MODELLING OF AIRBORNE TRANSMISSIONS OF RESPIRATORY DROPLETS CONTAINING SARS-COV-2 VIRUS

Benjamin Mignot

School of Chemical and Process Engineering, University of Leeds, UK

UNIVERSITY OF LEEDS

Transmission pathways of respiratory diseases

Droplet route

Large droplets expelled from an infected person to a susceptible person's mucosae (mouth and nose) or conjunctiva (eyes)

Contact route

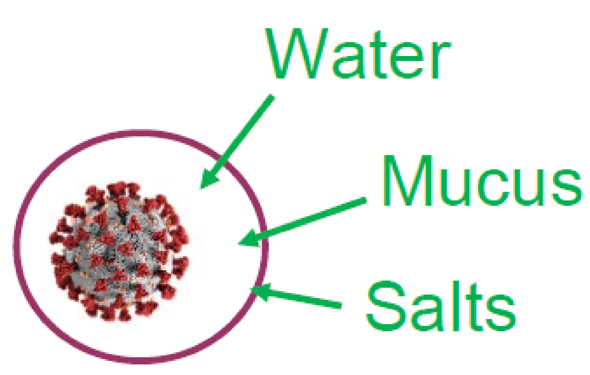
Direct: shaking hands

Indirect: contaminated surfaces (fomites)

Airborne route

Solid residues from evaporated exhaled droplets inhaled by a susceptible host

Evidence shows SARS-CoV-2 is airborne[1]



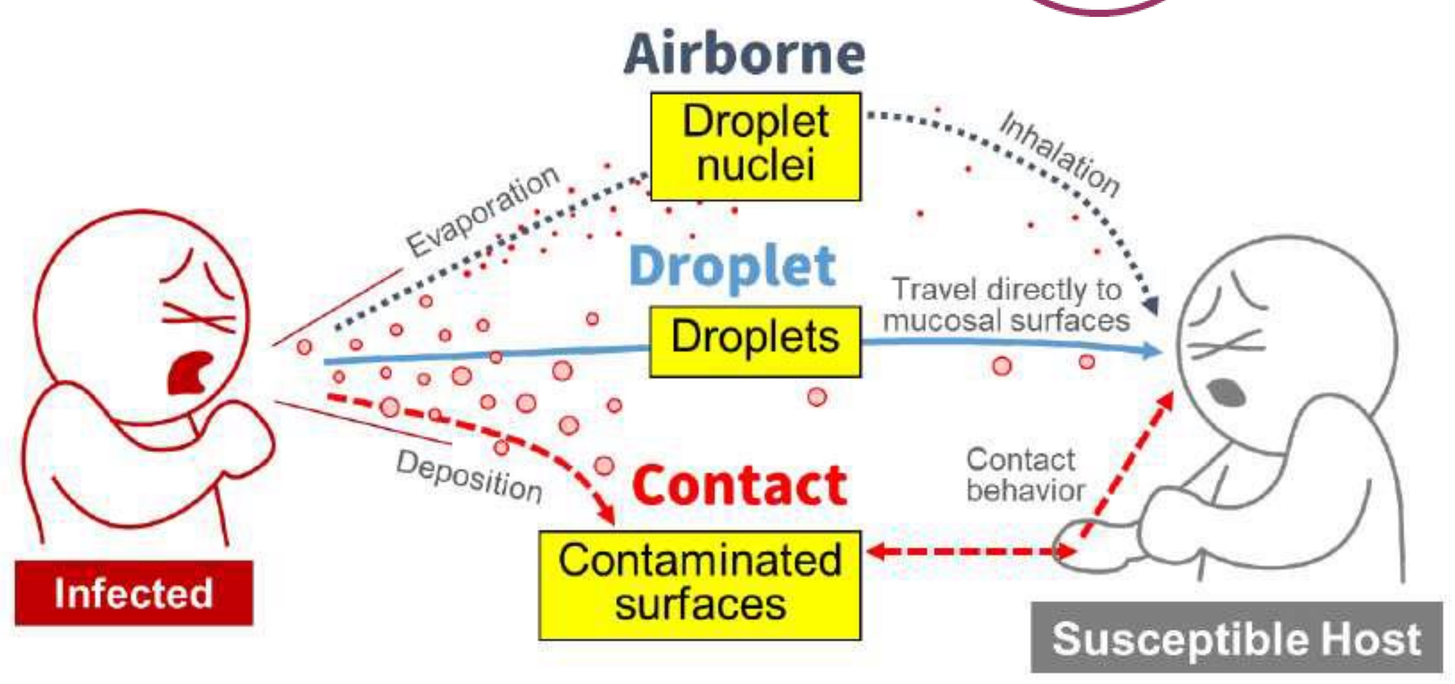


Figure 1: Modes of transmission of exhaled pathogens[2]

Expiratory droplet generation and drying

- Droplets are generated in respiratory tract via wind shear forces
  - High speed air stream through narrow passages over the surface of a liquid creates droplets by atomisation
  - Originate from either the bronchioles, larynx or the mouth, depending on expiratory activity (RH close to 100%)
- Droplets undergo heat and mass transfers with the ambient air
  - Complex composition: water, salt, protein, lipid and pathogens
  - Shrink to a droplet nucleus (solid residue) after evaporation

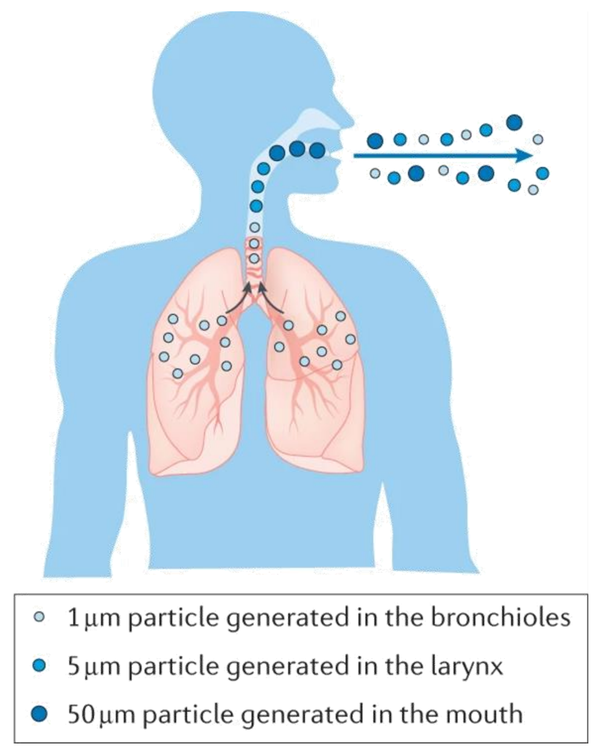


Figure 2: Size of exhaled droplets from different origins[3]

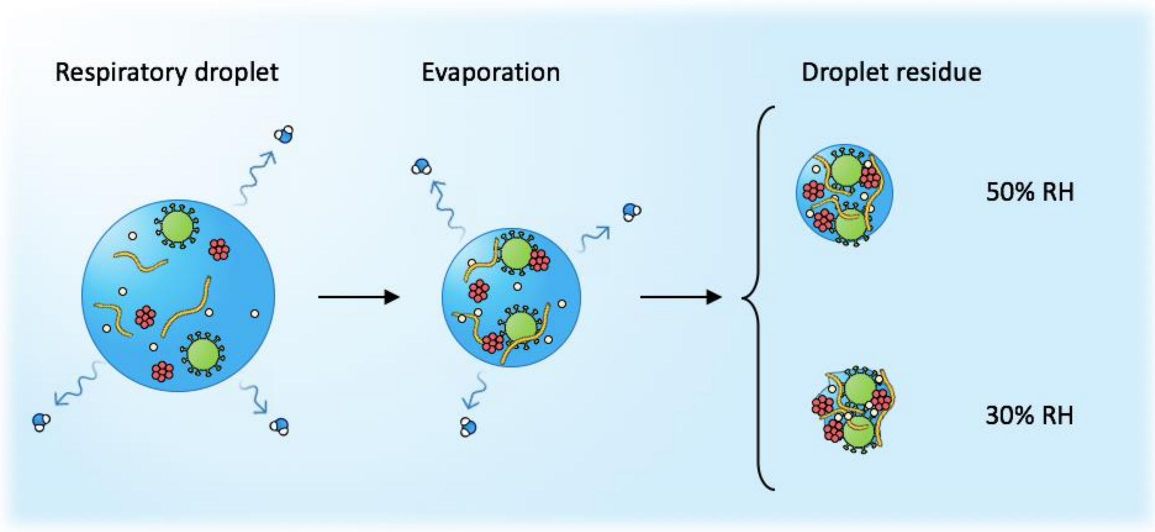


Figure 3: Drying of a respiratory droplet[4]

Research questions

- How do microscopic droplets dry after being released in the atmosphere?
- How far do these airborne particles travel in air currents?
- What type of microstructure does the solid residue formed from the droplet have?
- Can the understanding of these phenomena help us provide guidance on indoor ventilation and social distancing?

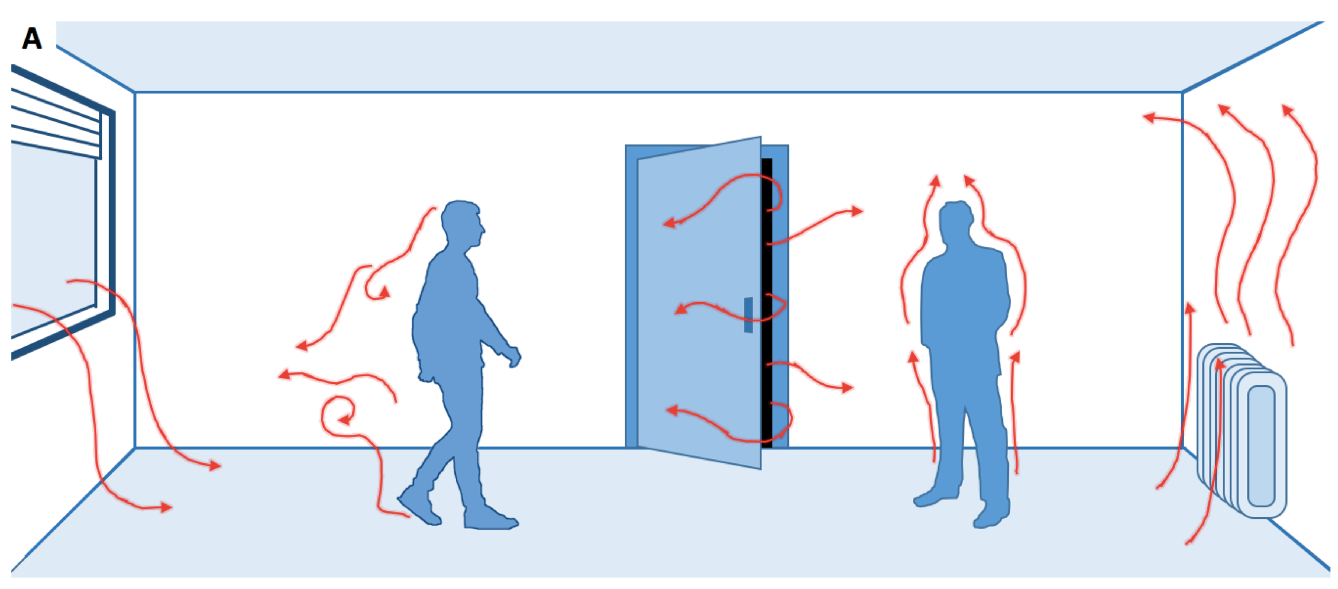


Figure 4: Example of air currents inside a room[4]

Programme

$$\frac{dm_p}{dt} = \frac{4\pi r_p M_v D_\infty Cp}{RT_\infty} \ln\left[\frac{(1-(p_{va}/p))}{(1-(p_{v\infty}/p))}\right]$$

Equation 1: Diffusive mass flux of vapour from a droplet surface[5]

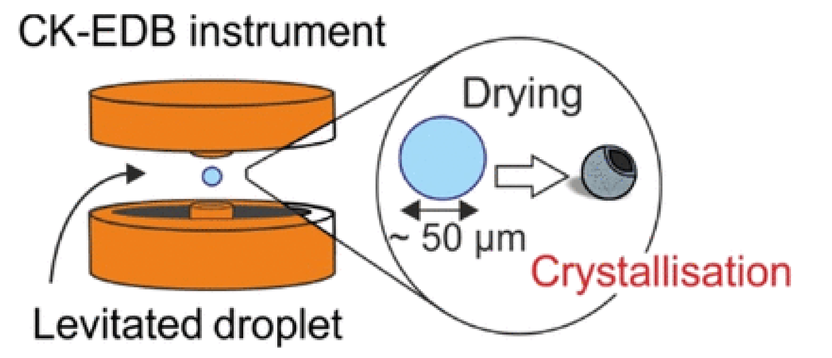


Figure 5: Droplet evaporation measurement using CK-EDB[6]

- Develop a first principle model for the evaporation of respiratory droplet ⇄ Validate model using Comparative-Kinetics Electrodynamic Balance (CK-EDB) for single levitating droplets
- ↓
- Modelling of aerosol dispersion using Computational Fluid Dynamics (CFD) ⇄ Create atomization system to simulate respiratory activities. Use to validate CFD tool
- ↓
- Apply modelling tool to different types of confined environments

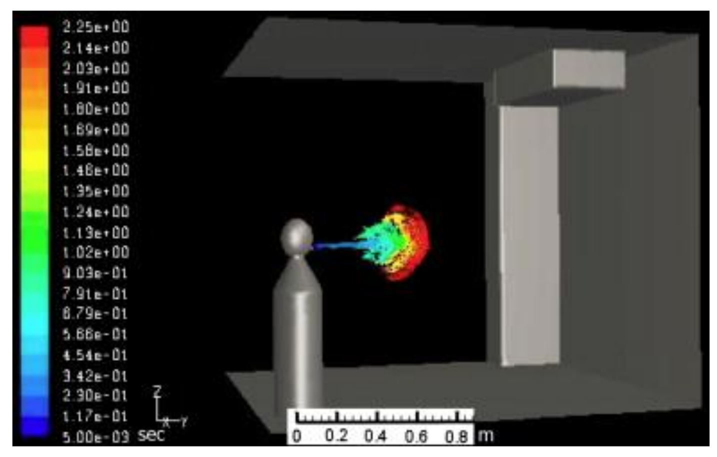


Figure 6: Particles residence time emitted by cough using a CFD model[7]

Responsible and scientific innovation

- Dual use concern: knowledge of aerosol dispersion indoors could be used to spread infectious pathogens
- Government or local authorities could target places or groups of people by using these guidelines incorrectly
- Social distancing and ventilation require sufficient resources and may increase energy consumption
- Modelling tool could be applied to other diseases (TB, influenza, measles)

TBS: modelling deposition of inhaled particles

- Simulations of aerosol deposition are computationally expensive
- An approximation of results without particle tracking would be useful
- Correlations have been found between particle deposition and wall shear stress (WSS), or with local Stokes number
- Goal is to investigate in which situations (geometry, flow, particle sizes, etc) these options give a good correlation with deposition

References

1. Morawska and Cao. 2020. Environment International 139.
2. Da Silva. 2020. The REHVA European HVAC Journal 57(3).
3. Morawska and Buonanno. 2021. Nature Reviews Physics 3(5).
4. Božič and Kanduč. 2021. Journal of Biological Physics 47(1).
5. Kukkonen, et al. 1989. Journal of Aerosol Science 20(7).
6. Gregson, et al. 2019. Journal of Physical Chemistry B 123(1).
7. Redrow, et al. 2011. Building and Environment 46(10).