# The modes of transmission of SARS-CoV-2: What we know now & how to protect ourselves

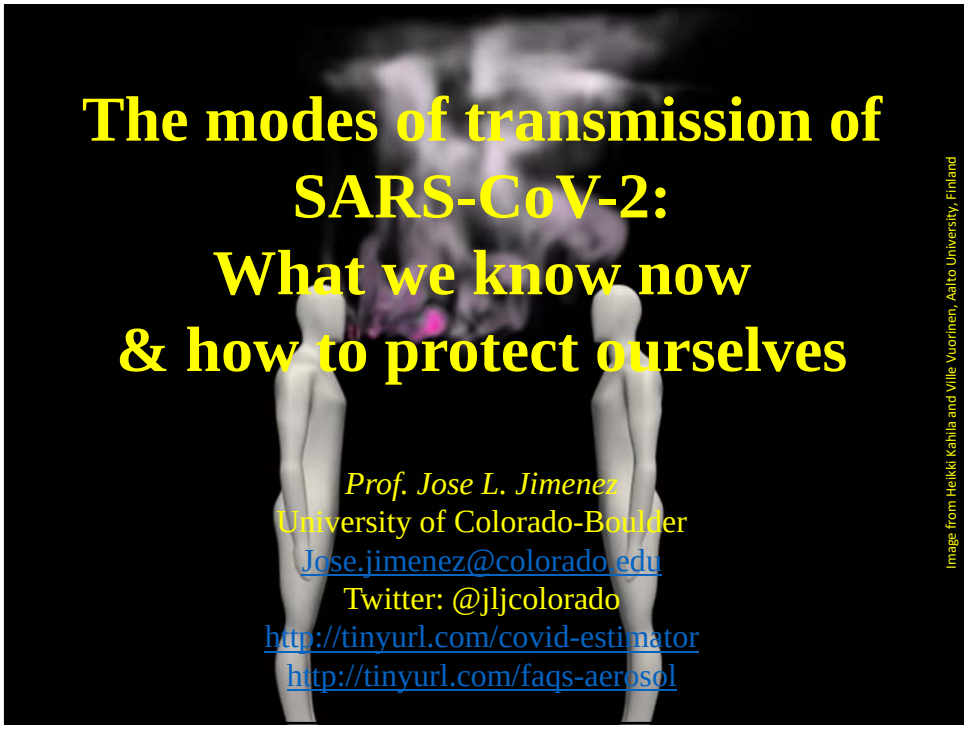

Image from Heikki Kahila and Ville Vuorinen, Aalto University, Finland

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Jose.jimenez@colorado.edu
Twitter: @jljcolorado
http://tinyurl.com/covid-estimator
http://tinyurl.com/faqs-aerosol

University of Colorado Boulder

1. What do we know about the modes of transmission?

2. How can we protect ourselves against infection?

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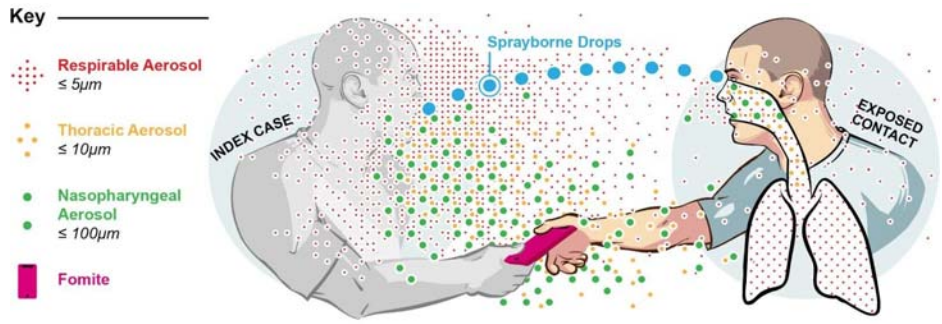
# Droplets vs. Aerosols vs. Surfaces




- Droplets:
  - Ballistic projectiles
  - Infect by impact on eyes, nostrils or mouth
- Aerosols
  - Float in the air
  - Infect by inhalation

From Milton, 2020: https://academic.oup.com/jpids/article/doi/10.1093/jpids/piaa079/5875939 (w/ update courtesy of Prof. Milton)

# What do we know about transmission?

- Surfaces not major:
  - E.g. hand-washing reduced 16%


  - *Disinfecting surfaces not very important*

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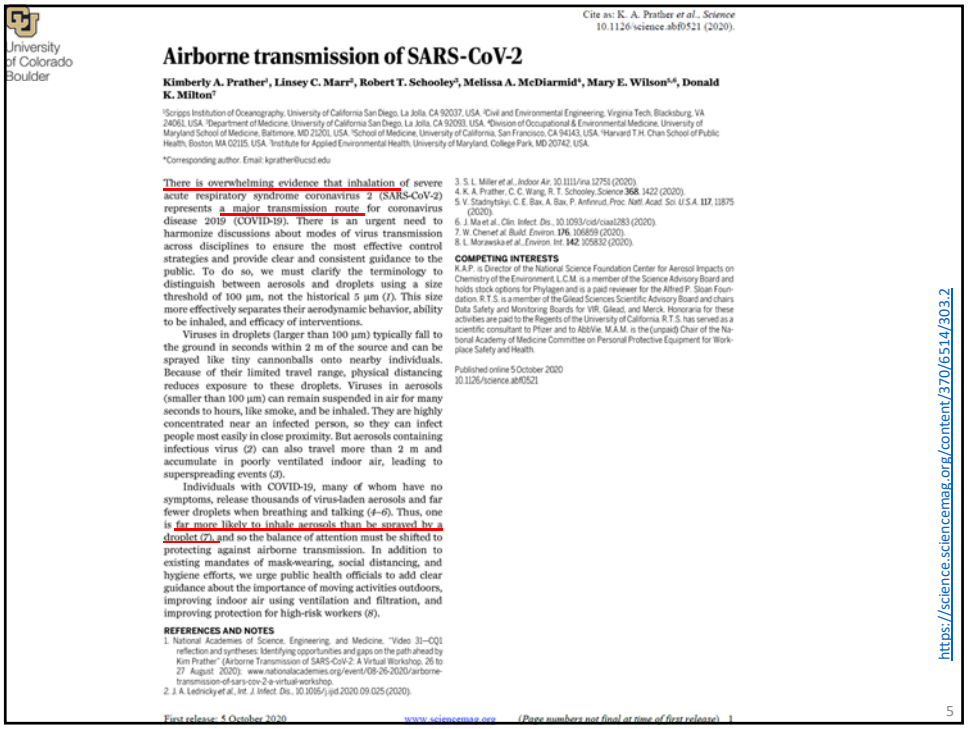

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Cite as: K. A. Prather *et al.*, *Science* 10.1126/science.abf0521 (2020).

# Airborne transmission of SARS-CoV-2

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There is overwhelming evidence that inhalation of severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) represents a major transmission route for coronavirus disease 2019 (COVID-19). There is an urgent need to harmonize discussions about modes of virus transmission across disciplines to ensure the most effective control strategies and provide clear and consistent guidance to the public. To do so, we must clarify the terminology to distinguish between aerosols and droplets using a size threshold of 100 μm, not the historical 5 μm (*1*). This size more effectively separates their aerodynamic behavior, ability to be inhaled, and efficacy of interventions.

Viruses in droplets (larger than 100 μm) typically fall to the ground in seconds within 2 m of the source and can be sprayed like tiny cannonballs onto nearby individuals. Because of their limited travel range, physical distancing reduces exposure to these droplets. Viruses in aerosols (smaller than 100 μm) can remain suspended in air for many seconds to hours, like smoke, and be inhaled. They are highly concentrated near an infected person, so they can infect people most easily in close proximity. But aerosols containing infectious virus (*2*) can also travel more than 2 m and accumulate in poorly ventilated indoor air, leading to superspreading events (*3*).

Individuals with COVID-19, many of whom have no symptoms, release thousands of virus-laden aerosols and far fewer droplets when breathing and talking (*4*–*6*). Thus, one is far more likely to inhale aerosols than be sprayed by a droplet (*7*), and so the balance of attention must be shifted to protecting against airborne transmission. In addition to existing mandates of mask-wearing, social distancing, and hygiene efforts, we urge public health officials to add clear guidance about the importance of moving activities outdoors, improving indoor air using ventilation and filtration, and improving protection for high-risk workers (*8*).

**REFERENCES AND NOTES**

1. National Academies of Science, Engineering, and Medicine. "Video 31—Q1 reflection and syntheses: Identifying opportunities and gaps on the path ahead by Kim Prather" (Airborne Transmission of SARS-CoV-2: A Virtual Workshop, 26 to 27 August 2020). www.nationalacademies.org/event/08-26-2020/airborne-transmission-of-sars-cov-2-a-virtual-workshop.
2. J. A. Lednicky *et al.*, *Int. J. Infect. Dis.*, 10.1016/j.ijid.2020.09.025 (2020).
3. S. L. Miller *et al.*, *Indoor Air*, 10.1111/ina.12751 (2020).
4. K. A. Prather, C. C. Wang, R. T. Schooley, *Science* **368**, 1422 (2020).
5. V. Stadnytskyi, C. E. Bax, A. Bax, P. Anfinrud, *Proc. Natl. Acad. Sci. U.S.A.* **117**, 11875 (2020).
6. J. Ma *et al.*, *Clin. Infect. Dis.*, 10.1093/cid/ciaa1283 (2020).
7. W. Chen *et al.*, *Build. Environ.* **176**, 106859 (2020).
8. L. Morawska *et al.*, *Environ. Int.* **142**, 105832 (2020).

**COMPETING INTERESTS**

K.A.P. is Director of the National Science Foundation Center for Aerosol Impacts on Chemistry of the Environment. L.C.M. is a member of the Science Advisory Board and holds stock options for Phylagen and is a paid reviewer for the Alfred P. Sloan Foundation. R.T.S. is a member of the Gilead Sciences Scientific Advisory Board and chairs Data Safety and Monitoring Boards for VIR, Gilead, and Merck. Honoraria for these activities are paid to the Regents of the University of California. R.T.S. has served as a scientific consultant to Pfizer and to AbbVie. M.A.M. is the (unpaid) Chair of the National Academy of Medicine Committee on Personal Protective Equipment for Workplace Safety and Health.

Published online 5 October 2020
10.1126/science.abf0521



https://science.sciencemag.org/content/370/6514/303.2

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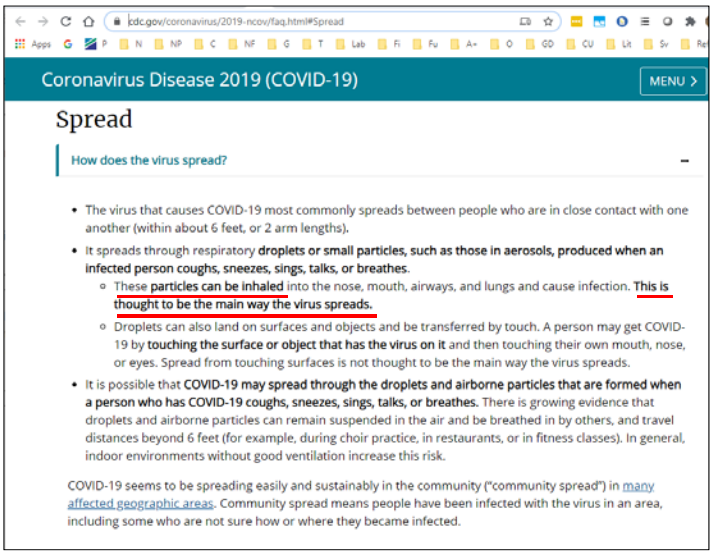
# CDC accepts aerosols as the main way



cdc.gov/coronavirus/2019-ncov/faq.html#Spread

Coronavirus Disease 2019 (COVID-19) MENU >

## Spread

How does the virus spread?

- The virus that causes COVID-19 most commonly spreads between people who are in close contact with one another (within about 6 feet, or 2 arm lengths).
- It spreads through respiratory **droplets or small particles, such as those in aerosols, produced when an infected person coughs, sneezes, sings, talks, or breathes.**
  - These **particles can be inhaled** into the nose, mouth, airways, and lungs and cause infection. **This is thought to be the main way the virus spreads.**
  - Droplets can also land on surfaces and objects and be transferred by touch. A person may get COVID-19 by **touching the surface or object that has the virus on it** and then touching their own mouth, nose, or eyes. Spread from touching surfaces is not thought to be the main way the virus spreads.
- It is possible that **COVID-19 may spread through the droplets and airborne particles that are formed when a person who has COVID-19 coughs, sneezes, sings, talks, or breathes.** There is growing evidence that droplets and airborne particles can remain suspended in the air and be breathed in by others, and travel distances beyond 6 feet (for example, during choir practice, in restaurants, or in fitness classes). In general, indoor environments without good ventilation increase this risk.

COVID-19 seems to be spreading easily and sustainably in the community ("community spread") in many affected geographic areas. Community spread means people have been infected with the virus in an area, including some who are not sure how or where they became infected.

- Quietly updated on 9-Oct-2020
- Puts back language from earlier removed update
- Only aerosols (< 100 μm) can be inhaled
- If it can be inhaled, it can reach beyond 1 m
- CDC calls them "small droplets" to favor "droplet precautions" in hospitals… which protect pretty well against aerosols!

https://www.cdc.gov/coronavirus/2019-ncov/faq.html#Spread

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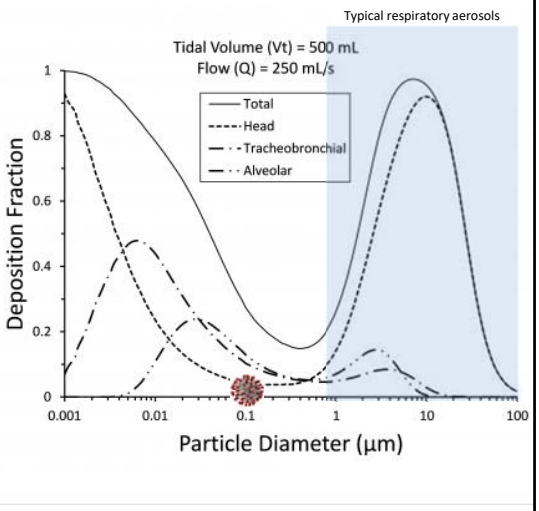
# Aerosol Deposition in Resp. Tract

- Studied extensively for cold war biowarfare, pollution, occupational health, tobacco smoke, drug delivery to the lungs etc.
- Only aerosols < 100 µm can be inhaled
  - ➔ **If it can be inhaled, it can reach > 1 m beyond a person!**
- Only aerosols ~< 5 µm can reach deep lung
  - E.g. tuberculosis
- But most aerosols at 5 µm deposited in head region




https://www.epa.gov/pmcourse/particle-pollution-exposure

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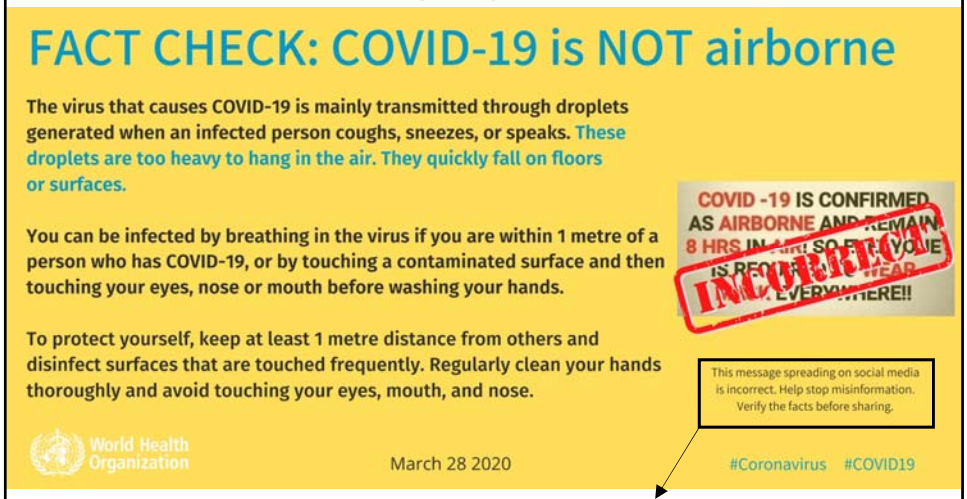
# WHO's messaging




This message spreading on social media is incorrect. Help stop misinformation. Verify the facts before sharing.

https://twitter.com/WHO/status/1243972193169616898

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# WHO's Latest Scientific Brief

## Transmission of SARS-CoV-2: implications for infection prevention precautions

Scientific brief

9 July 2020

World Health Organization

Transmission of SARS-CoV-2 can occur through direct, indirect, or close contact with infected people through infected secretions such as saliva and respiratory secretions or their respiratory droplets, which are expelled when an infected person coughs, sneezes, talks or sings.(2-10) Respiratory droplets are >5-10 µm in diameter whereas droplets ≤5µm in diameter are referred to as droplet nuclei or aerosols.(11) Respiratory droplet transmission can occur when a person is in close contact (within 1 metre) with an infected person who has respiratory symptoms (e.g. coughing or sneezing) or who is talking or singing; in these circumstances, respiratory droplets that include virus can reach the mouth, nose or eyes of a susceptible person and can result in infection. Indirect contact transmission involving contact of a susceptible host with a contaminated object or surface (fomite transmission) may also be possible (see below).

The physics of exhaled air and flow physics have generated hypotheses about possible mechanisms of SARS-CoV-2 transmission through aerosols.(13-16) These theories suggest that 1) a number of respiratory droplets generate microscopic aerosols (<5 µm) by evaporating, and 2) normal breathing and talking results in exhaled aerosols. Thus, a susceptible person could inhale aerosols, and could become infected if the aerosols contain the virus in sufficient quantity to cause infection within the recipient. However, the proportion of exhaled droplet nuclei or of respiratory droplets that evaporate to generate aerosols, and the infectious dose of viable SARS-CoV-2 required to cause infection in another person are not known, but it has been studied for other respiratory viruses.(17)

https://www.who.int/publications/i/item/modes-of-transmission-of-virus-causing-covid-19-implications-for-ipc-precaution-recommendations

# WHO: ventilation is important! *But Why?*

- In the last week: ventilation is important, open windows, 6 ACH…
- But they don't say?
  - Christian Drosten: "We have to explain how the virus is transmitted"



http://www.covidisairborne.org


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# Spain's Ministry of Science


Contribuyen: Antonio Alcamí (CBM-CSIC), Margarita del Val (CBM-CSIC), Miguel Hernán (Harvard University), Pello Latassa (Gobierno La Rioja), José Luis Jiménez (University of Colorado), Xavier Querol (IDAEA-CSIC), Gloria Sánchez (IATA-CSIC), Alfonso Valencia (BSC-CNS)

**Conclusión del grupo redactor**

**Existe una evidencia significativa sobre la transmisión de la infección por SARS-CoV-2 por vía de aerosoles. Hay también un apoyo sustancial de la comunidad científica a la posibilidad de que sea la forma de transmisión dominante, y a que sea la forma más habitual de contagio en eventos de super-propagación. Existe una falta de evidencia que apoye la importancia de la vía de las gotículas, y es bien posible que esta vía haya sido sobreestimada. Dada la situación, el grupo redactor de este informe propone actuaciones en positivo basadas en el principio de precaución.**

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# What do we know about transmission?

- Surfaces not major
- **Easily transmitted in close proximity**

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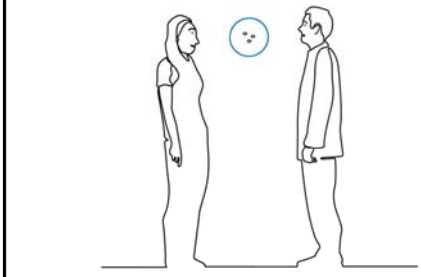
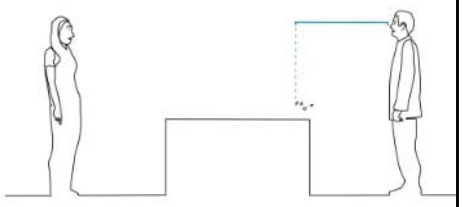
# WHO: why social distance helps

Close: droplets can hit eyes / nose / mouth



These droplets can land in the mouths or noses of people who are nearby.

Far: droplets fall to the ground



These droplets are too heavy to travel far in the air –
they only travel approximately one metre and quickly settle on surfaces.

WHO types: ease of infection in close proximity <u>is proof of droplets</u>
➔ really it is only 1 of 2 plausible hypotheses

https://twitter.com/WHO/status/1244258441880797184

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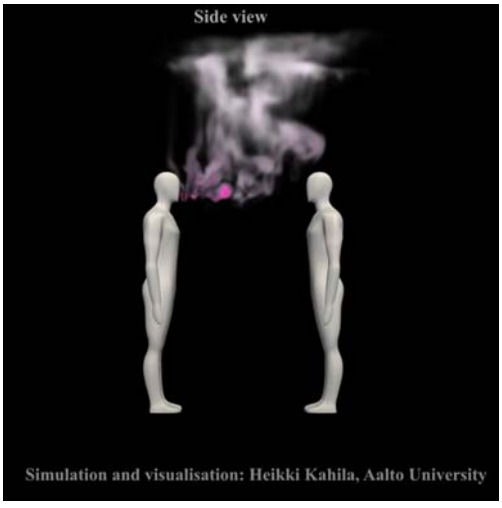
# Alternative explanation of social distance

<u>Real exhaled $CO_2$</u>

<u>CFD Simulation</u>




- Exhaled air when talking loses momentum in <0.5-1 m, starts rising
  - Can explain why social distance works to reduce disease transmission
- Consistent results
  - $CO_2$ is directly imaged (experiment) but offers less visual contrast and range than simulation

https://twitter.com/SEE_Fluids_UK/status/1314565418980462594
https://www.youtube.com/watch?v=EcpQBxBdr5g

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# Close Proximity vs. Shared Room Air

- Observation that social distance works *alone* does not prove droplets or aerosols. We need to look at more evidence
- Is there infection when sharing room air?
  - If droplets: safe with distance
  - If aerosols: not safe. With time and low-ventilation, infection can happen

https://www.kunr.org/post/dri-researchers-find-e-cigs-leave-cancer-causing-chemicals-lungs#stream/0
https://www.dailykos.com/stories/2019/11/16/1899711/-The-Smoke-Filled-Room-Unsolicited-Advice-as-Who-Should-Be-Vice

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# What do we know about transmission?

- Surfaces not major
- Easily transmitted in close proximity
- **Indoors >> outdoors**

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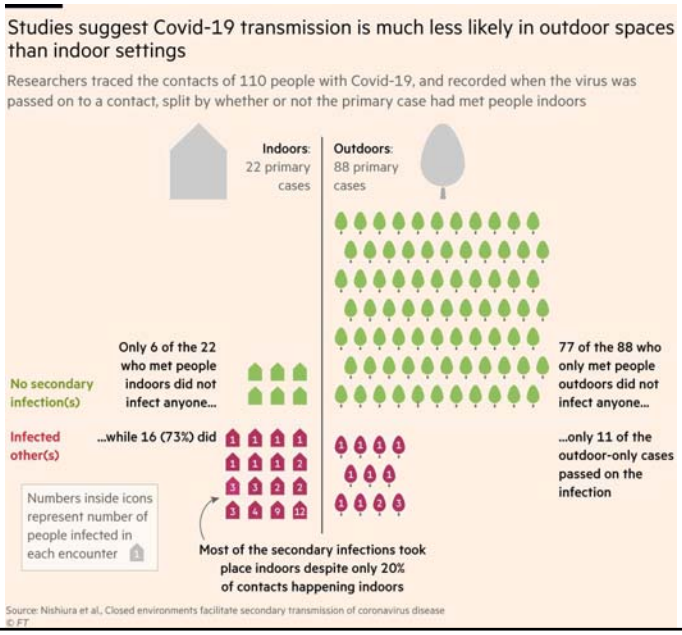
# Indoors vs. Outdoor




https://twitter.com/mugecevik/status/1308080074986524672

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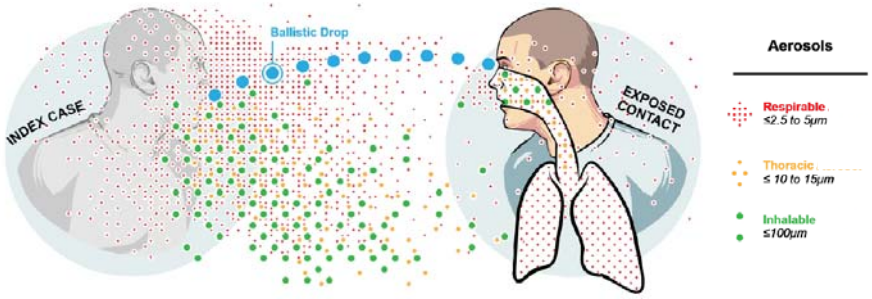
# Droplets vs. Aerosols: Indoors vs Outdoors




- Droplets:
  - Ballistic projectiles, not perturbed outdoors in light winds
  - Infection should be similar outdoors
- Aerosols
  - Float in the air, rise & are removed much more efficiently
  - Expect much less infection outdoors

From Milton, 2020: https://academic.oup.com/jpids/article/doi/10.1093/jpids/piaa079/5875939

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- Indoors >> outdoors
- WHO: "Different" than accepted airborne diseases:
  - Airborne: Measles, tuberculosis, chickenpox
  - COVID-19 more similar to "droplet diseases" such as flu
    - $R_0$ ~ 2.5
  - High dispersion, "superspreading"
    - 10-20% of infected lead to 80% of new infections ($R_0$ ~ 10-20)

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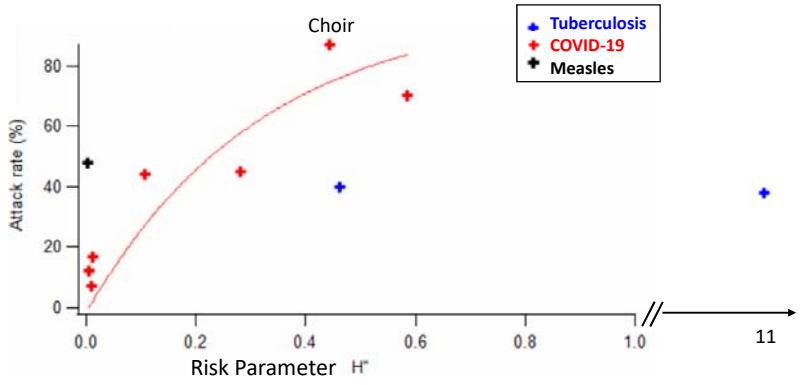
# Example Superspreading Event: Skagit Choir

- Clearest case in my opinion
  - Choir not social w/ each other. Arrive in time, sing, 10 min break, sing, leave immediately after
  - 2.5 hr rehearsal: 1 index case, 52 new infections (13 m behind). PH & Choir: rehearsal is where it happened
- Fomites / Surfaces?
  - Agreed to be inefficient (e.g. CDC)
  - They knew about COVID-19, strong early message on surfaces. No touch, sanitizer, propped doors.
  - Index case didn't touch any objects, only ~3 people went to same bathroom
- Droplets?
  - No one 3 m in front of index. Index case didn't talk to others. Others talked to 2-3 ppl in 10 min break
  - No way to impact droplets on eyes, nostrils, mouths of 52 people
    - CDC says "15 min. of close proximity" are needed
- Aerosols?
  - Low ventilation, room well mixed, long time, no masks → easy to explain
  - Amount of virus ~10 times bus and restaurant (singing all the time vs. talking intermittently, consistent with measurements)
- All SS events point to aerosols. **None** point to fomites or droplets

Miller et al., Indoor Air, 2020. https://doi.org/10.1111/ina.12751 21

# Multiple Outbreaks are Consistent




- Consistency suggests similar mechanism
- Measles clearly more contagious
- TB much less so on average, can approach COVID-19 on some outbreaks

Peng, Jimenez, et al., in prep. 22

## What do we know about transmission?

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    - $R_0$ ~ 2.5
  - High dispersion, "superspreading"
    - 10-20% of infected lead to 80% of new infections ($R_0$ ~ 10-20)
  - **Often not very contagious**
    - **Many don't transmit to anybody**
    - **Attack rate in households not very high**
    - **"Droplet precautions" work ok with very ill patients**

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## Droplet or Aerosol Diseases?

| Disease A | Disease B |
|---|---|
| • Transmission is through **droplets**. Successful transmission requires close contact within 1 m | • Respiratory **droplet** transmission can occur in close contact (within 1 m) with an infected person |
| • Following hospitalization of 182 patients, only one secondary case occurred, despite free circulation of air | • No transmission to 41 health care workers exposed for >10 min and <2 m of patient with intense intubation, wearing medical masks (85%) of N95 (15%) |
| • Outbreaks aboard ships, in school buses, schools, poorly ventilated rooms, and in bars | • Outbreaks aboard ships, buses, poorly ventilated restaurants, bars, choirs |

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# Droplet or Aerosol Diseases?

| Disease A | Disease B |
|---|---|
| • Transmission is through **droplets**. Successful transmission requires close contact within 1 m<br>**Tuberculosis (1950) & Measles (1985)** | • Respiratory **droplet** transmission can occur in close contact (within 1 m) with an infected person<br>**WHO on COVID-19** |
| • Following hospitalization of 182 patients, only one secondary case occurred, despite free circulation of air<br>**Measles (1985)** | • No transmission to 41 health care workers exposed for >10 min and <2 m of patient with intense intubation, wearing medical masks (85%) of N95 (15%)<br>**WHO IPC Comm. on COVID-19** |
| • Outbreaks aboard ships, in school buses, schools, poorly ventilated rooms, bars<br>**Tuberculosis and/or measles** | • Outbreaks aboard ships, buses, poorly ventilated restaurants, bars, choirs **COVID-19** |

https://www.who.int/publications/i/item/modes-of-transmission-of-virus-causing-covid-19-implications-for-ipc-precaution-recommendations
https://pediatrics.aappublications.org/content/75/4/676.long
https://doi.org/10.1093/clinids/23.5.954

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# The eagle and the chicken

- Some medical experts:
  - "If measles flies like an eagle, SARS-CoV-2 flies like a chicken"
  - Implication: when a disease is airborne, they can see it immediately. They couldn't miss it!
- A small problem:
  - The same professions spent 75 years telling us that measles was a chicken (till ~1985)
  - And 40 years telling us that tuberculosis was a chicken (till ~1950)
- In reality:
  - Measles: eagle
  - SARS-CoV-2: pigeon
  - Tuberculosis: turkey
  - Airborne diseases only have to survive as a disease, they don't need to be highly contagious

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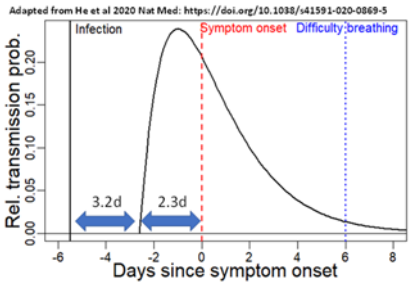
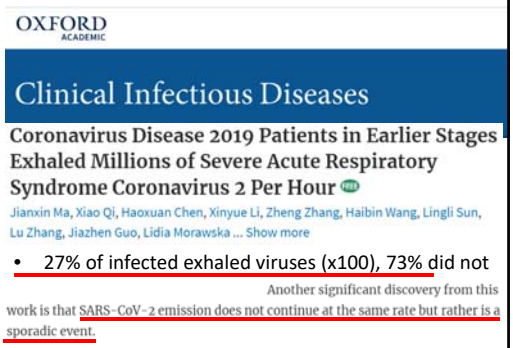
# Variability of Infective Aerosol Emission

- WHO mental model: constant & high aerosol emission by all infected
  - If not consistent w/ some obs., conclude *disease (instead of some ppl.)* never on aerosols




Courtesy of A. Malm Kilpatrick


OXFORD ACADEMIC

Clinical Infectious Diseases

**Coronavirus Disease 2019 Patients in Earlier Stages Exhaled Millions of Severe Acute Respiratory Syndrome Coronavirus 2 Per Hour**

Jianxin Ma, Xiao Qi, Haoxuan Chen, Xinyue Li, Zheng Zhang, Haibin Wang, Lingli Sun, Lu Zhang, Jiazhen Guo, Lidia Morawska ... Show more

- 27% of infected exhaled viruses (x100), 73% did not

Another significant discovery from this work is that SARS-CoV-2 emission does not continue at the same rate but rather is a sporadic event.

- Superspreading?
  - Certainly wrong time in wrong location (crowded, time, low-vent. no masks, vocalization)
  - Superspreading ppl? Some emit x10 more aerosols, also high variability in viral loads
  - Lack of transmission? Infectious aerosols highly variable
    - No aerosols THAT time, NOT NEVER
  - Measles: 75 yrs to accept aerosol transmission (~1985), because of famous cases of no transmission w/ shared air!

https://www.nature.com/articles/s41591-020-0869-5 Don Milton's lecture (high recommended): https://t.co/sL6bwRf1u4
https://doi.org/10.1093/cid/ciaa1283

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  - High dispersion, "superspreading"
    - 10-20% of infected lead to 80% of new infections ($R_0$ ~ 10-20)
  - Often not very contagious
    - Many don't transmit to anybody
    - Attack rate in households not very high
    - "Droplet precautions" work ok with very ill patients
- **WHO: "Droplets larger, have many more viruses"**
  - **Is that correct?**

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# WHO's Latest Scientific Brief

## Transmission of SARS-CoV-2: implications for infection prevention precautions

Scientific brief

9 July 2020

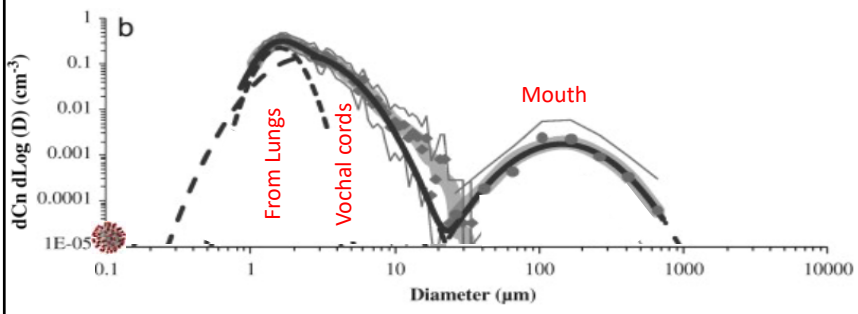
World Health Organization

Transmission of SARS-CoV-2 can occur through direct, indirect, or close contact with infected people through infected secretions such as saliva and respiratory secretions or their respiratory droplets, which are expelled when an infected person coughs, sneezes, talks or sings.(2-10) Respiratory droplets are >5-10 µm in diameter whereas droplets ≤5µm in diameter are referred to as droplet nuclei or aerosols.(11) Respiratory droplet transmission can occur when a person is in close contact (within 1 metre) with an infected person who has respiratory symptoms (e.g. coughing or sneezing) or who is talking or singing; in these circumstances, respiratory droplets that include virus can reach the mouth, nose or eyes of a susceptible person and can result in infection. Indirect contact transmission involving contact of a susceptible host with a contaminated object or surface (fomite transmission) may also be possible (see below).

The physics of exhaled air and flow physics have generated hypotheses about possible mechanisms of SARS-CoV-2 transmission through aerosols.(13-16) These theories suggest that 1) a number of respiratory droplets generate microscopic aerosols (<5 µm) by evaporating, and 2) normal breathing and talking results in exhaled aerosols. Thus, a susceptible person could inhale aerosols, and could become infected if the aerosols contain the virus in sufficient quantity to cause infection within the recipient. However, the proportion of exhaled droplet nuclei or of respiratory droplets that evaporate to generate aerosols, and the infectious dose of viable SARS-CoV-2 required to cause infection in another person are not known, but it has been studied for other respiratory viruses.(17)

https://www.who.int/publications/i/item/modes-of-transmission-of-virus-causing-covid-19-implications-for-ipc-precaution-recommendations

# Droplets & aerosols when talking




From Johnson et al., *J. Aerosol Sci.* (2011)
Black line is best estimate
Emitted respiratory particles when speaking

https://doi.org/10.1016/j.jaerosci.2011.07.009

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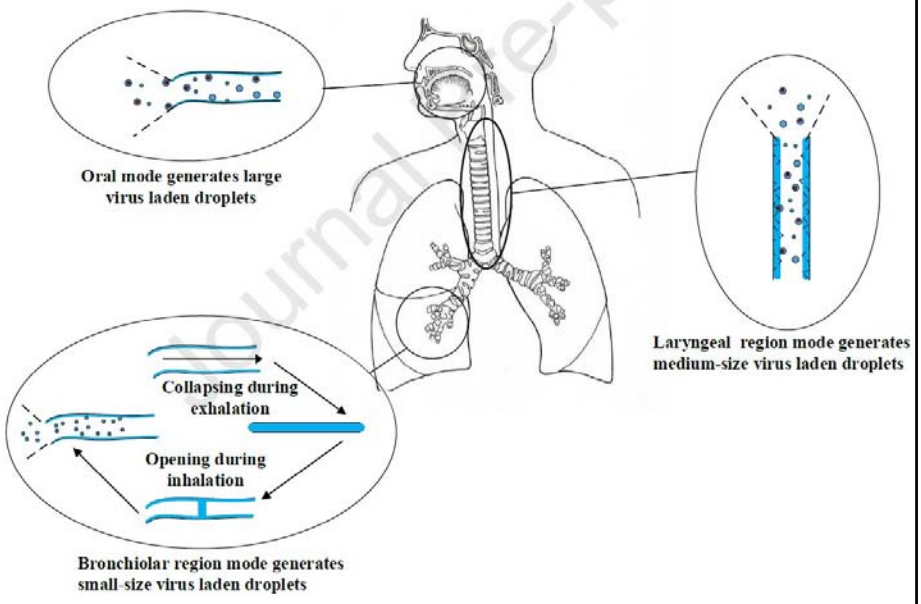
# Sources of Respiratory Aerosols




https://www.sciencedirect.com/science/article/pii/S0269749120364563

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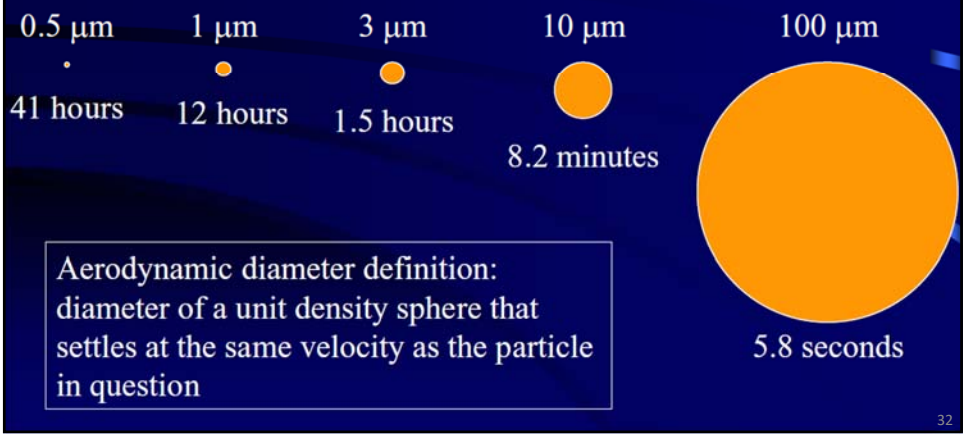
CDC: "Aerosols 101" tutorial on their web page
https://www.cdc.gov/niosh/topics/aerosols/default.html

# Particle Settling in Still Air

Time to settle 5 feet by unit density spheres




Aerodynamic diameter definition: diameter of a unit density sphere that settles at the same velocity as the particle in question

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# Dr. Anthony Fauci Admitted 5 µm is an Error on 10-Sep

- ”There was some real misunderstanding about respiratory droplets and so-called aerosolised particles. The aerosol and particles physicists that have approached us now have told us that we really have got it wrong over many years and that particles greater > 5 µm still stay in the air much much longer than we have thought when we used to say empirically > 5 µm drops to the ground, 5 µm might be aerosolized, we know now that's just not the case.”
- **“Bottom line is this: there is much more aerosol than we thought”**

https://masscpr.hms.harvard.edu/event/harvard-medical-school-grand-rounds-featuring-dr-anthony-s-fauci

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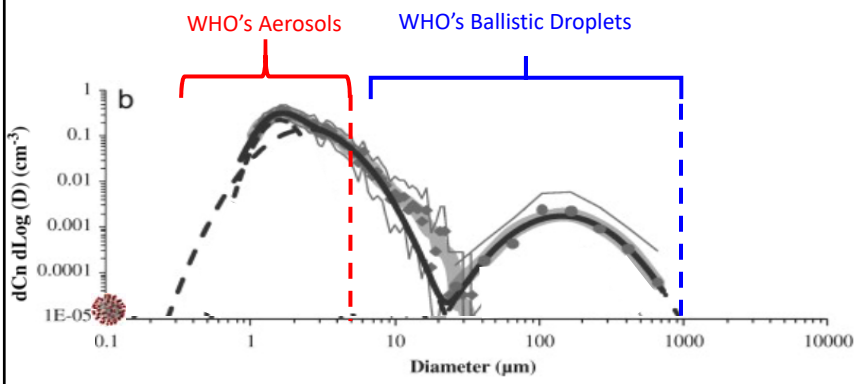
# Droplets when talking: WHO’s view




From Johnson et al., *J. Aerosol Sci.* (2011)
Black line is best estimate
Emitted respiratory particles when speaking

- x50 times more aerosols than droplets
- But droplets are larger, may carry more virus

https://doi.org/10.1016/j.jaerosci.2011.07.009

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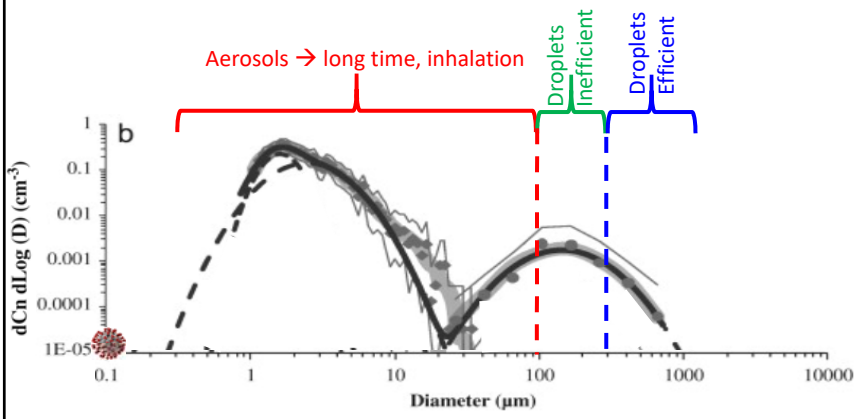
# Droplets when talking: few, low prob.




- For every large droplet, there are 1000 aerosols
- Droplets have to hit very small targets
- Aerosols float a long time, many chances to be inhaled

https://doi.org/10.1016/j.jaerosci.2011.07.009

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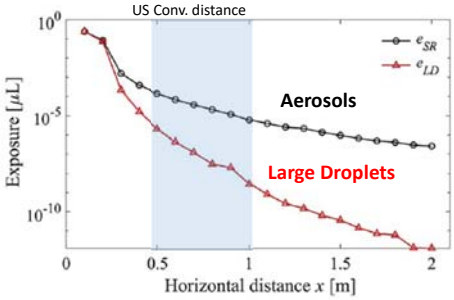
# Dose: droplets vs. aerosols when talking

- Aerosol volume dose is x100-x2000 times larger than for droplets when talking
- Droplets only ½ on direct hit from cough / sneeze




- For all diseases where measured, pathogens more concentrated in smaller particles (< 5 µm typical)
  - Tuberculosis, measles, flu, RSV
- Also anisotropic infection, e.g. for flu & smallpox
  - Infective dose is x100 lower for small aerosols into lung than nose deposition
  - For the same symptoms, dose needed is x100000 larger for the nose than for small aerosols


> Reviewing the literature on large droplet transmission, one can find no direct evidence for large droplets as the route of transmission of any disease.

https://www.sciencedirect.com/science/article/pii/S0360132320302183 & https://www.thelancet.com/journals/lanres/article/PIIS2213-2600(20)30323-4/fulltext

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# What do we know about transmission?

- Surfaces not major
- Easily transmitted in close proximity
- Indoors >> outdoors
- WHO: "Different" than accepted airborne diseases:
  - Airborne: Measles, tuberculosis, chickenpox
  - COVID-19 more similar to "droplet diseases" such as flu
    - $R_0$ ~ 2.5
  - High dispersion, "superspreading"
    - 10-20% of infected lead to 80% of new infections ($R_0$ ~ 10-20)
  - Often not very contagious
    - Many don't transmit to anybody
    - Attack rate in households not very high
    - "Droplet precautions" work ok with very ill patients
- WHO: "Droplets larger, have many more viruses"
  - Is that correct?
- **Difficult to sample infections virus from room air**
  - **True, but never done for measles or tuberculosis**
  - **Impressive technological advances (VIVAS) were needed, has been done by Lednicky et al. (2020)**

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# To learn more about aerosol transmission

- Highly recommend watching Don Milton's webinar
  - Medical doctor, aerobiologist
  - https://t.co/sL6bwRf1u4
- For extensive details (11 hrs of talks + discussion)
  - Workshop from the US National Academies of Sciences, Engineering, and Medicine
  - This workshop was the basis for the Prather et al. letter to Science (5-October, https://science.sciencemag.org/content/370/6514/303.2)
  - https://www.nationalacademies.org/event/08-26-2020/airborne-transmission-of-sars-cov-2-a-virtual-workshop

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# How we got here

- 1910: Chapin's *The Sources and Modes of Infection*
  - "Contact Infection"
    - Germs don't live outside the body, in swamps, trash etc.
    - Germs live inside of people, contact with other people needed for infection
    - Realizes close proximity leads to infection (correct)
  - Problem for him: "It is impossible to teach people to avoid contact infection while they are firmly convinced that the air is the chief vehicle of infection"
    - "In air infection, it becomes evident that our knowledge is far too scanty, and that the available evidence is far from conclusive"
  - Solution!
    - Indication of droplets (Flügge 1894). Aerosols not measureable yet
    - "There is no evidence that [air infection] is is an appreciable factor in the maintenance of most of our common contagious diseases. We are warranted, then, in discarding it as a working hypothesis, and devoting our chief attention to the prevention of contact infection."
  - To prove air infection: extraordinary claims require extraordinary evidence
  - Becomes established paradigm, till WHO today

https://archive.org/details/sourcesmodesofin00ch

In reviewing the subject of air infection it becomes evident that our knowledge is still far too scanty, and that the available evidence is far from conclusive. Yet it is of the greatest practical importance that we should know definitely just what danger there is of air-borne infection and in what diseases it is to be feared. Infection by air, if it does take place, as is commonly believed, is so difficult to avoid or guard against, and so universal in its action, that it discourages effort to avoid other sources of danger. If the sick-room is filled with floating contagium, of what use is it to make much of an effort to guard against contact infection? If it should prove, as I firmly believe, that contact infection is the chief way in which the contagious diseases spread, an exaggerated idea of the importance of air-borne infection is most mischievous. It is impossible, as I know from experience, to teach people to avoid contact infection while they are firmly convinced that the air is the chief vehicle of infection.

While it is not possible at present to state with exactness the part played by aerial infection in the transmission of the different infectious diseases, we are by the evidence forced to the conclusion that the current ideas in regard to the importance of infection by air are unwarranted. Without denying the possibility of such infection, it may be fairly affirmed that there is no evidence that it is an appreciable factor in the maintenance of most of our common contagious diseases. We are warranted, then, in discarding it as a working hypothesis and devoting our chief attention to the prevention of contact infection. It will be a great relief to most persons to be freed from the specter of infected air, a specter which has pursued the race from the time of Hippocrates, and we may rest assured that if people can as a consequence be better taught to practice strict personal cleanliness, they will be led to do that which will more than anything else prevent aerial infection also, if that should in the end be proved to be of more importance than now appears.

# How did we end up here?

- Chapin's 1910 Legacy
  - To prove air infection: "extraordinary claims require extraordinary evidence"
  - Becomes established paradigm, till WHO today
- 1930s on: Wells, Riley & others fight fierce resistance
  - Measles, chickenpox, TB: droplet/fomites for decades
    - Finally demonstrated, but only because so contagious (long-range outbreaks), and/or evidence unequivocal (TB)
  - But great progress against diseases w/ vaccines, antibiotics etc. Never a top issue till now
- Now: confusion of artifact of history w/ law of nature!
  - "All aerosol-transmitted diseases must be highly contagious all the time"
    - No reason, disease only needs to survive as a disease

https://archive.org/details/sourcesmodesofin00ch & https://books.google.com/books/about/How_to_Avoid_Infection.html?id=vS47AQAAMAAJ

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# Paper from WHO IPC Committee

- $R_0$ not high enough compared to measles
  - Confusing artifact of history w/ law of nature; forgetting TB
- 5 μm error
  - No real understanding of aerosols
- Cases of no transmission w/ shared air
  - Attack rate in households
  - Anecdotal evidence in hospitals
  - Assume constant emission without saying it. Can be explained by demonstrated variable emission
- "Droplet precautions seem to work in hospitals
  - Very sick people are less contagious, Droplet Prec. Protect ~80% against aerosols in 1-10 μm range


BMC Part of Springer Nature

Antimicrobial Resistance & Infection Control

Use of medical face masks versus particulate respirators as a component of personal protective equipment for health care workers in the context of the COVID-19 pandemic

- Aerosol Generating Procedures are important
  - We'll see next

https://aricjournal.biomedcentral.com/articles/10.1186/s13756-020-00779-6#change-history

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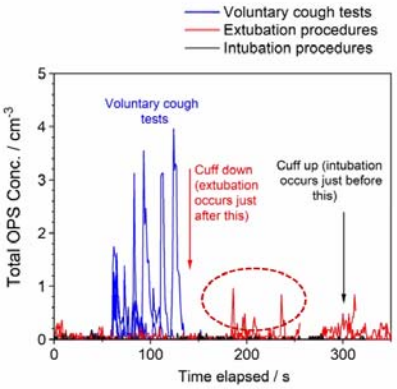
# Aerosol-generating Procedures?




Average particle concentration sampled in a 10 s window: (± standard error)

| | |
|---|---|
| Intubation procedure | 0.012 ± 0.003 |
| Extubations with no coughs | 0.15 ± 0.01 |
| Cough detected in an extubation | 1.7 ± 0.1 |
| Single voluntary cough | 8.2 ± 0.8 |
| Background during theatre operational hours | 0.052 |

Currently classified as "Aerosol Generating Procedure" – Full PPE

Not classed as an AGP

Extubation generates more detectable aerosol than intubation (esp. when patient coughed) but falls below the current criterion for designation as a high-risk aerosol-generating procedure.

Slide adapted from courtesy of J.P. Reid

A quantitative evaluation of aerosol generation during tracheal intubation and extubation
J. Brown F. K. A. Gregson A. Shrimpton T. M. Cook B. R. Bzdek J. P. Reid A. E. Pickering
https://associationofanaesthetists-publications.onlinelibrary.wiley.com/doi/10.1111/anae.15292

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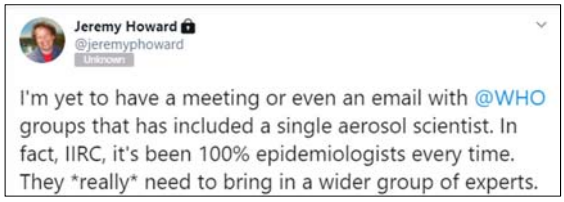
# How did we end up here? Part II

- Aerosols have never been considered important for disease transmission
  - Not studied by most in medical profession & epidemiology
  - Almost total lack of experts at WHO




  - Key WHO committee is dominated by hand-washing experts
    - Miraculously, the first thing they recommended against COVID-19 was lots of hand washing!
      - Now we know that only cuts transmission ~16% (UK study)
    - They have published a paper, w/ errors and misconceptions about aerosols
      - https://aricjournal.biomedcentral.com/articles/10.1186/s13756-020-00779-6

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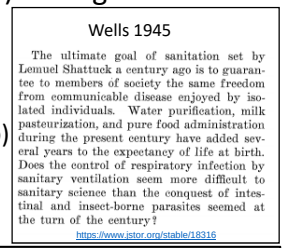
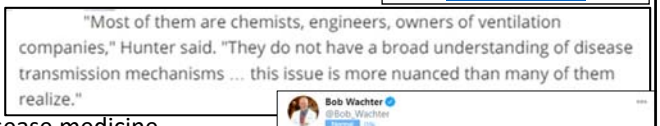
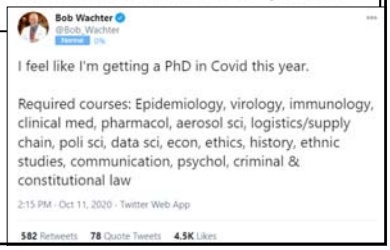
# The coming paradigm shift

- Chapin's 1910 error finally becoming obvious
  - Most respiratory diseases go (at least partially) through aerosols
    - Best in close proximity
    - Can transmit in shared room air w/ low ventilation
    - Most contagious diseases can transmit long-range
    - Wide range of contagiousness (COVID = mid + disp)




- Huge implications
  - For seasonal flu, future pandemics, others
- Major resistance




  - Shift in infectious disease medicine & epid., pushed by "ignorant intruders"
- Extremely important to collaborate across disciplines
  - Aerosol science NOT most important discipline by far. But crucial error

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# 1. What do we know about the modes of transmission?

# 2. How can we protect ourselves against infection?

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http://tinyurl.com/preguntas-espanol

https://tinyurl.com/FAQ-aerosols (62 pages)

**FAQs on Protecting Yourself from COVID-19 Aerosol Transmission**

Shortcut to this page: https://tinyurl.com/FAQ-aerosols
*Version: 1.65, 15-Sep-2020*

If you want to jump over other details and go straight to the recommendations, click here.

# Preventing Transmission of COVID-19

- We need “layers of protection.” No magic bullet
- Think about trying to not breathe smoke
- Some people still think that if they wear a mask and keep 6 ft apart, they are totally safe – this is false!
- Outdoors, distanced, and with masks is almost completely safe. ONLY almost-silver bullet
- Indoors is never completely safe. No silver bullet
  - **A**void or reduce
  - **C**rowding
  - **I**ndoors
  - low **V**entilation
  - **C**lose proximity
  - long **D**uration
  - **U**nmasked
  - **T**alking/singing/shouting
  - (mnemonic: "A CIViC DUTy“)

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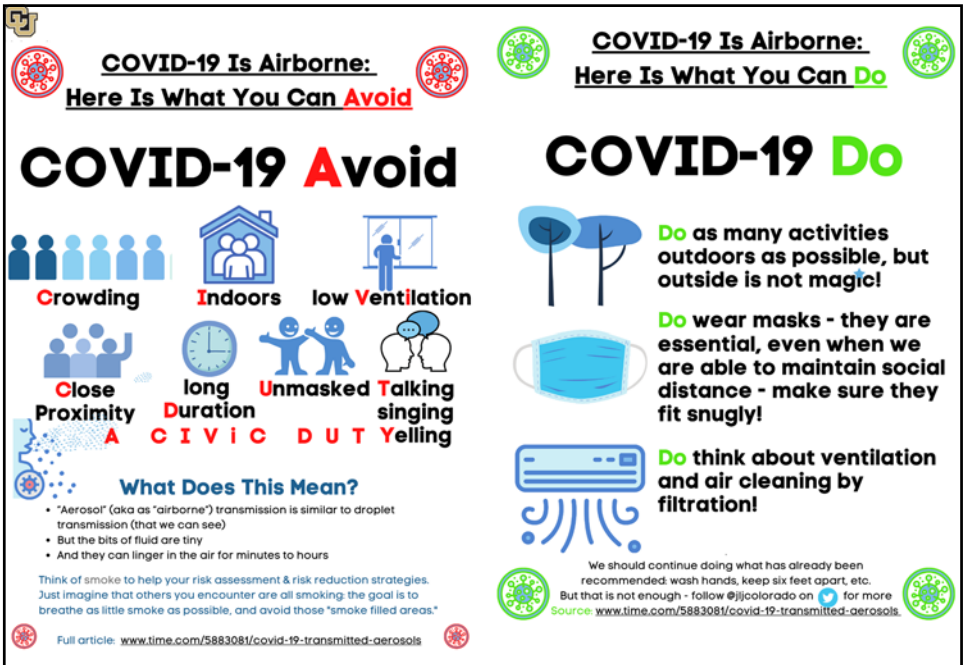


Editable copies in several languages
https://docs.google.com/presentation/d/1a9p7rf7Lxcw63MwW3mG5At22bROm2syZCil8d-ZL_wk/edit#slide=id.g94e30fbf10_172_23

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# Risk of different situations

| Type and level of group activity | Low occupancy | | | High occupancy | | |
|---|---|---|---|---|---|---|
| | Outdoors and well ventilated | Indoors and well ventilated | Poorly ventilated | Outdoors and well ventilated | Indoors and well ventilated | Poorly ventilated |
| **Wearing face coverings, contact for short time** | | | | | | |
| Silent | | | | | | |
| Speaking | | | | | | |
| Shouting, singing | | | | | | |
| **Wearing face coverings, contact for prolonged time** | | | | | | |
| Silent | | | | | | |
| Speaking | | * | | * | | |
| Shouting, singing | | | | | | |
| **No face coverings, contact for short time** | | | | | | |
| Silent | | | | | | |
| Speaking | | | | | | |
| Shouting, singing | | | | | | |
| **No face coverings, contact for prolonged time** | | | | | | |
| Silent | | | | | | |
| Speaking | | | | | | |
| Shouting, singing | | | | | | |

**Risk of transmission** Low Medium High

* Borderline case that is highly dependent on quantitative definitions of distancing, number of individuals, and time of exposure

https://www.bmj.com/content/370/bmj.m3223

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# Do activities outdoors when possible


https://www.nytimes.com/2020/07/17/nyregion/coronavirus-nyc-schools-reopening-outdoors.html

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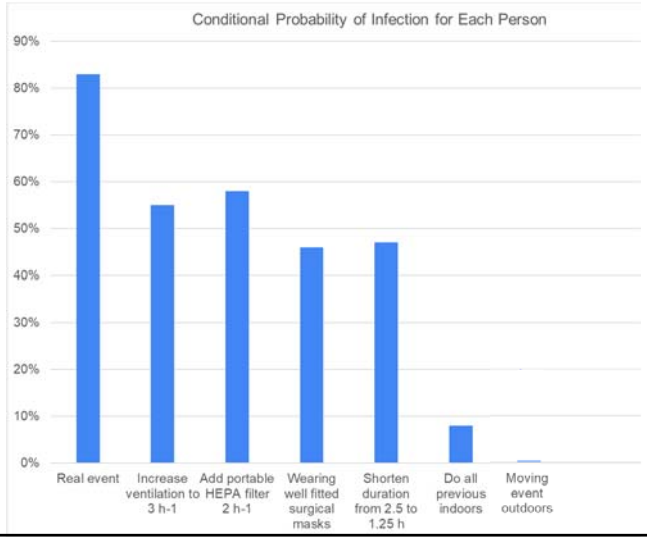
# Indoors never totally safe, can mitigate

- What happens if we could change conditions
- All are changing only 1 thing, except “do all previous indoors”




Calculated with: https://tinyurl.com/covid-estimator

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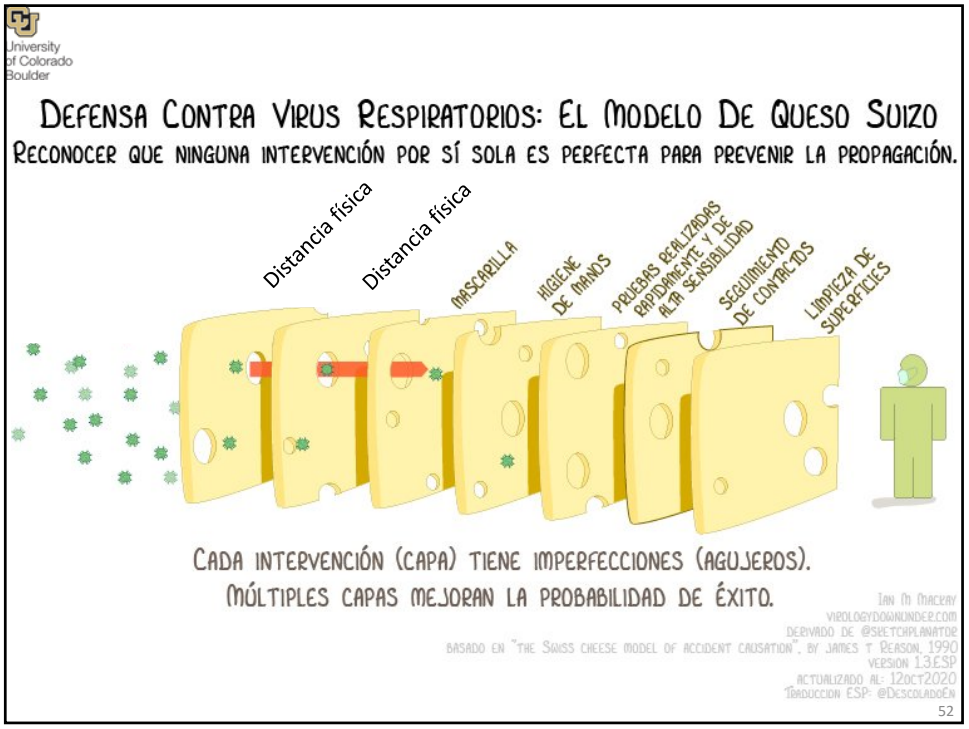


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# What Ventilation Rate is Needed?

- Liters/s/person is the best indicator (better than ACH)
- Outbreaks of COVID-19 at ~1-3 L/s/p
- Recommend at least 12.5 L/s/p (REHVA), more if possible

| | High Ventilation Dorm | Low Ventilation Dorm |
|---|---|---|
| CO2 concentrations in rooms | 1230 ppm | 1490 ppm |
| Dorm rooms' ventilation rates | 6 L/s/person | 2 L/s/person |
| # ARI cases / total subjects | 1 / 11 | 47 / 109 |

ventilation rates of < **5 L/s per person** may be impacting acute respiratory infections

Zhu S, Jenkins S, Addo K, et al. Ventilation and laboratory confirmed acute respiratory infection (ARI) rates in college residence halls in College Park, Maryland. *Environment International*. 2020;137:105537. doi:10.1016/j.envint.2020.105537

outdoor air supply rates **< 25 L/s per person** increase the risk of sick building symptoms, increase short-term sick leave, and decrease productivity

Wargocki P, Sundell J, Bischof W, et al. Ventilation and health in non-industrial indoor environments: report from a European Multidisciplinary Scientific Consensus Meeting (EUROVEN). *Indoor Air*. 2
doi:10.1034/j.1600-0668.2

- Prof. Shelly Miller during National Academy of Sciences, Engineering, and Medicine Workshop
- https://www.nationalacademies.org/event/08-26-2020/airborne-transmission-of-sars-cov-2-a-virtual-workshop

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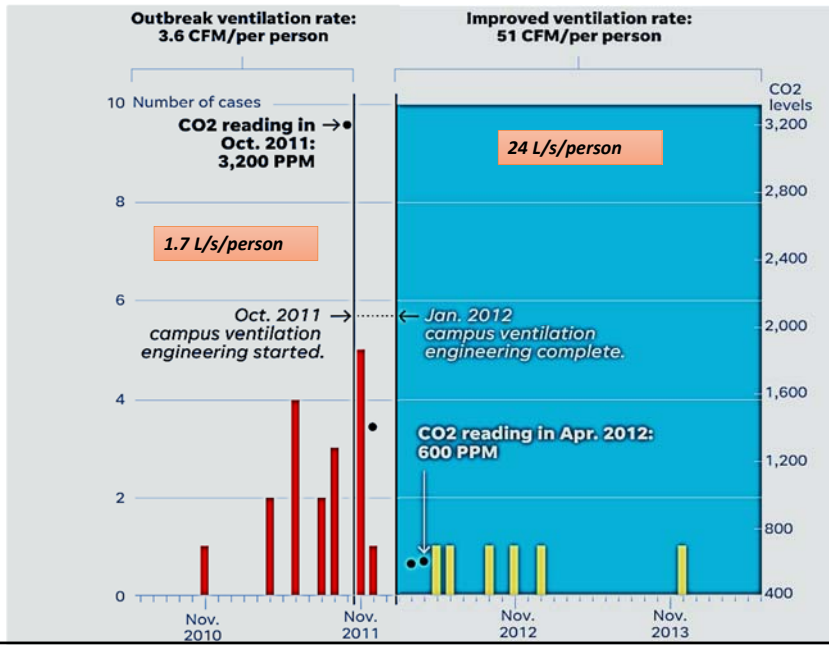
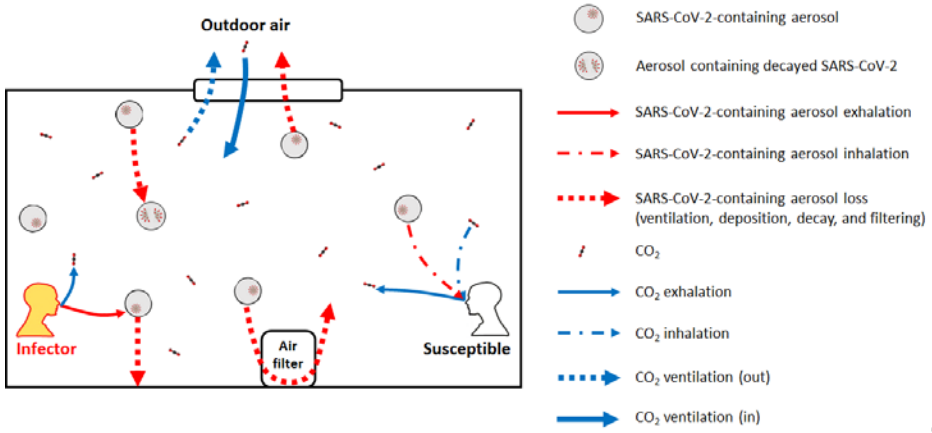
# Ventilation stopped TB outbreak




Adapted from Shelly Miller
https://onlinelibrary.wiley.com/doi/full/10.1111/ina.12639
https://www.usatoday.com/in-depth/graphics/2020/10/18/improving-indoor-air-quality-prevent-covid-19/3566978001/

# Using $CO_2$ as an Indicator (<700 ppm)




- https://medium.com/@jjose_19945/how-to-quantify-the-ventilation-rate-of-an-indoor-space-using-a-cheap-co2-monitor-4d8b6d4dab44?source=friends_link&sk=6cda52f5682a4a450a10691f07d1ad2c
- Citizen science: see #COVIDCO2 in Twitter, post data there, help your community
- Details of CO2 level: see our paper & estimator; https://twitter.com/jljcolorado/status/1304398049528012800

Slide from Dr. Zhe Peng

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# Example of $CO_2$ (NDIR technology)

*~400 ppm = 0% / 800 = 1% re-breathing / 4400 = 10% re-breathing*

Outdoors


In car, 2 people + child

Windows, closed, recirculated air →


Windows closed, ventilation system w/ outdoor air →


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# Every public space should display $CO_2$




- Real-time indication of ventilation everywhere
  - Many people would learn what's safe and unsafe quickly
  - How to account for filtration?
- The technology exists to do this at $200 per unit (less if massive)
  - https://www.co2meter.com/products/csense-large-wall-co2-meter
  - https://www.pce-inst-benelux.nl/technische-specificaties/multifunctionele-co2-meter-pce-ac-2000.htm

Bar pic from https://www.graffitiindoorad.com/our-clients

First suggested to me by Bertrand Waucquez (major of Kraainen, Belgium)

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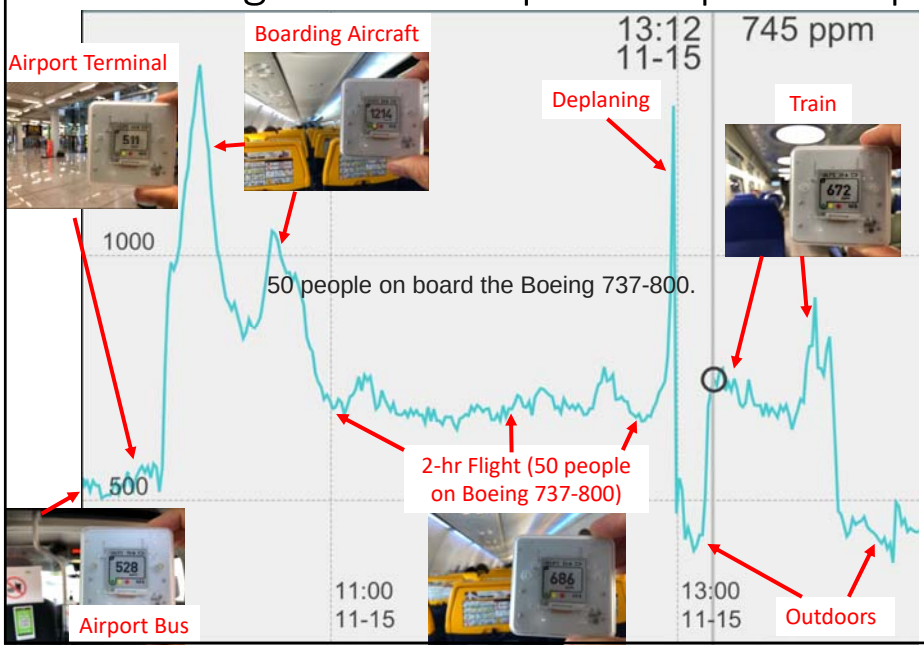
# A colleague's 2-hr airplane trip in Europe

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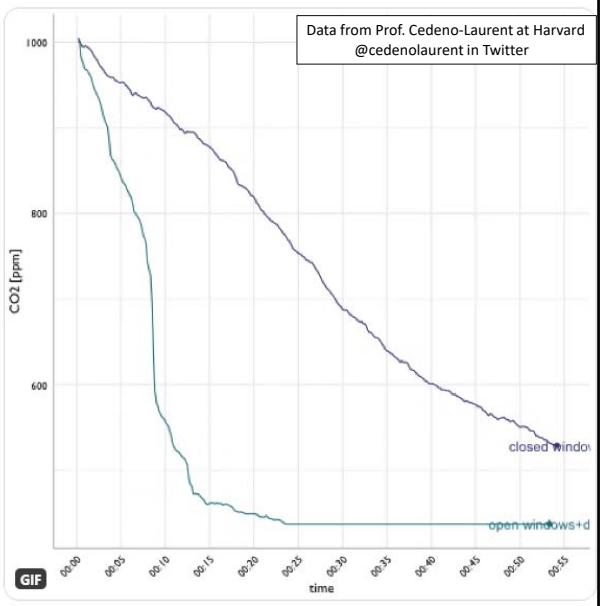
# $CO_2$ w/ open vs closed windows

- Simple experiment: have $CO_2$, then leave space, watch the decay
  - Can quantify ventilation rate (see post)
- Opening windows dramatically increases ventilation rate
- How much to open windows?
  - Depends on room and weather / wind
  - Need to measure $CO_2$ so that we can be objective




https://medium.com/@jjose_19945/how-to-quantify-the-ventilation-rate-of-an-indoor-space-using-a-cheap-co2-monitor-4d8b6d4dab44?source=friends_link&sk=6cda52f5682a4a450a10691f07d1ad2c

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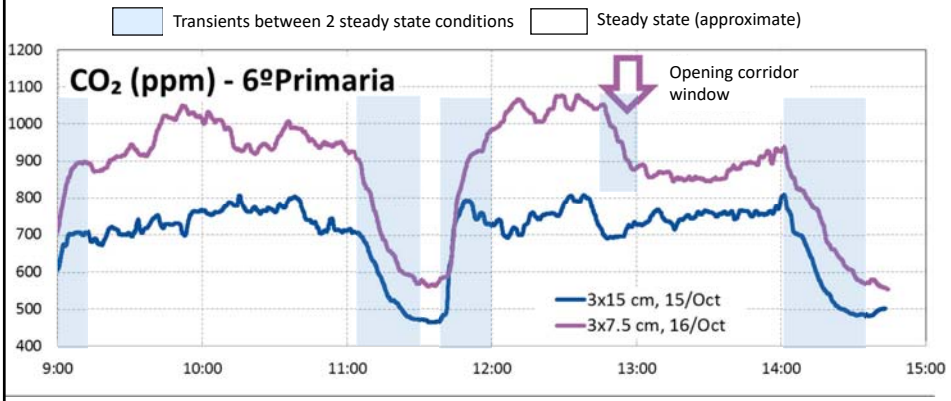
# Ventilation 101 w/ $CO_2$ Meter




- Room quickly reaches steady state for exhaled air & $CO_2$
  - How quickly? With the ventilation timescale
- In many spaces modest window opening is enough
  - Depends strongly on local wind
  - But in other classrooms windows are not enough (not shown)

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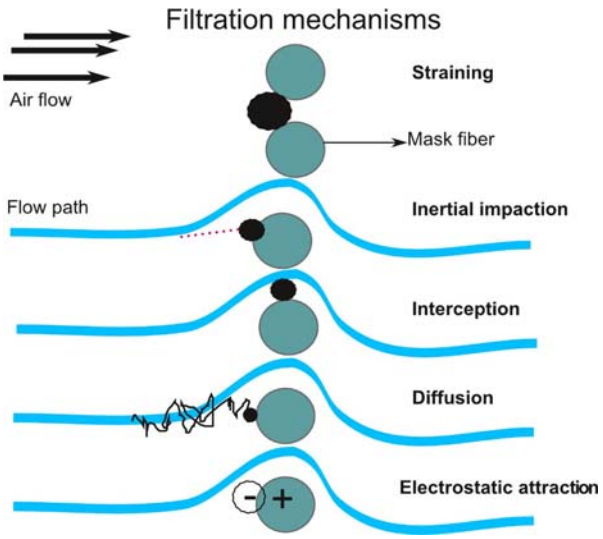
# Masks / filters are not sieves!




https://t.co/JPSjST639t?amp=1 https://youtu.be/eAdanPfQdCA

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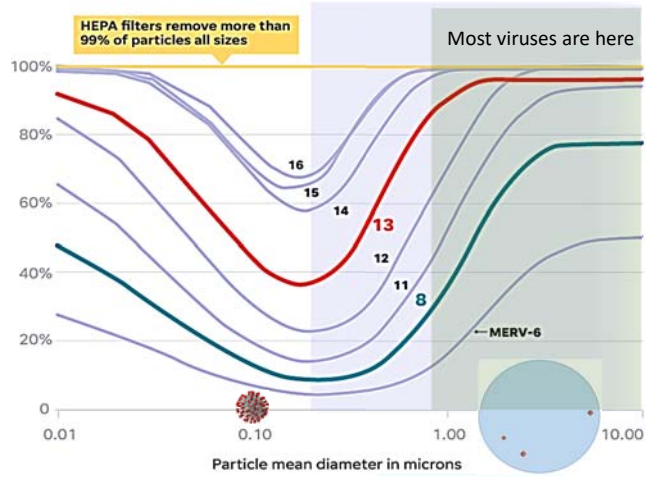
# Filters & Masks work!

*Masks are just filters that we wear*



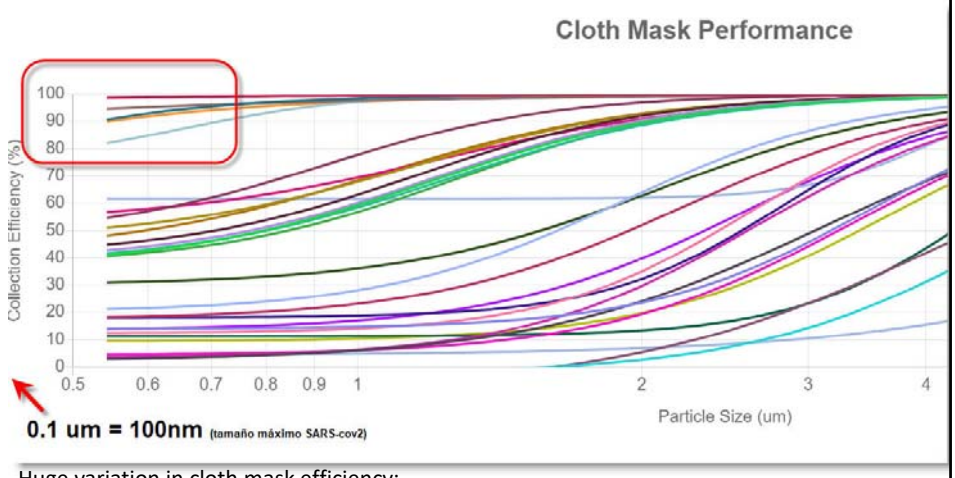

- Virus is not naked in the air
- Supermicron range is likely what matters most
- Going from MERV 8 to MERV 13 is a large improvement
- Most existing HVAC can't tolerate HEPA, fan not strong enough
- What matters is overall removal (flow * efficiency), not 100% in a single pass

- To say that masks or filters don't remove some virus from the air is like saying that you won't be warmer if you put on a coat. It contradicts basic physics. It is like the Flat Earth Theory

https://www.ashrae.org/technical-resources/filtration-disinfection
https://www.usatoday.com/in-depth/graphics/2020/10/18/improving-indoor-air-quality-prevent-covid-19/3566978001/

62

# Cloth Mask efficiency: varies widely




Huge variation in cloth mask efficiency:

- Some almost as good as N95
- Others (e.g. bandanas) do something but far less

From John Volckens' CSU mask testing database: http://jv.colostate.edu/masktesting/

63

# Mask Fit is Critical

- Pay attention to mask fit: avoid gaps, tight around the nose
  - I see lots of people w/ loose masks
  - Don't stand behind someone with a poorly-fitting mask
- Keep mask on when speaking, x10 times more aerosols than just breathing
  - 50 times more when yelling or singing loudly

Visualization by Prof. Philomena Bluyssen, TU Delft, The Netherlands https://youtu.be/mJ81IBTMvcU

64

# Gaps in mask kill their efficiency



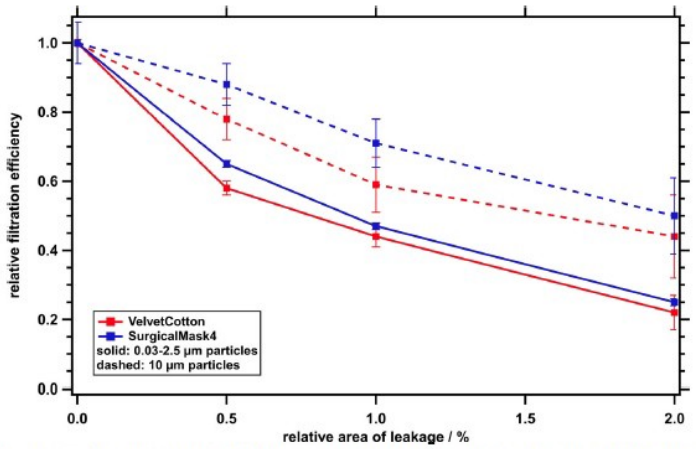



**Figure 8.** Filtration efficiency for velvet cotton (red) and surgical mask (blue) samples for $d_p \leq 2.5\,\mu m$ (solid line) and $d_p = 10\,\mu m$ (dashed line) versus relative leak area, normalized to the leak-free sample. Here, measurements of neutralized (*CPC setup*) and ambient aerosol (*SMPS/OPC setup*) were averaged, where available.

Figure: Drewnick, F., et al. (2020). *Aerosol Science and Technology*, 1–17. https://www.tandfonline.com/doi/full/10.1080/02786826.2020.1817846

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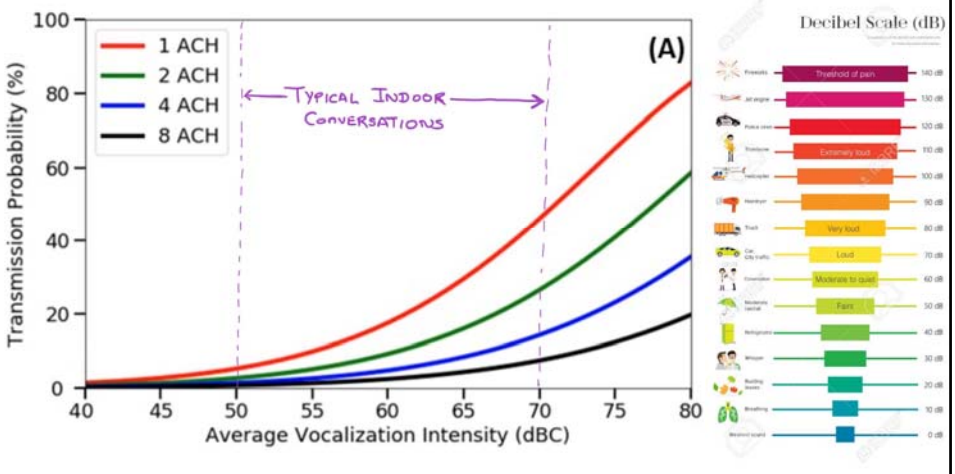
# Talking less loudly reduces transmission




- Take conversations outdoors (distanced & w/ masks) whenever possible

Santiago Barreda, Sima Asadi, Christopher D. Cappa, Anthony S. Wexler, Nicole M. Bouvier, William D. Ristenpart. The Impact of Vocalization Loudness on COVID-19 Transmission in Indoor Spaces. Submitted, preprint at: arxiv.org/abs/2009.04060

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# Air Cleaning

- Recommendations in this order:
  1. Ventilation
  2. Filtration
     - Mechanical systems, portable HEPA, or fan + filter
  3. Germicidal UV
     - Only w/ professional design, installation, and maintenance

1. We do NOT recommend
   1. Spraying disinfectants (HOCl, ozone, etc.)
      - ONLY when nobody is present, and when enough time will pass until people arrive for disinfectant to be gone
   2. air cleaners based on chemistry (ions, plasmas, OH, $H_2O_2$
      - Many of them do kill pathogens
      - The same chemistry that kills the pathogens also reacts with abundant VOCs indoors, and leads to formation of potentially toxic (chemical) aerosols and oxidized VOCs

https://www.sciencedirect.com/science/article/pii/S0160412020317876
https://twitter.com/jljcolorado/status/1291758303089852417
https://medium.com/@dbc007/the-air-chemistry-behind-fogging-for-sars-cov-2-disinfection-ac3df05326bc

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# Air cleaners by filtration really work!


ACH = CADR / Room Volume
https://calculadora-cadr.web.app/

Cheaper Fan + Filter

- 9.5 in https://tinyurl.com/FAQ-aerosols
- Dr. Javier Ballester, Univ. de Zaragoza
  - tinyurl.com/yc7bpdkg

HEPA adapted from Shelly Miller / Fan + filter from Jim Rosenthal

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# Germicidal UV Works

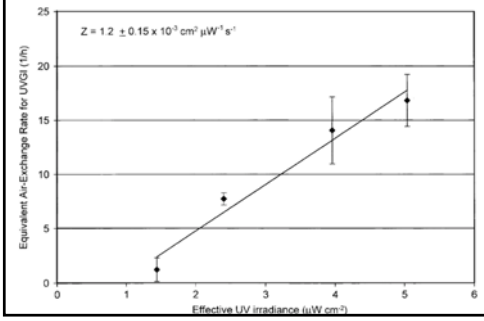
Dec., 1943

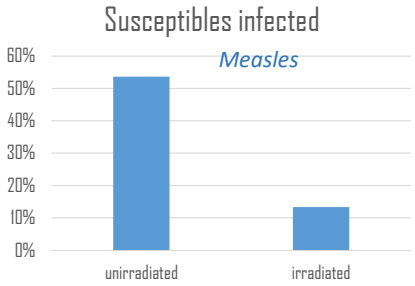
## Air Disinfection in Day Schools*

W. F. WELLS

*Associate Professor in Research in Air-borne Infection, Laboratories for the Study of Air-borne Infection,† Department of Preventive Medicine and Public Health, University of Pennsylvania School of Medicine, Philadelphia, Pa.*

*The first sentence of this paper reads: "The prevalence of respiratory infection during the season of indoor congregation suggests a natural relationship between ventilation and communicable disease."*




- More expensive & complex
- More risks
- Do where needed, by professionals

Slide adapted from Prof. Shelly Miller

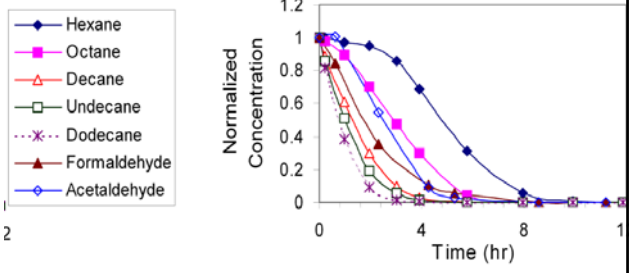
https://ajph.aphapublications.org/doi/10.2105/AJPH.33.12.1436

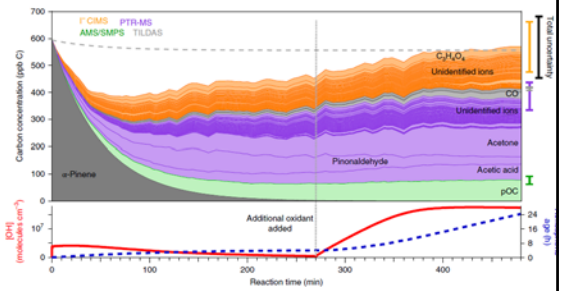
https://www.sciencedirect.com/science/article/pii/S1352231002008257#FIG7

# Air cleaners based on chemistry?

*Ionizers, plasmas, oxidation, photocat.*

- These products destroy VOCs through chemistry
  - VOCs *very* abundant indoors
- They make oxidized VOCs and (chemical) aerosols, more toxic than VOCs
  - Not studied TMK
  - Precautionary principle ➔ can't recommend




https://www.researchgate.net/publication/275344400_Performance_of_Air_Cleaners_for_Removing_Multi-Volatile_Organic_Compounds_in_Indoor_Air

https://www.nature.com/articles/s41557-018-0002-2

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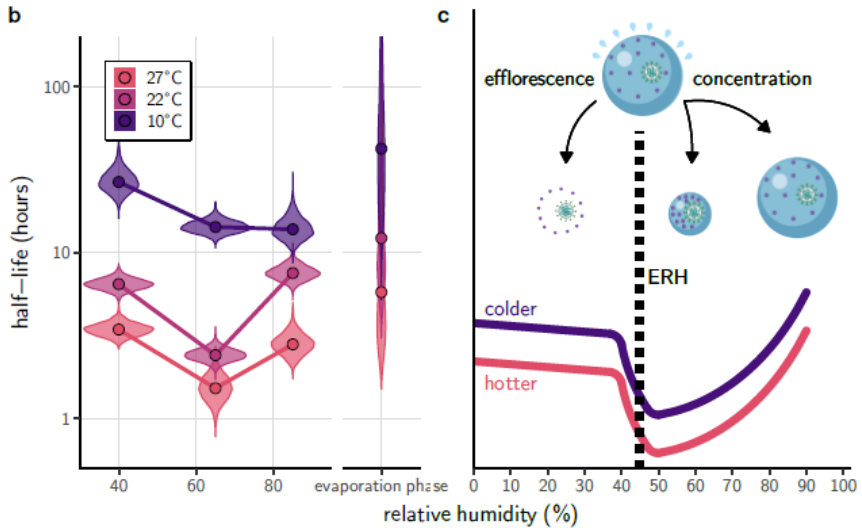
# Virus deactivation vs. T & RH




https://www.biorxiv.org/content/10.1101/2020.10.16.341883v1
https://twitter.com/linseymarr/status/1317510581910441984

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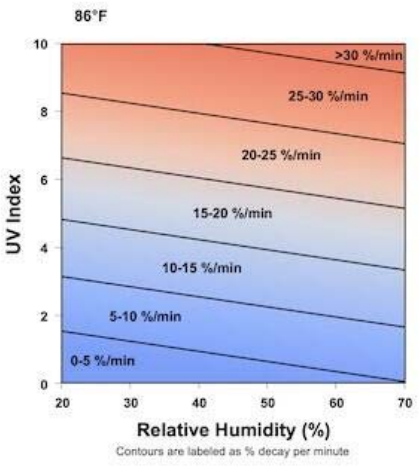
# Effect of Temperature, Humidity, UV

- For enveloped viruses, higher survival at low RH
  - Flu, SARS-CoV-2
  - Some differences in results
- Low T increases lifetime
  - Weak effect
  - Important for meat packing (10°C)
- Solar UV decreases lifetime
  - 5 min – 30 min outdoors, depends on latitude etc.




https://www.dhs.gov/science-and-technology/sars-airborne-calculator

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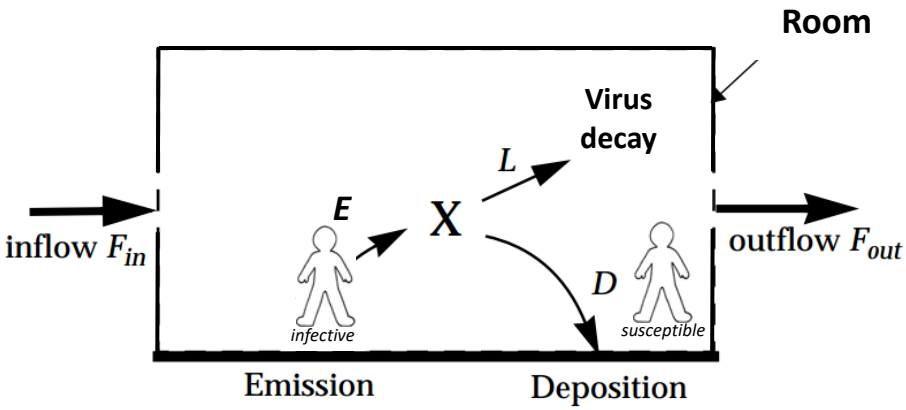
# Simple "box model" of room-level transmission




- Infective emits virus particles, which mix in the room
  - Ignore details of mixing, which can be important at times, but are very specific to each situation (think or test with smoke)
  - Susceptible breathes in some of those particles over time, some probability of infection (Wells-Riley)
- Same as modeling radon. Ordinary differential equations, solved analytically
  - Numerical solution also possible (maybe in future version, allows more complicated events)
- Implemented in spreadsheet
  - Read "readme" and "FAQs" if you want to use it seriously http://tinyurl.com/covid-estimator

Adapted from Jacob Fig 3-1 http://acmg.seas.harvard.edu/people/faculty/dji/book/bookchap3.html#pgfId-112721

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# Aerosol Transmission Estimator

http://tinyurl.com/covid-estimator

| | A | B | C | D | E | F | G |
|---|---|---|---|---|---|---|---|
| | **Estimation of COVID-19 aerosol transmission: master spreadsheet, adapt this one to your case - Default values are for** | | | | | | |
| | This is a general spreadsheet applicable to any situation, under the assumptions of this model - *See notes specific to this case (if applicable) at the very bottom* | | | | | | |
| | Important inputs as highlighted in orange - change these for your situation | | | | | | |
| | Other, more specialized inputs are highlighted in yellow - change only for more advanced applications | | | | | | |
| | Calculations are not highlighted - don't change these unless you are sure you know what you are doing | | | | | | |
| | Results are in blue -- these are the numbers of interest for most people | | | | | | |
| | **Environmental Parameters** | | | | | | |
| | | **Value** | | | **Value in other units** | | **Source / Comments** |
| | Length of room | 25 | ft | | 7.6 | m | Can enter as ft or as m (once entered as m, changing in ft does |
| | Width of room | 20 | ft | = | 6.1 | m | Can enter as ft or as m (once entered as m, changing in ft does |
| | | 500 | sq ft | | 47 | m2 | Can overwrite the m2 one. If you want to enter sq ft, enter "=B1 |
| | Height | 10 | ft | = | 3.1 | m | Can enter as ft or as m (once entered as m, changing in ft does |
| | Volume | | | | 142 | m3 | Volume, calculated. (Can also enter directly, then changing dim |
| | Pressure | 0.95 | atm | | | | Used only for CO2 calculation |
| | Temperature | 20 | C | | | | Use web converter if needed for F --> C. Used for CO2 calcul |
| | Relative Humidity | 50 | % | | | | Not yet used, but may eventually be used for survival rate of vi |
| | Background CO2 Outdoors | 415 | ppm | | | | See readme |
| | Duration of event | 50 | min | | 0.8 | h | Value for your situation of interest |
| | Number of repetitions of event | 180 | times | | | | For e.g. multiple class meetings, multiple commutes in public t |

- Tutorials in English & Spanish: https://www.youtube.com/channel/UChUCsAMXy8f01R3rWqj4z6A
- Many calculators inspired in this one or derived independently, all consistent to my knowledge

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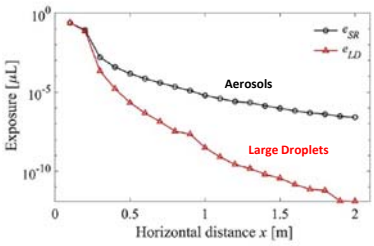
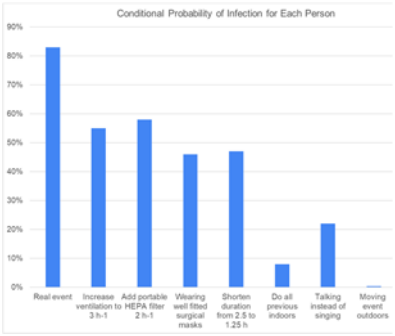
# Conclusions

Smoke analogy: proximity & room

Aerosols dominate when talking




Indoors: layers of protection




Need to fit masks well

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# •BACKUP SLIDES

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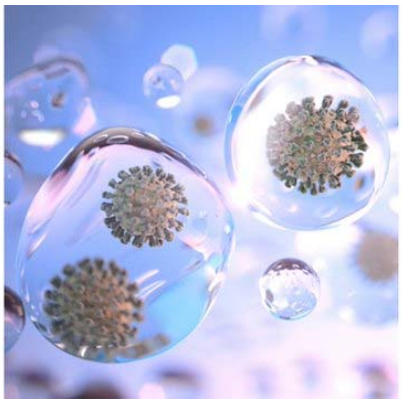
# Many visualizations are incorrect

Incorrect

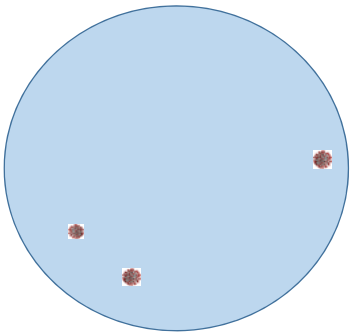
- Aerosols too small relative to the virus (look like 0.2-0.3 µm)
- Looks like water + virus only
- Mass fraction of virus very high



From Klompas et al., JAMA (2020)
https://jamanetwork.com/journals/jama/fullarticle/2768396

More correct

- More typical: few micron aerosol
- Mucin, NaCl, water + sprinkle of virus
- Mass fraction of virus very low



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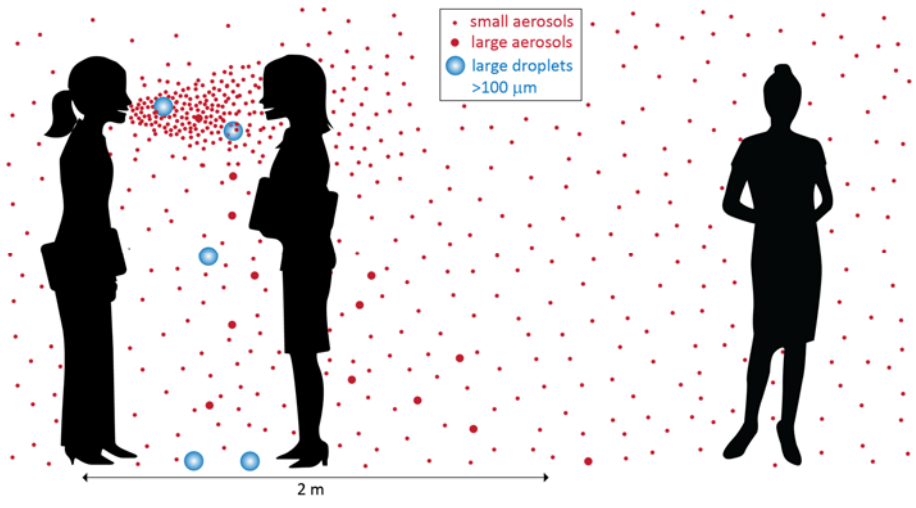


Courtesy of Linsey Marr

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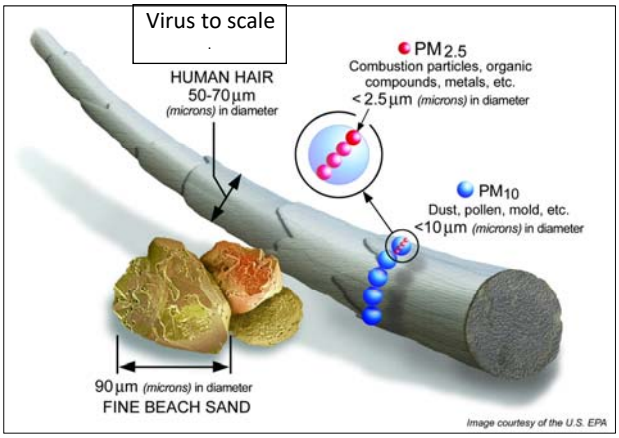
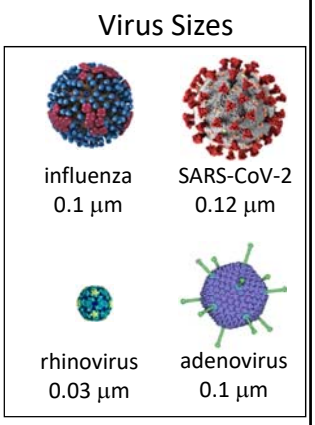
# Illustration of Virus Size




https://www.cdc.gov/flu/resource-center/freeresources/graphics/images.htm, http://solutionsdesignedforhealthcare.com/rhinovirus, https://phil.cdc.gov/Details.aspx?pid=23312, https://pdb101.rcsb.org/motm/132

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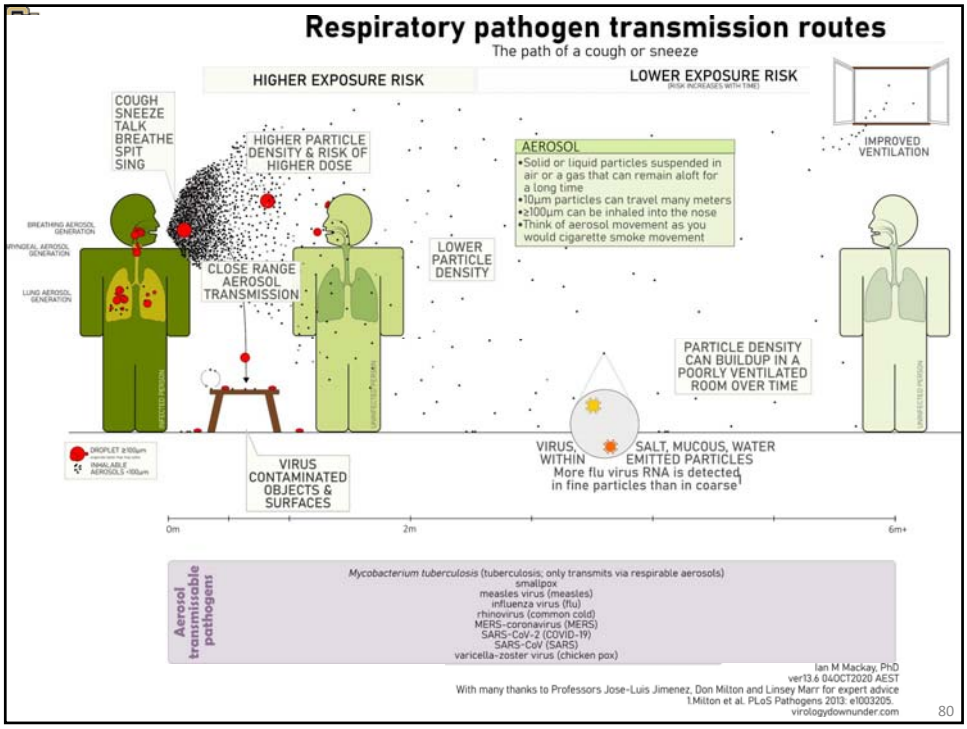


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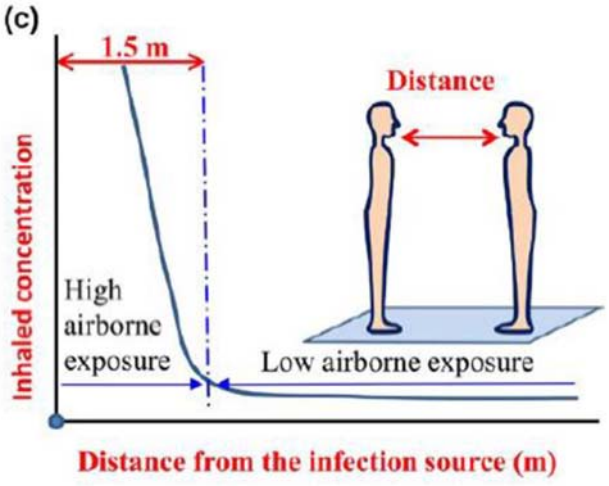
# Close proximity: aerosol most concentrated




Exposure from droplet nuclei (aerosols) in rooms with sufficient ventilation

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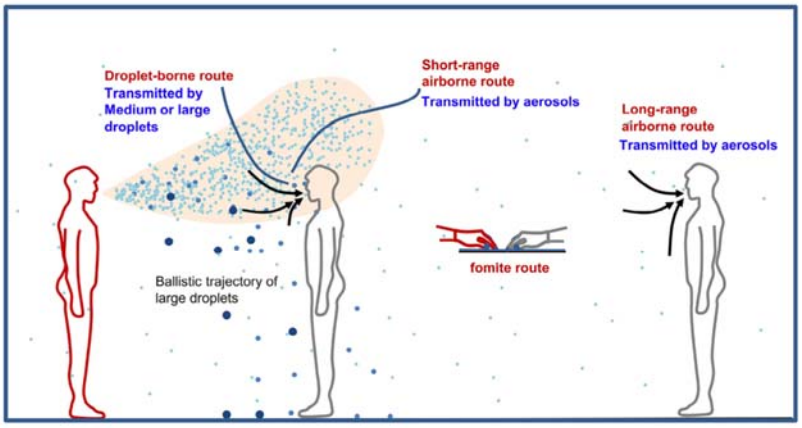
# Why social distance most likely works

Wei, J., Li, Y., 2016. Airborne spread of infectious agents in the indoor environment. American Journal of Infection Control 44, S102–S108




- Large droplets (>100 μm) : Fast deposition due to the domination of gravitational force
- Medium droplets between 5 and 100 μm
- Small droplets or droplet nuclei, or aerosols (< 5 μm): Responsible for airborne transmission

2 m = 6 ft can keep you out of the short-range aerosol transmission plume

Courtesy of Shelly Miller

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# Meteorology: falling droplets for rain

SEPTEMBER 1969 K. V. BEARD AND H. R. PRUPPACHER

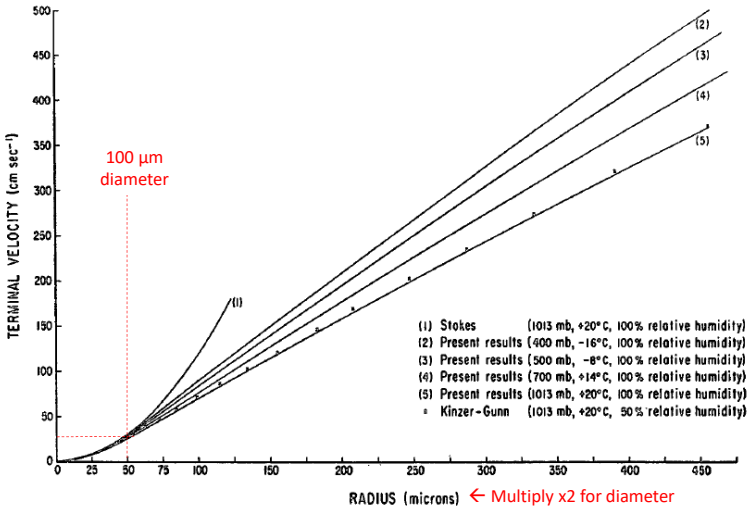


FIG. 5. Terminal velocity of water drops of various sizes and under various environmental conditions.

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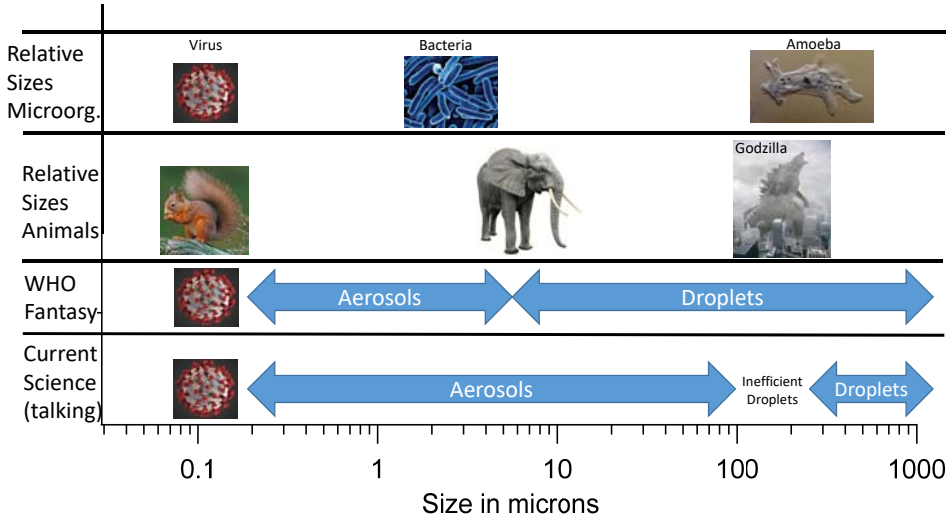
# WHO's Massive Error on A / D Sizes




https://twitter.com/jljcolorado/status/1295518786951319552

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# Aerosol Myths

(a) If it's aerosol, it has to be like measles
(b) If it's aerosol, it has to infect at long range
(c) If it's aerosol, R0 must be very high
(d) If infects at close proximity, it proves droplets and disproves aerosols
(e) If it's aerosol, then surgical masks are useless

- *All false, see e.g. Medscape perspective*
- ***a, b, c: confusing an artifact of history with a law of nature***
- *d, e: out-of-date with the science*

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# Summary of evidence for different modes

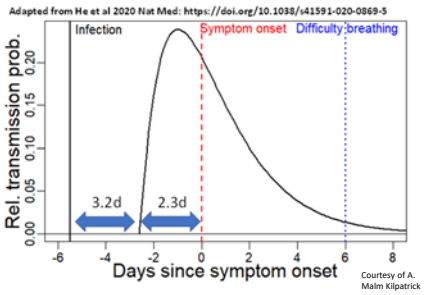
*More detail & references at http://tinyurl.com/aerosol-pros-cons*
*Preliminary, being written up for publication; feedback most welcome*

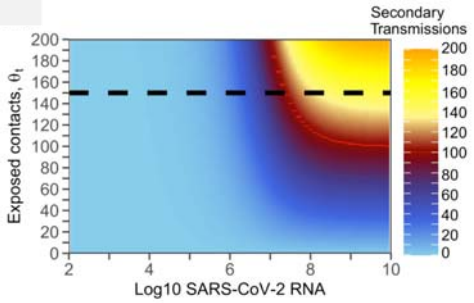
**Key:**
✓: evidence
✓✓: very strong ev.
X: no evidence
X: evidence against
n/a: not applicable
*(v1.47, 18-Sep-2020)*

| | Droplets | Fomites | Aerosols |
|---|---|---|---|
| Outdoors << Indoors | X | ✓ | ✓✓ |
| Similar viruses demonstrated | X | ✓ | ✓ |
| Animal models | ? | ✓ | ✓ |
| Superspreading events | X | X | ✓✓ |
| Supersp. Patterns similar to known aerosol diseases | n/a | n/a | ✓ |
| Importance of close proximity | ✓ | X | ✓✓ |
| Consistency of close prox. & room-level | X | X | ✓ |
| Physical plausibility (talking) | X | ✓ | ✓ |
| Physical plausibility (cough, sneeze) | ✓ | ✓ | ✓ |
| Impact of reduced ventilation | X | X | ✓ |
| SARS-CoV-2 infectivity demonstrated in real world | X | X | ✓ |
| SARS-CoV-2 infectivity demonstrated in lab | X | ✓ | ✓ |
| "Droplet" PPE works reasonably well | ✓ | ✓ | ✓ |
| Transmission by a/pre-symptomatics (no cough) | X | ✓ | ✓ |
| Infection through eyes | ✓ | ✓ | ✓ |
| Transmission risk models | ✓ | ✓ | ✓ |

# What causes superspread?

Goyal, A., Reeves, D. B., Cardozo-Ojeda, E. F., Schiffer, J. T. & Mayer, B. T. **Wrong person, place and time**: viral load and contact network structure predict SARS-CoV-2 transmission and super-spreading events. *medRxiv* (2020).




- Superspreading people? Some emit x10 more aerosols, also higher viral loads
- Lack of transmission? People only infectious for short period

Slide adapted from Prof. Shelly Miller

https://www.medrxiv.org/content/10.1101/2020.08.07.20169920v3

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# History of measles & TB

## Measles (1985)

Most public health authorities believe that the primary mode of transmission is by large respiratory droplets which remain suspended in air for short time intervals.[2] Successful transmission in this manner requires close contact between susceptible individuals and a source patient, usually within 1 m (3 ft). Data supporting respiratory droplet spread come from studies conducted in the early 20th century.[3] Following hospitalization of 182 patients with measles at two hospitals, only one secondary case of measles occurred. Transmission was limited despite free circulation of air in both hospitals, presumably because measures were taken to prevent direct contact between patients with measles and others who were susceptible.

## COVID-19 (WHO IPC)

Another report in a clinical setting in which 41 health care workers (HCWs) were exposed for over 10 min and within 2 m of a patient with confirmed COVID-19 during an intense and difficult intubation and non-invasive ventilation scenario, involving multiple AGMPs, revealed no transmission events of SARS-CoV-2 with repetitive testing of all the HCWs [23]. The majority (85%) of the HCWs were wearing a medical mask and other appropriate PPE while the remainder wore an N95 respirator.

## Tuberculosis

The other sources of information regarding ventilation are various reports on ''accidents of nature'' leading to outbreaks [9]. Most notable among these are outbreaks aboard ships [66–71] and among persons on school buses [72, 73], in poorly ventilated classrooms [74], and in bars [75]. Perhaps the best-studied incident occurred aboard the USS *Byrd,* where 139 (46%) of 308 crew members tuberculin-converted (i.e., converted to tuberculin positivity) and disease developed in 7 (2.3%) [66–68]. Infection was spread by recirculation of contaminated air along closed ventilatory circuits, and high conversion rates were noted in specific sleeping compartments along a ventilatory system. In one compartment housing 6 crewmen with tuberculosis, 52 (79%) of 66 personnel tuberculin-converted; in the next compartment, which shared ventilation with the first, 46 (57%) of 81 tuberculin-converted. This compared to a rate among new recruits of 3.4%.

https://pediatrics.aappublications.org/content/75/4/676.long
https://academic.oup.com/cid/article/23/5/954/415327

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# Impact of outdoor schools in winter

- News of the school quickly spread, with newspapers across the country running an identical report shortly after the school opened: "Little faces that were sallow and pinched a few weeks ago have a healthy flush, and children who were too tired to play are beginning to show some interest in life. All of this ... is what the fresh-air school has accomplished."
- https://www.washingtonpost.com/history/2020/09/14/open-air-schools-outdoor-coronavirus/

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# Masks less different above 1 micron

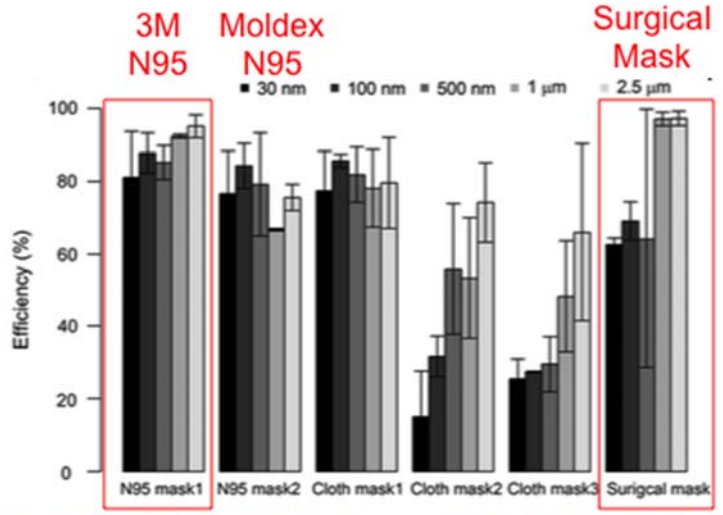


**Figure 2.** Efficiency of masks in removal of five polystyrene latex (PSL) particle sizes at a flow rate of 19 L/min. Error bars are the standard deviation from three experiments.

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# For now we are on our own!


From experience talking to governments, schools, companies, and inviduals: as long as aerosol transmission is effectively denied by the major organizations, it is extremely difficult to get measures to control it in place. E.g.:


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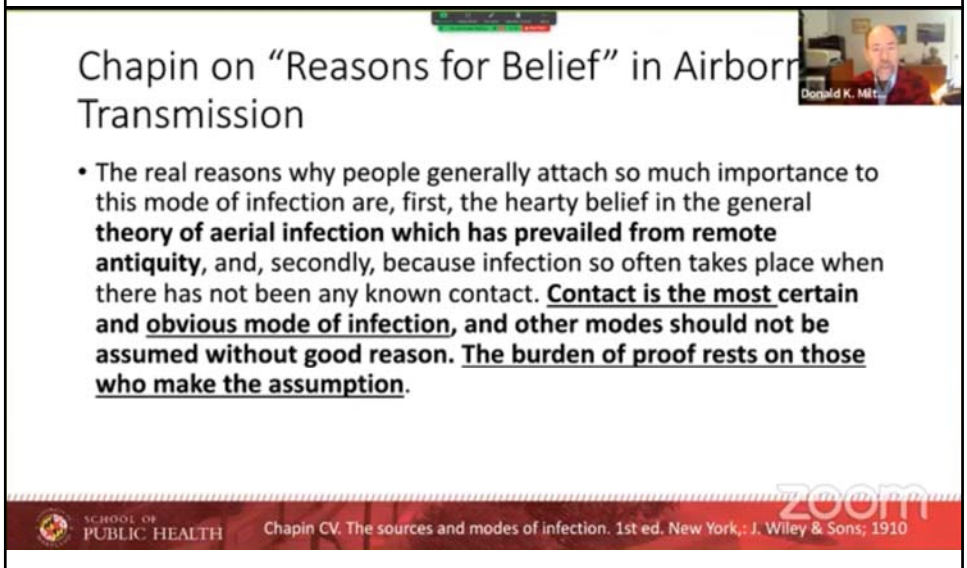


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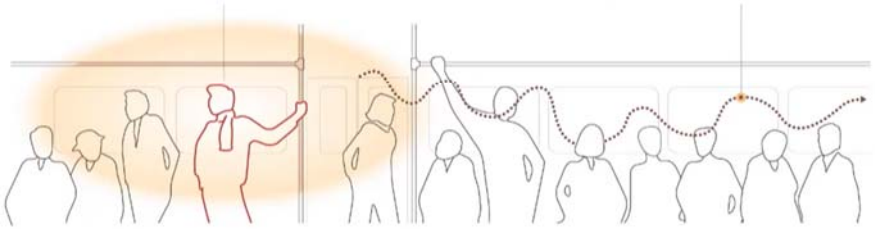
# CDC's view of droplets vs aerosols

## Droplet Transmission and Airborne Spread

**Droplet: infectious particles are projectiles; spread limited by gravity**

**Airborne: infectious droplet nuclei; remain airborne minutes to hours, potential spread by air currents (e.g., via HVAC)**



CDC

New York Times, January 31, 2020

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