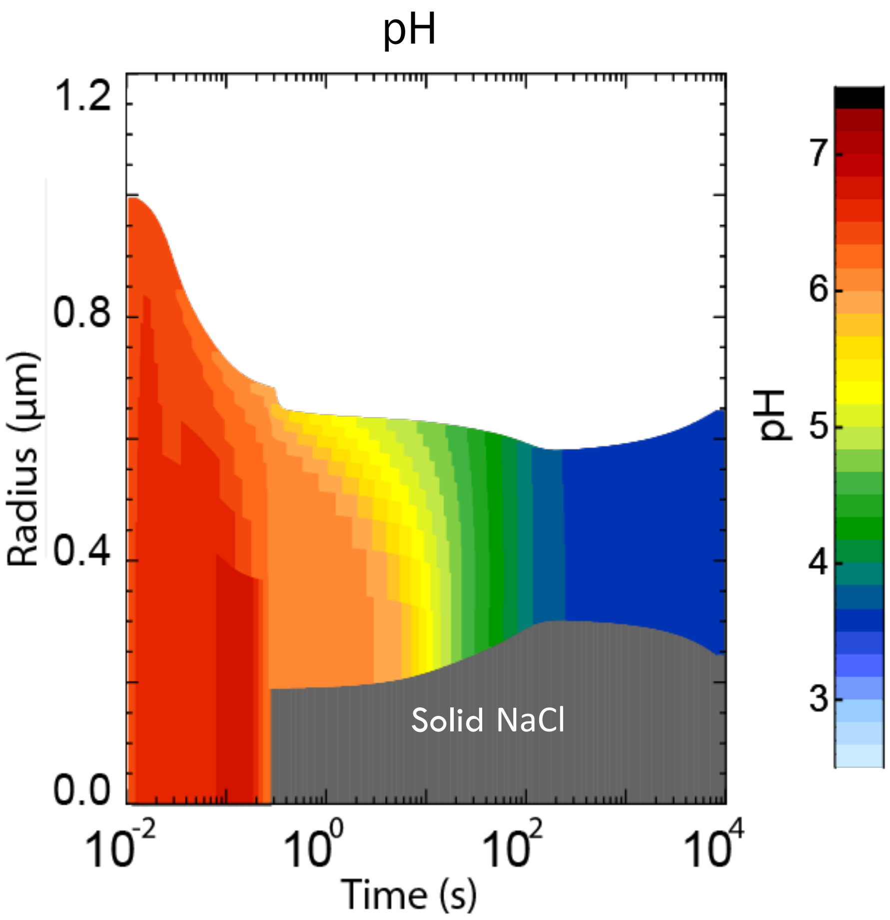


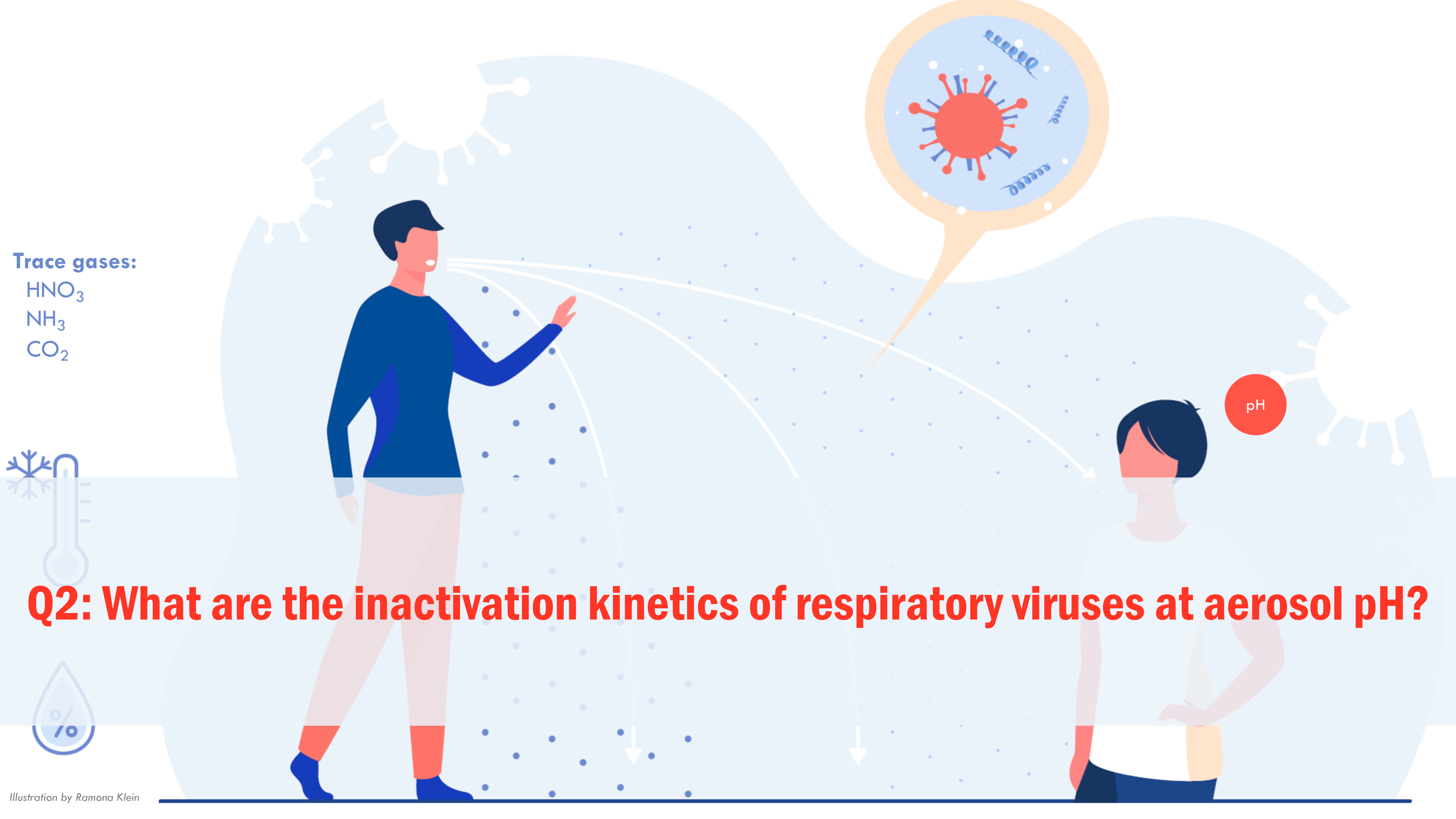
Aerosol pH in typical indoor air

Exhaled air:
RH = 91%
T = 313 K
x_{CO_2} ≈ 50,000 ppm
x_{HNO_3} = 0 ppb
x_{NH_3} ≈ 200 ppb

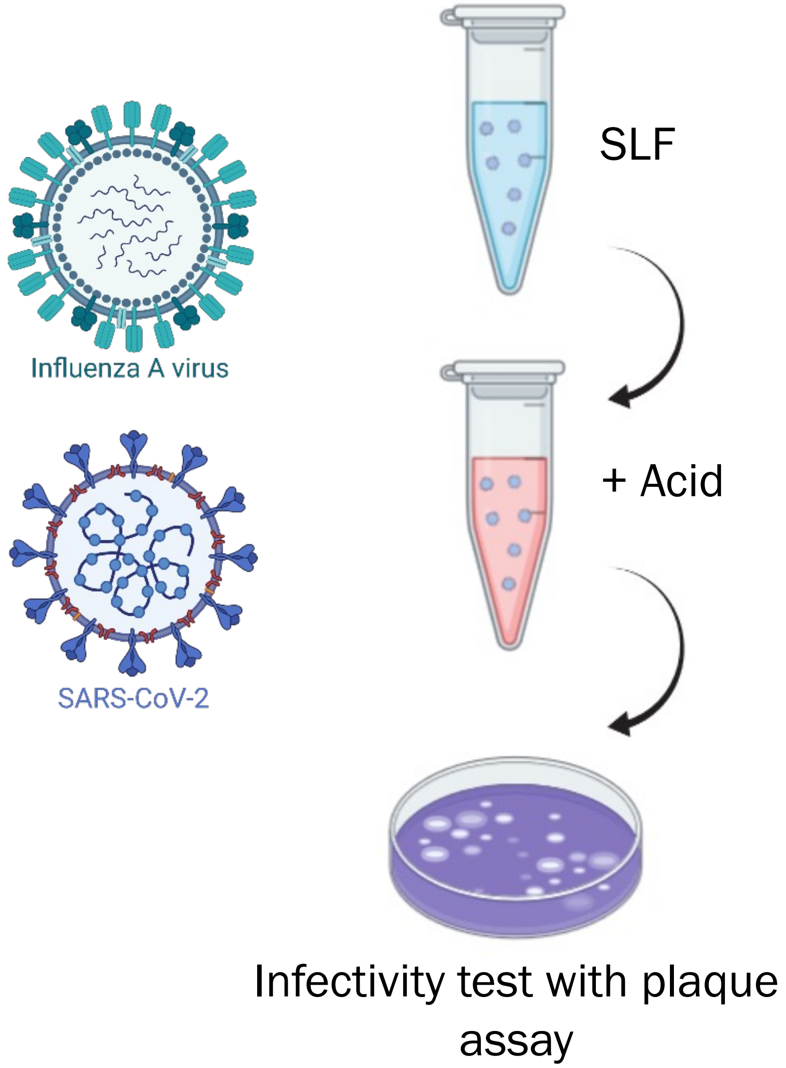
Indoor air:
RH = 50%
T = 293 K
x_{CO_2} = 600 ppm
x_{HNO_3} ≈ 0.3 ppb
x_{NH_3} ≈ 40 ppb



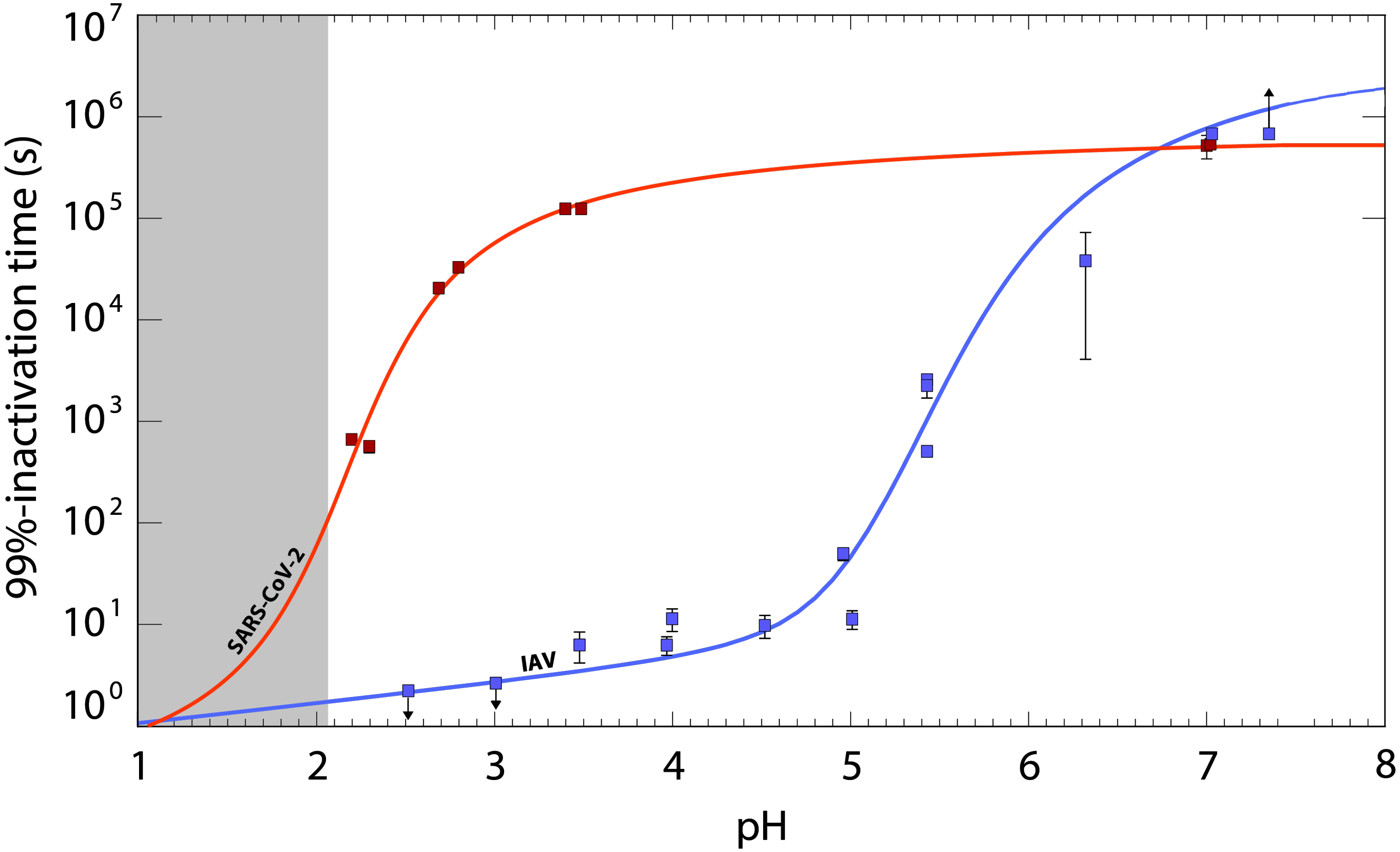



Trace gases:
HNO_3
NH_3
CO_2
pH
Q2: What are the inactivation kinetics of respiratory viruses at aerosol pH?
Illustration by Ramona Klein

Virus inactivation times in SLF from pH 2 to 7.5



Virus inactivation times in SLF from pH 2 to 7.5



Influenza virus

Faster inactivation at lower pH

SARS-CoV-2

Longer inactivation times than influenza virus

Requires more acidic pH

Acid-sensitivity depends on virus entry mechanism

Coronaviruses: the spike glycoprotein becomes fusion competent through cleavage by host proteases

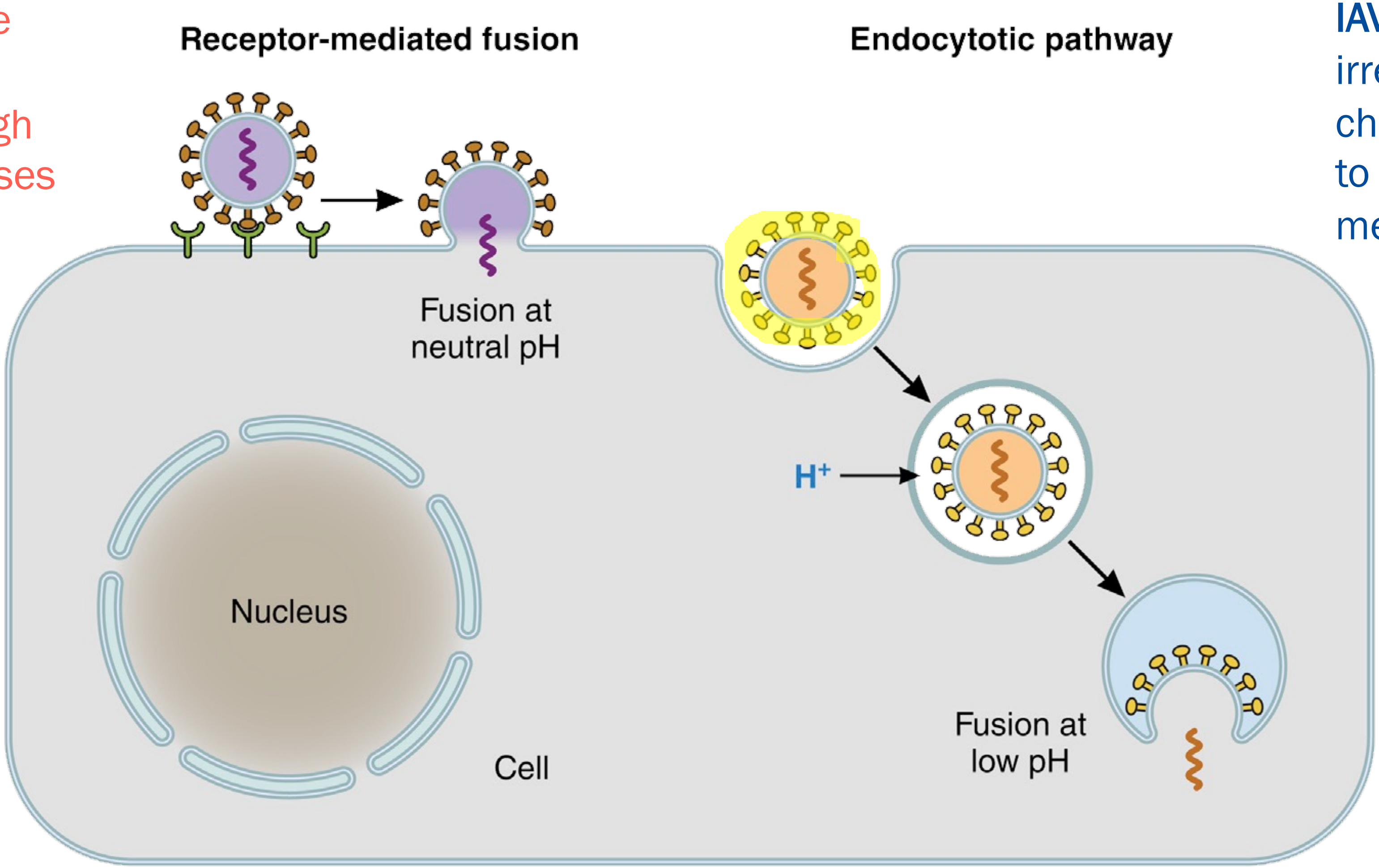
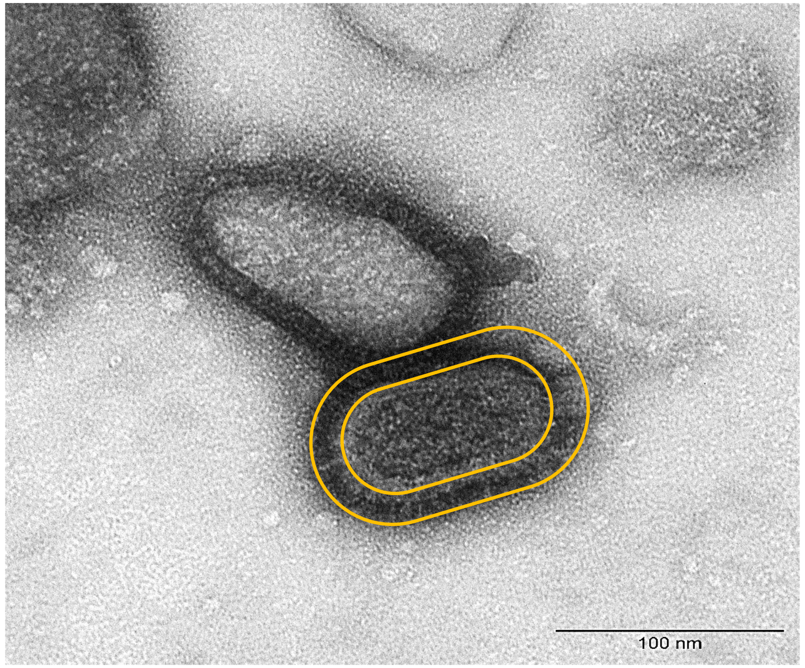


Figure from Cohen, (2016) Biophysical journal, 110(5), 1028-1032.

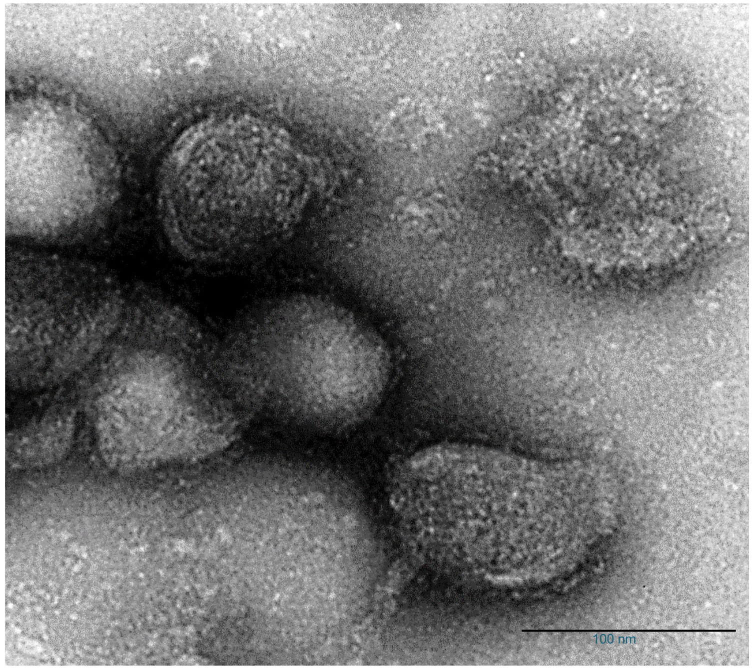
IAV: needs an acid-induced, irreversible conformational change of HA protein to fuse with endosomal membrane

Acid-induced changes in influenza virus prevent entry

pH 7



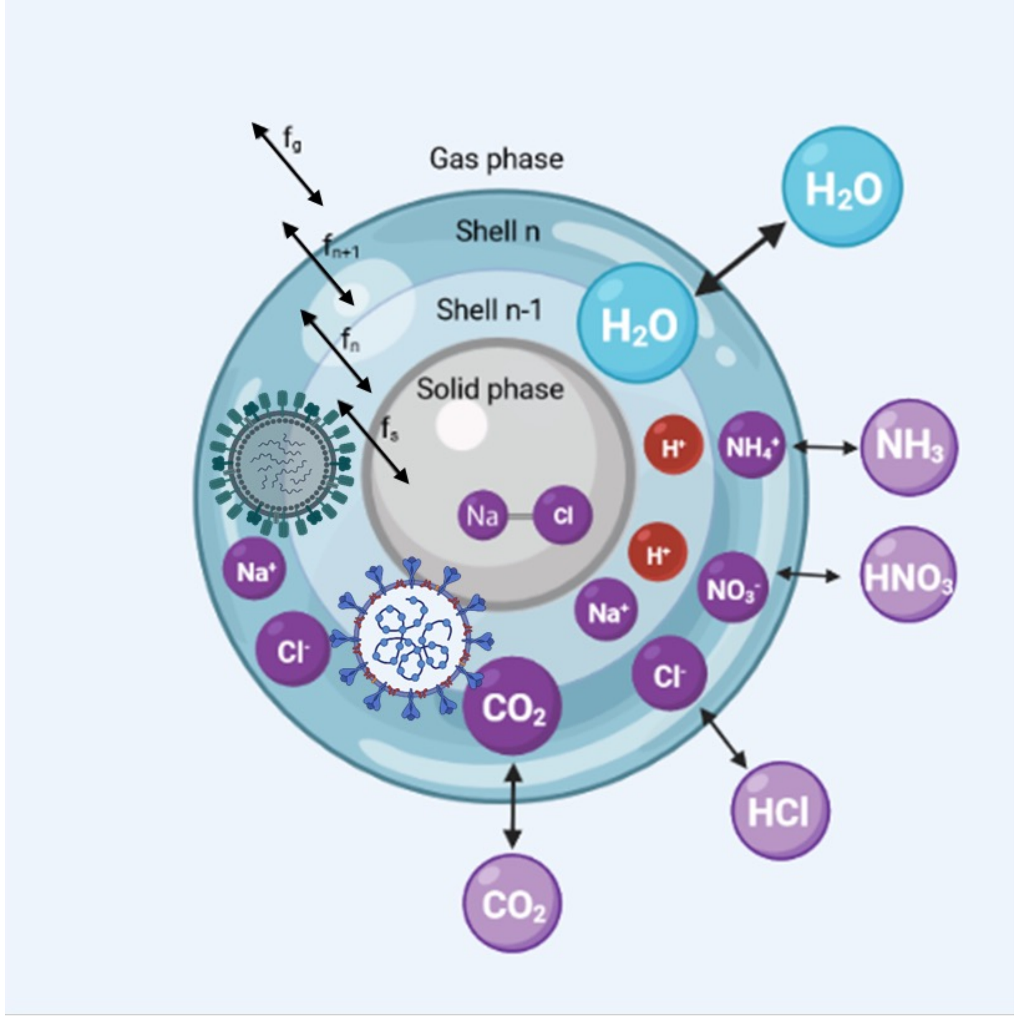
pH 4



- HA change occurs in acidic aerosol conditions within 10 s, outside the host
- Virus becomes unable to attach to host cell and cause infection

Back to the respiratory aerosol model

1. Mass transfer
2. Heat transfer
3. Chemistry
4. Kinetics (diffusion of H2O and ions)
5. Deliquescence and efflorescence
6. Charge neutrality
7. Virus inactivation kinetics



IAV is inactivated in expiratory aerosol…

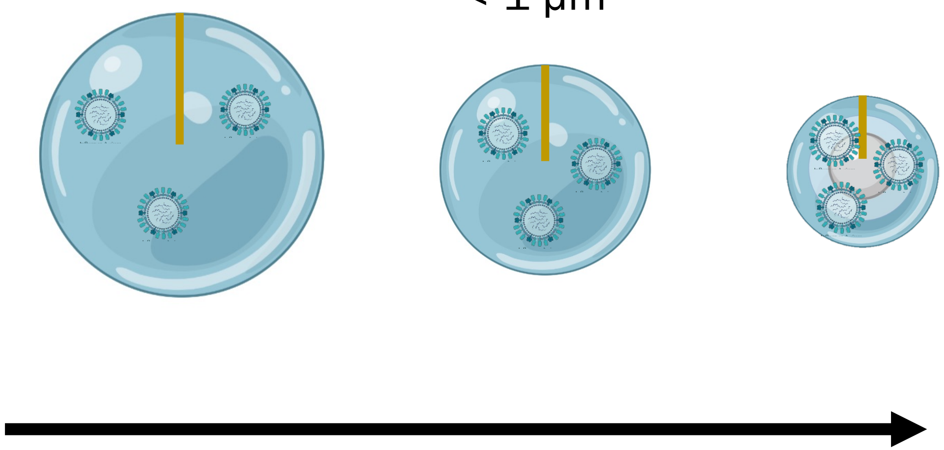
Exhaled air:

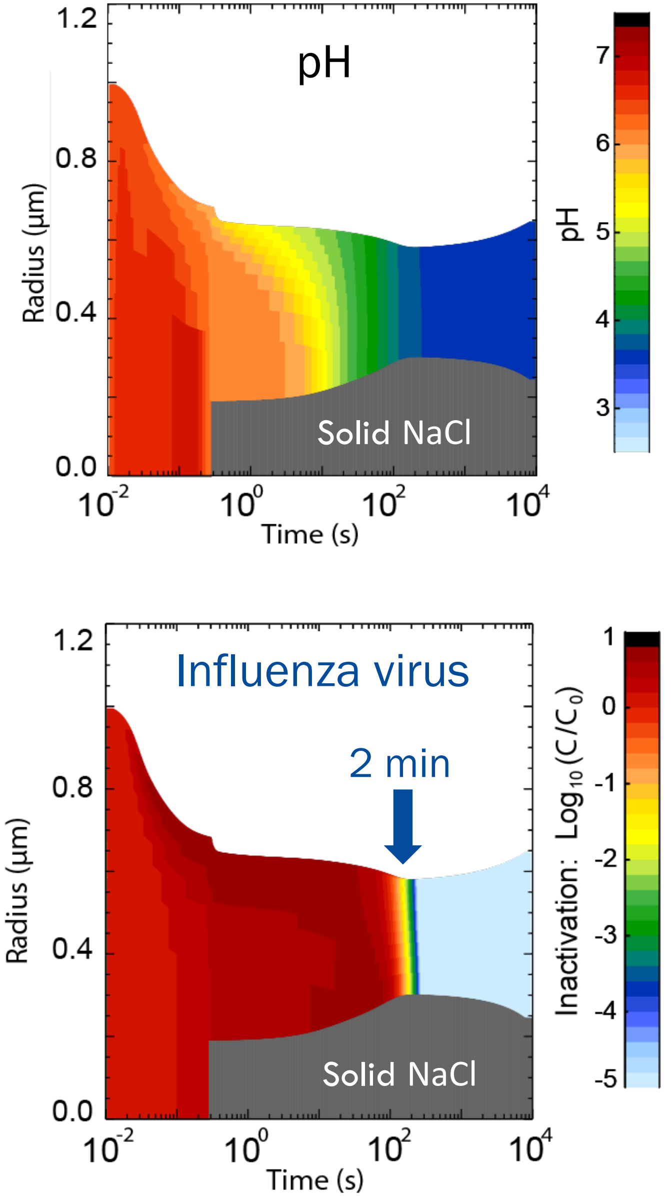
RH = 91%
T = 313 K
x_{CO_2} ≈ 50,000 ppm
x_{HNO_3} = 0 ppb
x_{NH_3} ≈ 200 ppb

Indoor air:

RH = 50%
T = 293 K
x_{CO_2} = 600 ppm
x_{HNO_3} ≈ 0.3 ppb
x_{NH_3} ≈ 40 ppb

Has the flu!





...but SARS-CoV-2 is not

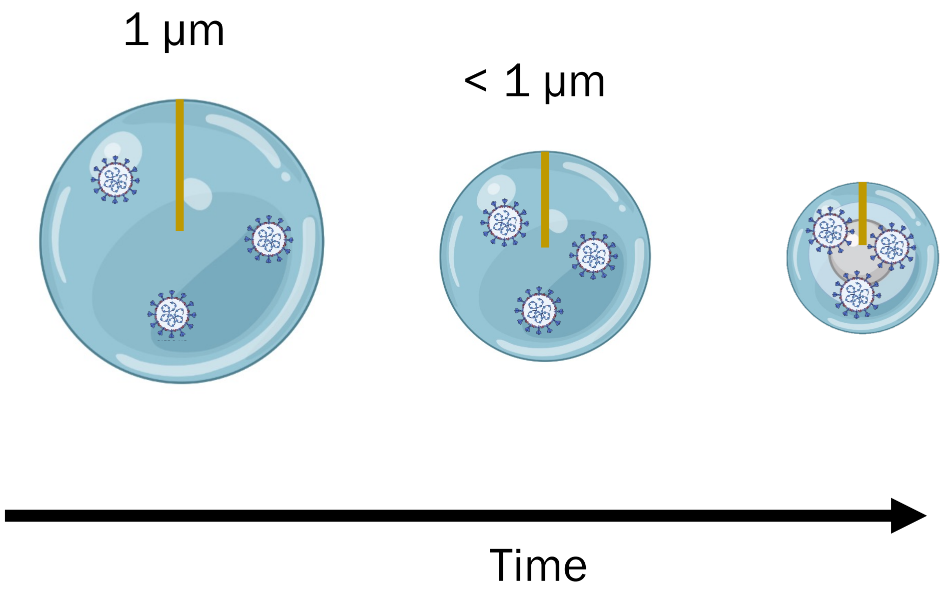
Exhaled air:

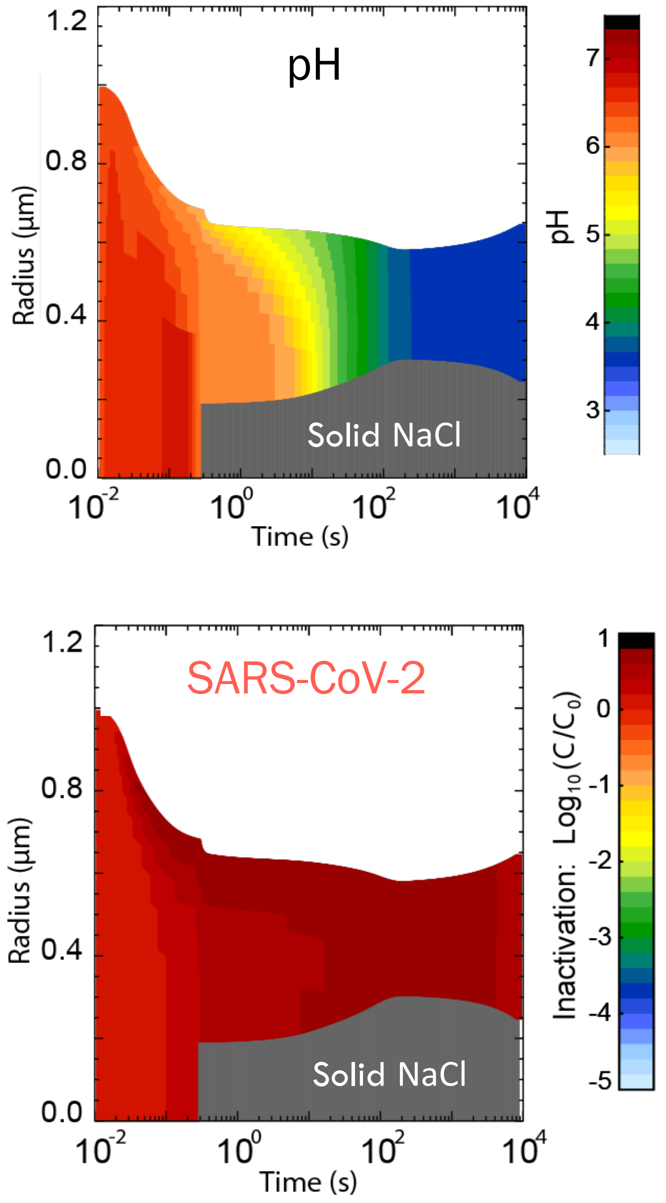
RH = 91%
T = 313 K
x_{CO_2} ≈ 50,000 ppm
x_{HNO_3} = 0 ppb
x_{NH_3} ≈ 200 ppb

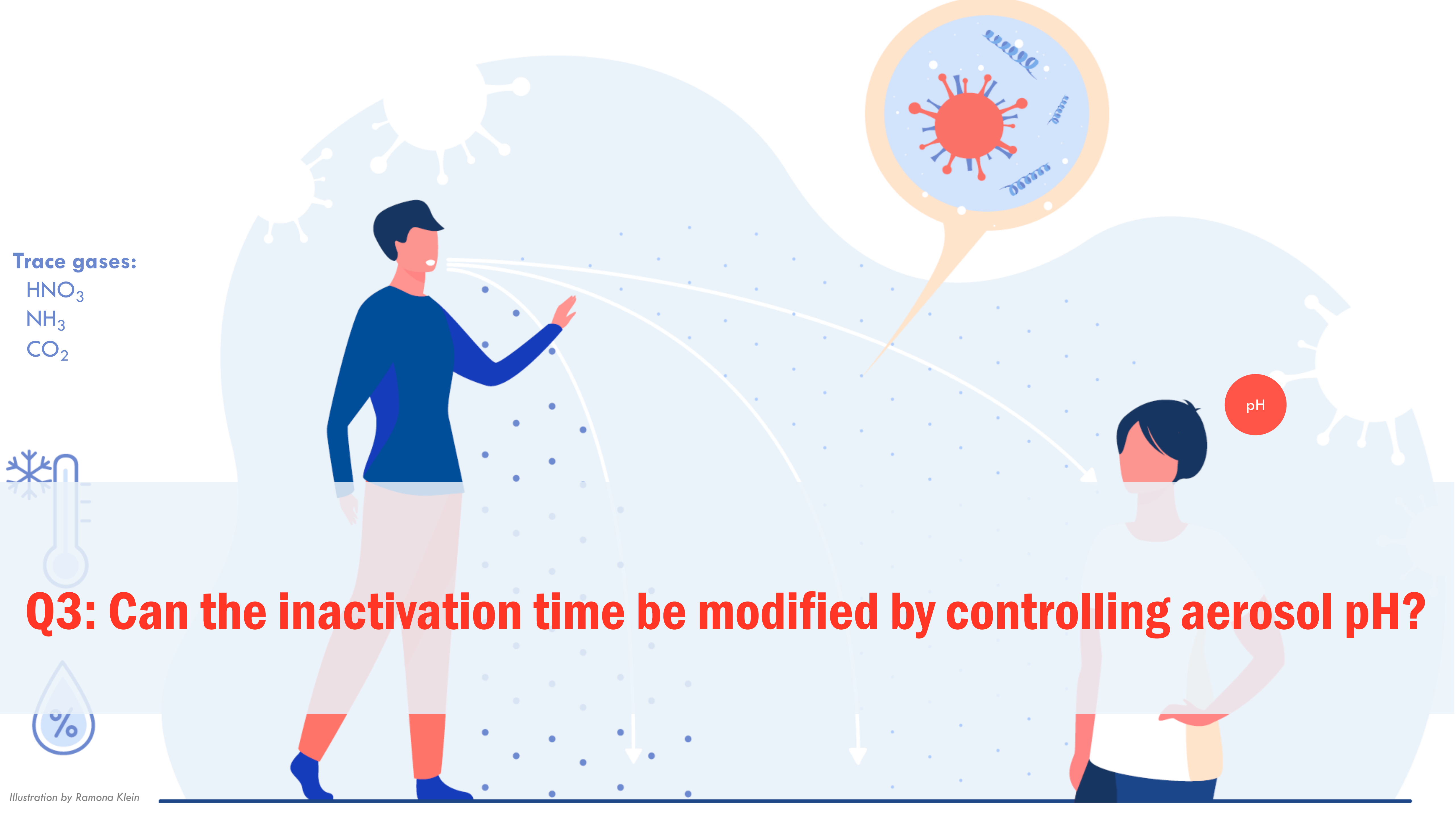
Indoor air:

RH = 50%
T = 293 K
x_{CO_2} = 600 ppm
x_{HNO_3} ≈ 0.3 ppb
x_{NH_3} ≈ 40 ppb

Has COVID!

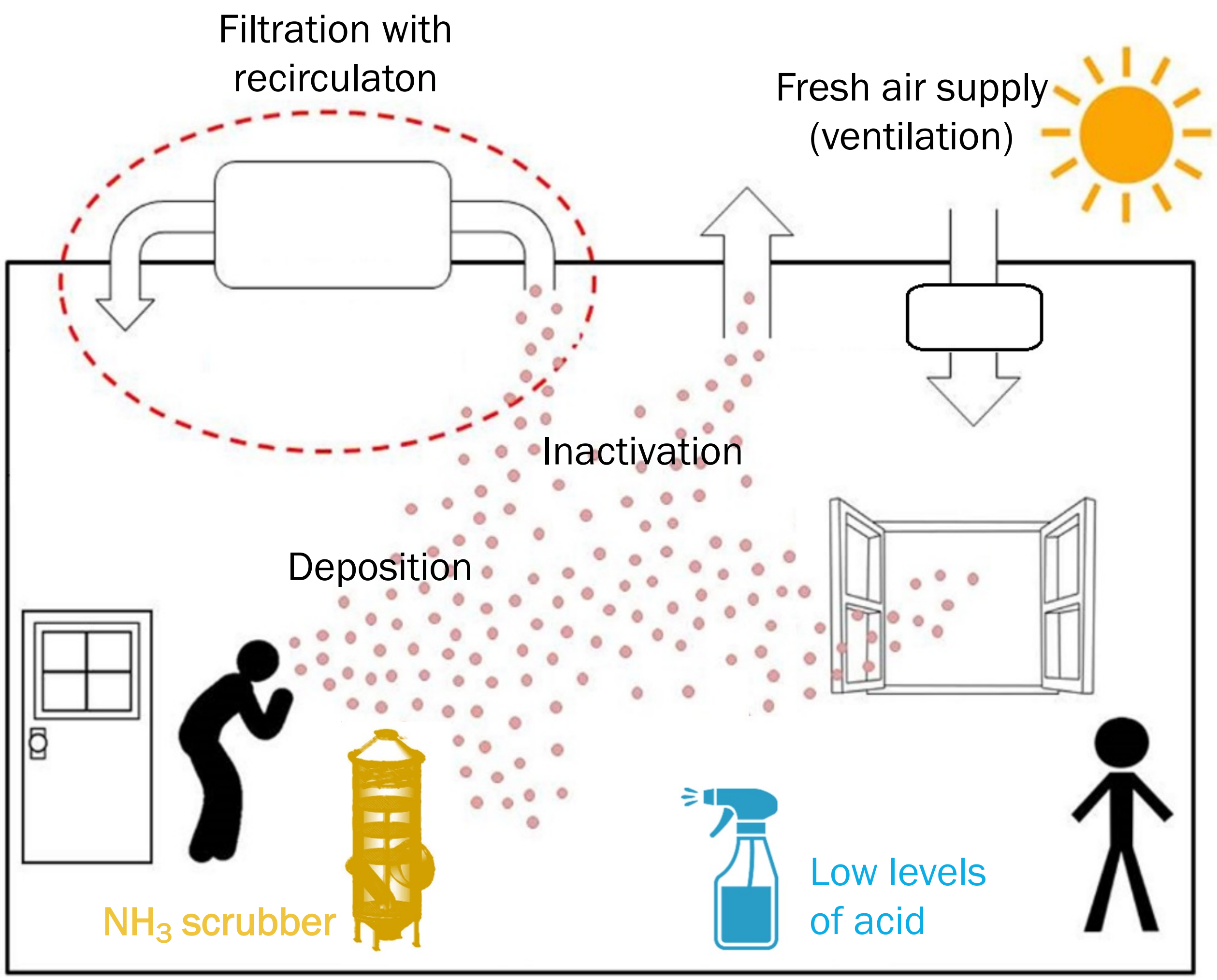


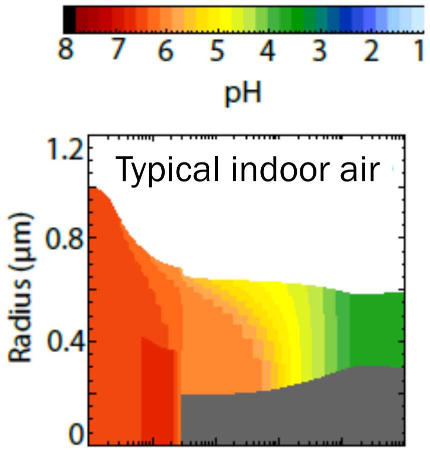




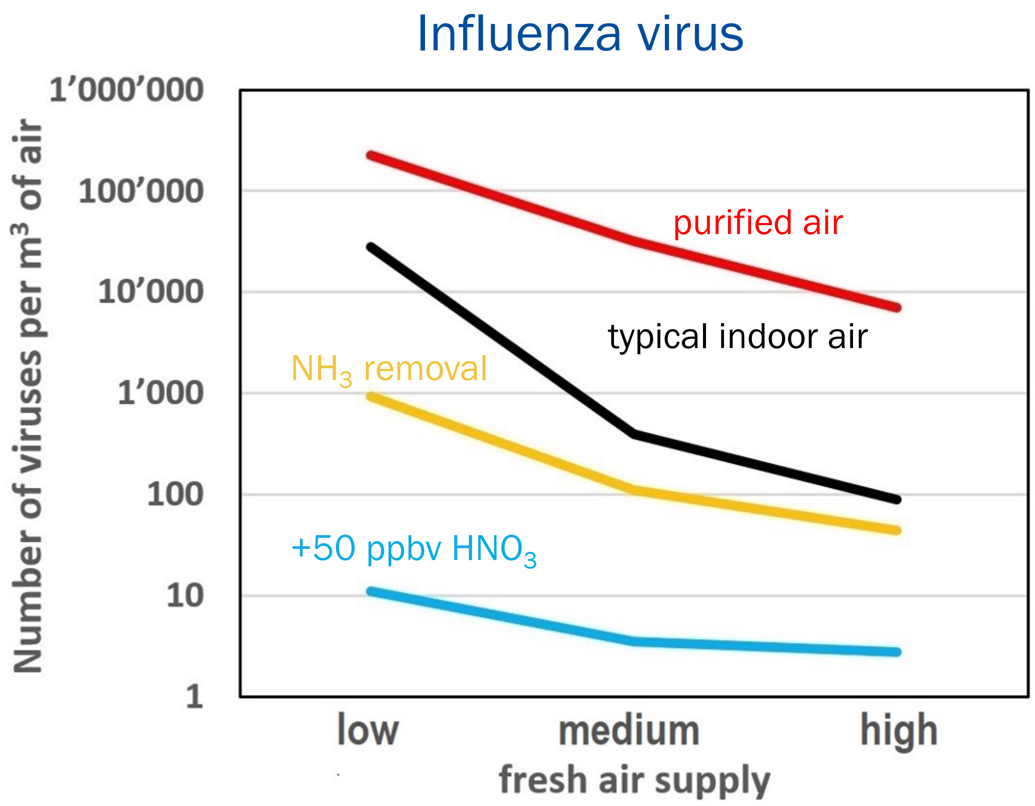
Q3: Can the inactivation time be modified by controlling aerosol pH?

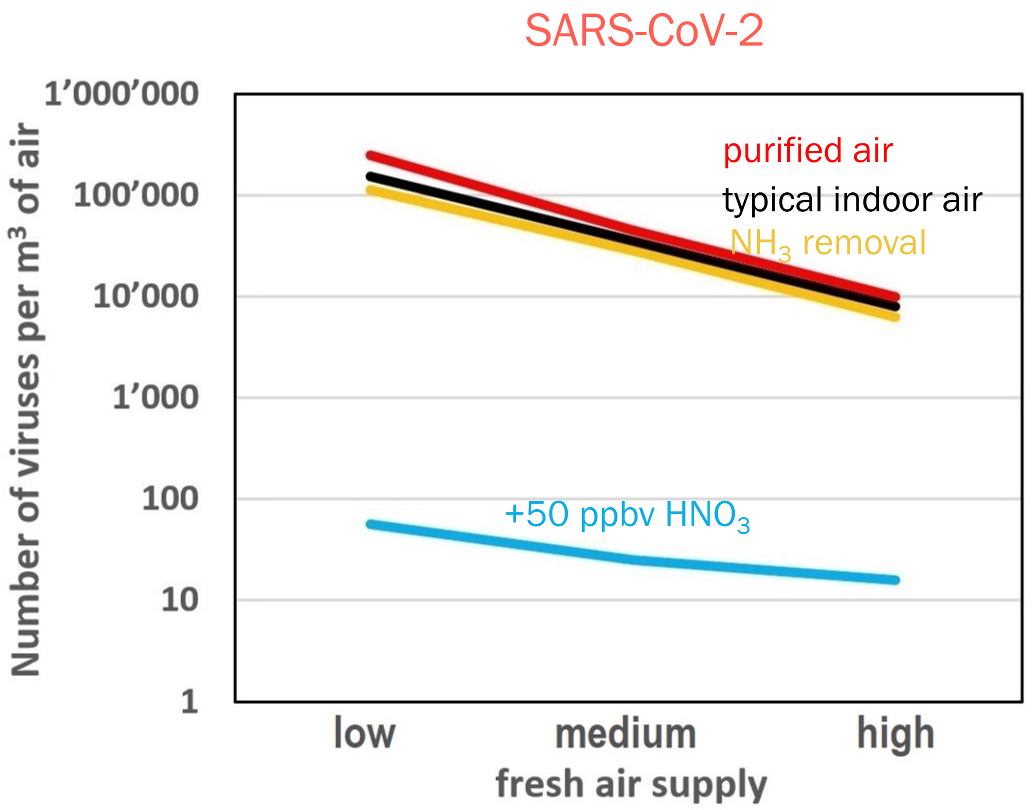
Options for aerosol pH control





Options for aerosol pH control





Supply fresh air!
Remove ammonia!
Possibly enrich acids!
Careful with filtration!

Pros and cons of air treatment methods

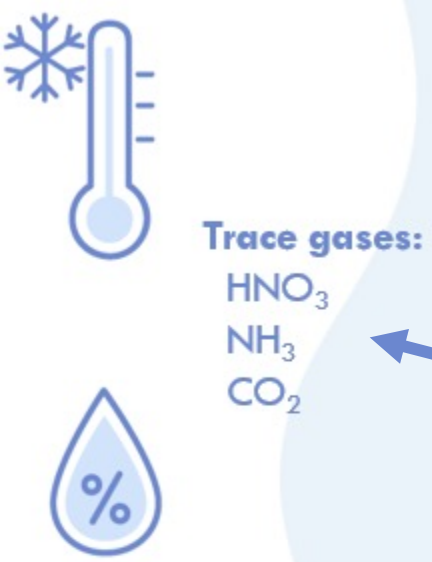
Air Treatment Method	Pros	Cons	Research Needs
Fresh air supply (ACH)	Supplies acid from outdoors, removes NH_3	Increased energy costs	Trade-off between energy use and air quality maintenance
Filtration (e.g., HEPA filters) of fresh or recirculated air	Removes allergens, PM and chemicals	Likely removes HNO_3 and elevates aerosol pH	Effect of filters on volatile acids and bases and ultimately aerosol pH
NH_3 scrubbing	Remove volatile base, but also other air constituents	Not effective for pH-inactivation of coronaviruses	Currently mainly used at large-scale (farms), adaptation to smaller scale applications needed, e.g., for gyms, class rooms
Acid addition	Effective even against quite acid-resistant viruses (SARS-CoV-2)	Low acceptability? Effects on health and infrastructure are unknown	Identify innocuous, effective acids; dispensing and control system needed

Conclusion

pH control can be an effective strategy to limit the transmission of a disease in indoor environments such as hospitals and schools; it is possibly more effective than ventilation (though you should do that, too!)

Conclusion

pH control can be an effective strategy to limit the transmission of a disease in indoor environments such as hospitals and schools; it is possibly more effective than ventilation (though you should do that, too!)



Understanding the physics and chemistry of the environment is extremely important for understanding the fate of biological contaminants.

Thank you!

Swiss National Science Foundation

EPFL ETH zürich University of Zurich[UZH]

Environmental Science & Technology
pubs.acs.org/est
Article

Expiratory Aerosol pH: The Overlooked Driver of Airborne Virus Inactivation

Beiping Luo, Aline Schaub, Irina Glas, Liviana K. Klein, Shannon C. David, Nir Bluvshtein, Kalliopi Violaki, Ghislain Motos, Marie O. Pohl, Walter Hugentobler, Athanasios Nenes, Ulrich K. Krieger, Silke Stertz, Thomas Peter,* and Tamar Kohn*

Beiping Luo

Aline Schaub

Irina Glas

Liviana Klein

Shannon David

Oscar Vadas

Marie Pohl

Nir Bluvshtein

Ghislain Motos

Kalliopi Violaki

Walter Hugentobler

Athanasios Nenes

Ulrich Krieger

Silke Stertz

Thomas Peter

Many images created in Biorender