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

Prof. Jose L. Jimenez
University of Colorado-Boulder
Jose.jimenez@colorado.edu
Twitter: @jljcolorado
http://tinyurl.com/covid-estimator
http://tinyurl.com/faqs-aerosol

Airborne transmission of SARS-CoV-2
Kimberly A. Prater¹, Lianey C. Mars¹, Robert T. Schooley⁴, Melissa A. McDermott¹, Mary K. Wilson⁵, Donald E. Nelson²

There is increasing evidence that coordination of severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) exposure and effective aerosol control, by airborne transmission of respiratory droplets, is critical to limit the spread of infection. This article describes the latest evidence on the mechanisms of airborne transmission, including the role of aerosols in SARS-CoV-2 infection, and the evidence for the benefits of strategies to reduce airborne transmission. The article also discusses the potential impact of airborne transmission on the spread of SARS-CoV-2 and the role of respiratory aerosols in the transmission of SARS-CoV-2.

REFERENCES AND NOTES

¹National Academy of Sciences, Engineering, and Medicine, "VITALS 3-D: Effective surface and personal protective strategies for the SARS-CoV-2 pandemic," 3 April 2020, https://www.nationalacademies.org/~/media/Files/Activity%20Files/Coronavirus/20200403-VITALS-3-D.pdf
What do we know about transmission?

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

Droplets vs. Aerosols

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

WHO’s messaging

FACT CHECK: COVID-19 is NOT airborne

The virus that causes COVID-19 is mainly transmitted through droplets generated when an infected person coughs, sneezes, or speaks. These droplets are too heavy to hang in the air. They quickly fall on floors or surfaces.

You can be infected by breathing in the virus if you are within 1 metre of a person who has COVID-19, or by touching a contaminated surface and then touching your eyes, nose or mouth before washing your hands.

To protect yourself, keep at least 1 metre distance from others and disinfect surfaces that are touched frequently. Regularly clean your hands thoroughly and avoid touching your eyes, mouth, and nose.

March 28 2020

WHO’s Latest Scientific Brief

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

Scientific brief
9 July 2020

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. (1) 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 infections 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)
CDC accepts aerosols as the main way

- 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
- Therefore close proximity and shared-room transmission are connected through aerosols

What do we know about transmission?

- Surfaces not major: e.g. hand-washing reduced 16%
- Easily transmitted in close proximity
**WHO: why social distance helps**

Close: droplets can hit eyes / nose / mouth

Far: droplets fall to the ground

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

**Another explanation for social distance**

- Expiratory plume visualized by smoke
- Avoid breathing exhaled air, can explain social distance works
  - Observation that social distance works *alone* does not prove droplets or aerosols. We need to look at more evidence
- Shared room air?
  - If droplets: safe
  - If aerosols: not safe. With time and low-ventilation, infection can happen

Videos: social distance vs. aerosols

Real exhaled CO₂  CFD Simulation

- 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
  - CO₂ is directly imaged (experiment) but offers less visual contrast and range than simulation

Simulation and visualisation: Helkkil Kahila, Aalto University

https://twitter.com/SEE_Fluids_UK/status/1314566418980462594
https://www.youtube.com/watch?v=EcpQb86d5g

What do we know about transmission?

- Surfaces not major: e.g. hand-washing reduced 16%
- Easily transmitted in close proximity
- **Indoors >> outdoors**
Indoors vs. Outdoor

Studies suggest Covid-19 transmission is much less likely in outdoor spaces than indoor settings.

Researchers traced the contacts of 110 people with Covid-19, and recorded when the virus was passed on to a contact, split by whether or not the primary case had met people indoors.

- **Indoors**: 22 primary cases
  - Only 6 of the 22 who met people indoors did not infect anyone...
  - ...while 16 (73%) did.
- **Outdoors**: 88 primary cases
  - 77 of the 88 who only met people outdoors did not infect anyone...
  - ...only 11 of the outdoor-only cases passed on the infection.

Most of the secondary infections took place indoors despite only 20% of contacts happening indoors.


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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

What do we know about transmission?

• Surfaces not major: e.g. hand-washing reduced 16%
• Easily transmitted in close proximity
• Indoors >> outdoors
• “Different” than accepted airborne diseases:
  • Airborne: Measles, tuberculosis, chickenpox
  • COVID-19 more similar to “droplet diseases” such as flu
    • $R_0 \sim 2.5$
  • High dispersion, “superspreading”
    • 10-20% of infected lead to 80% of new infections ($R_0 \sim 10-20$)
Example Superspreading Event: Skagit Choir

- 2.5 hr rehearsal: 1 index case, 52 new infections (13 m behind)
- Fomites?
  - Agreed to be inefficient (e.g. CDC)
  - Index case didn’t touch any objects, ~3 people went to same bathroom
- Droplets?
  - 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

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  - “Droplet precautions” work ok with very ill patients

Droplet or Aerosol Diseases?

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Variability of Infective Aerosol Emission

- WHO mental model: constant & high aerosol emission by all infected
  - When that’s not consistent with observations, they conclude aerosols don’t transmit!

- Also anisotropic infection, e.g. for flu (Don Milton)
  - Infective dose is x100 lower for small aerosols into lung than nose deposition
  - For the same symptoms, dose is x100000 larger for the nose

- Superspreading?
  - Certainly wrong time in wrong location
  - Superspreading ppl? Some emit x10 more aerosols, also high variability in viral loads
  - Lack of transmission? People only infectious for short period

https://www.nature.com/articles/s41591-020-0869-5 Don Milton’s lecture (high recommended): https://t.co/sL6bwRf1u4
https://www.medrxiv.org/content/10.1101/2020.08.07.20169920v3

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- “Droplets larger, have many more viruses”
- Is that correct?
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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
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.2011.07.008

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Particle Settling in Still Air

Time to settle 5 feet by unit density spheres

<table>
<thead>
<tr>
<th>Diameter (μm)</th>
<th>0.5</th>
<th>1</th>
<th>3</th>
<th>10</th>
<th>100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time (hours)</td>
<td>41</td>
<td>12</td>
<td>1.5</td>
<td>8.2</td>
<td>5.8</td>
</tr>
</tbody>
</table>

Aerodynamic diameter definition: diameter of a unit density sphere that settles at the same velocity as the particle in question
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://masspr.hms.harvard.edu/event/harvard-medical-school-grand-rounds-featuring-dr-anthony-s-fauci

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
Aerosol Deposition in Resp. Tract

- Studied extensively (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

Infectious Dose:
droplets vs. aerosols when talking

- Aerosol volume dose is x100-x2000 times larger than for droplets

- For all diseases where measured, pathogens more concentrated in smaller particles (< 5 µm typical)
  - Tuberculosis, measles, flu, RSV

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

What do we know about transmission?

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    • Many don’t transmit to anybody
    • Attack rate in households not very high
    • “Droplet precautions” work ok with very ill patients
• “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)

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
How did we end up here?

Part I

• Theory of miasmas, diseases go long distances through air
  • 1860s: Pasteur discover germs
    • Evidence accumulates for transmission of different diseases
  • 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
    • Problem: “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 measurable yet
      • “There is no evidence that [air infection] 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
  • 1930s on: Wells, Riley & others fight fierce resistance
    • Measles, chickenpox, TB: droplet/fomites for decades
      • Finally demonstrated, but only because so contagious, and/or evidence unequivocal
    • 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”

https://archive.org/details/sourcesmodesofin00ch&page=21

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
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-low)
  - 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
    - Aerosols NOT most important. But crucial error

Wells 1945

The ultimate goal of sanitation set by Leonard Wells in 1945 was to guarantee to millions of humanity the same freedom from communicable diseases enjoyed by isolated individuals. Water purification, milk pasteurization, and prophylactic administration during the present century have added several years to the expectancy of life at birth. Does the control of respiratory infection by -tial ventilation seem more difficult to sanitary science than the conquest of intestinal and faecal-oral parasitism carried out at the turn of the century?

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](https://tinyurl.com/Preguntas-Espanol).

0. Questions about these FAQs
   0.1. What is the goal of these FAQs?
   0.2. Who has written these FAQs?
   0.3. I found a mistake, or would like something to be added or clarified, can you do that?
   0.4. Are these FAQs available in other languages?
   0.5. Can I use the information here in other publications etc.?

1. General questions about COVID-19 transmission
   1.1. How can I get COVID-19?
   1.2. What is the relative importance of the routes of transmission?
   1.3. But if COVID-19 was transmitted through aerosols, wouldn’t it be highly transmissible like measles, and have a very high R0 and long range transmission?
Preventing Transmission of COVID-19

• 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
  • Avoid or reduce
  • Crowding
  • Indoors
  • low Ventilation
  • Close proximity
  • long Duration
  • Unmasked
  • Talking/singing/shouting
  • (mnemonic: "A CIViC DUTy")
### Risk of different situations

<table>
<thead>
<tr>
<th>Type of activity</th>
<th>Low occupancy</th>
<th>High occupancy</th>
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<tr>
<td></td>
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*Risk of transmission: Low, Medium, High.*

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

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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”**

![Conditional Probability of Infection for Each Person](image)
Do activities outdoors when possible

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

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<tr>
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<td>1230 ppm</td>
<td>1400 ppm</td>
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<td>Dorm rooms’ ventilation rates</td>
<td>6 L/s/person</td>
<td>2 L/s/person</td>
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<tr>
<td># ARI cases / total subjects</td>
<td>1 / 11</td>
<td>47 / 109</td>
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Ventilation rates of < 5 L/s per person may be impacting acute respiratory infections

- Prof. Shelly Miller during National Academy of Sciences, Engineering, and Medicine Workshop

Outdoor air supply rates < 25 L/s per person increase the risk of sick building symptoms, increase short-term sick leave, and decrease productivity
Using CO₂ as a Analog (<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/jjcolorado/status/1304398049528012800

CO₂ w/ open vs closed windows

- Opening windows dramatically increases ventilation rate
- How much to open windows?
  - Depends on room and weather / wind
  - Need to measure CO₂ so that we can be objective
Ventilation stopped TB outbreak

- Many of the rooms had CO₂ levels above 3,000 ppm.
- When engineers improved air circulation and got CO₂ levels under 600 ppm, the outbreak completely stopped.
- Increase in ventilation = 97% of the decrease.

[Graph showing CO₂ concentration vs. time and number of cases]

Adapted from Prof. Shelly Miller

Filters & Masks work!

Masks are just filters that we wear

- 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.

[Graph showing particle size distribution and efficiency]

- 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.

https://www.ashrae.org/technical-resources/filtration-disinfection
Masks / filters are not sieves!

Filtration mechanisms
- Air flow
- Flow path
- Straining
- Inertial impaction
- Interception
- Diffusion
- Electrostatic attraction

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

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

Talking less loudly reduces transmission

- arxiv.org/abs/2009.04060

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/
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, H₂O₂)
      ▪ 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://twitter.com/jljcolorado/status/1291758303089852417
https://medium.com/@dbc007/the-air-chemistry-behind-fogging-for-sars-cov-2-disinfection-ach98386e

Air cleaners by filtration really work!

Air mega 305S Smart HEPA Air Purifier by Coway

Cheaper Fan + Filter

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

• 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
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

[Links to research papers]

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.

[Links to websites]

5/4
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."

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

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 of 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
**Aerosol Transmission Estimator**

http://tinyurl.com/covid-estimator

### 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:**

- Often, more specific inputs are highlighted in purple - change also for more advanced applications.
- Calculations are not highlighted - don't change 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**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Value in other units</th>
<th>Source / Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length of room</td>
<td>25 ft</td>
<td>7.6 m</td>
<td>Can enter as ft or as m (please consider as m, changing in ft does not change final result)</td>
</tr>
<tr>
<td>Width of room</td>
<td>20 ft</td>
<td>6.1 m</td>
<td>Can enter as ft or as m (please consider as m, changing in ft does not change final result)</td>
</tr>
<tr>
<td>Height</td>
<td>10 ft</td>
<td>3.1 m</td>
<td>Can enter as ft or as m (please consider as m, changing in ft does not change final result)</td>
</tr>
<tr>
<td>Volume</td>
<td>142 m³</td>
<td>142 m³</td>
<td>Volume, calculated (can also enter directly), then changing the m³ value, make sure to check my spread sheet for other calculations.</td>
</tr>
<tr>
<td>Pressure</td>
<td>0.95 atm</td>
<td></td>
<td>Used only for CO₂ calculation</td>
</tr>
<tr>
<td>Temperature</td>
<td>20°C</td>
<td></td>
<td>Use your own input.</td>
</tr>
<tr>
<td>Relative Humidity</td>
<td>50%</td>
<td></td>
<td>Not yet tested, may eventually be used for survival rate of CO₂.</td>
</tr>
<tr>
<td>Background CO₂</td>
<td>415 ppm</td>
<td></td>
<td>See spreadsheet.</td>
</tr>
<tr>
<td>Duration of event</td>
<td>30 min</td>
<td>0.5 h</td>
<td>Value for your situation of interest</td>
</tr>
<tr>
<td>Number of repetitions of event</td>
<td>100 times</td>
<td>For e.g. multiple class meetings, multiple commuters in public transport</td>
<td></td>
</tr>
</tbody>
</table>

**Tutorials in English & Spanish:** [https://www.youtube.com/channel/UCHUCAMXy8Q1R3rWq4z6A](https://www.youtube.com/channel/UCHUCAMXy8Q1R3rWq4z6A)

**Many calculators inspired in this one or derived independently, all consistent to my knowledge**

---

**Conclusions**

Smoke analogy: proximity & room

Aerosols dominate when talking

Indoors: layers of protection

Conditional probability of infection for fruit farmers

Need to fit masks well
Illustration of Virus Size

<table>
<thead>
<tr>
<th>Virus Sizes</th>
<th>Diameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>influenza</td>
<td>0.1 µm</td>
</tr>
<tr>
<td>SARS-CoV-2</td>
<td>0.12 µm</td>
</tr>
<tr>
<td>rhinovirus</td>
<td>0.03 µm</td>
</tr>
<tr>
<td>adenovirus</td>
<td>0.1 µm</td>
</tr>
</tbody>
</table>

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

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

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

Respiratory pathogen transmission routes

In higher exposure risk, the path of a cough or sneeze

In lower exposure risk, improved ventilation

With thanks to Professors Joel-Ikis Jimenez, Dan Nelson and Image Man for artwork advice, E. Cupid et al. for pathogen drawing.
Close proximity: aerosol most concentrated

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

Why social distance most likely works

2 m = 6 ft can keep you out of the short-range aerosol transmission plume
Meteorology: falling droplets for rain

K. V. Beard and H. R. Pruppacher

Terminal velocity (cm/s) vs RADIUS (microns)

100 µm diameter

Multiply x2 for diameter

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

WHO’s Massive Error on A/D Sizes

<table>
<thead>
<tr>
<th>Relative Sizes Microorg.</th>
<th>Virus</th>
<th>Bacteria</th>
<th>Amoeba</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relative Sizes Animals</td>
<td>😄</td>
<td></td>
<td></td>
</tr>
<tr>
<td>WHO Fantasy</td>
<td>😐</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Current Science (talking)</td>
<td>😞</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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

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

<table>
<thead>
<tr>
<th>Test</th>
<th>Droplets</th>
<th>Fomites</th>
<th>Aerosols</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outdoors &lt;&lt; Indoors</td>
<td>X</td>
<td>✓</td>
<td>✓✓</td>
</tr>
<tr>
<td>Similar viruses demonstrated</td>
<td>X</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Animal models</td>
<td>?</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Superspreading events</td>
<td>X</td>
<td>X</td>
<td>✓✓</td>
</tr>
<tr>
<td>Super Sap, Patterns similar to known aerosol diseases</td>
<td>n/a</td>
<td>n/a</td>
<td>✓</td>
</tr>
<tr>
<td>Importance of close proximity</td>
<td>✓</td>
<td>X</td>
<td>✓✓</td>
</tr>
<tr>
<td>Consistency of close prox. &amp; room-level</td>
<td>X</td>
<td>X</td>
<td>✓</td>
</tr>
<tr>
<td>Physical plausibility (talking)</td>
<td>X</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Physical plausibility (cough, sneeze)</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Impact of reduced ventilation</td>
<td>X</td>
<td>X</td>
<td>✓</td>
</tr>
<tr>
<td>SARS-CoV-2 infectivity demonstrated in real world</td>
<td>X</td>
<td>X</td>
<td>✓</td>
</tr>
<tr>
<td>SARS-CoV-2 infectivity demonstrated in lab</td>
<td>X</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>“Droplet” PPE works reasonably well</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Transmission by asymptomatics (no cough)</td>
<td>X</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Infection through eyes</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Transmission risk models</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>
What causes superspread?


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

Chapin’s motivations

- Not enough evidence
- Belief in air infection is very problematic
- Interpret absence of evidence as evidence of absence
- Say that airborne infection is almost impossible

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.
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/
Masks less different above 1 micron

For now we are on our own!

From experience talking to governments, schools, companies, and individuals: 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.:

FACT CHECK: COVID-19 is NOT airborne

The coronavirus is mainly transmitted through droplets generated when an infected person coughs, sneezes or speaks.

To protect yourself:
- keep 1m distance from others
- disinfect surfaces frequently
- wash/rub your hands
- avoid touching your face

World Health Organization (WHO) 🇬🇧

FACT: #COVID19 is NOT airborne.

No consultations with several businesses (e.g. Plantronics) who were interested in advice on mitigating aerosol transmission. Ultimate is none decided to act on virus because @WHO, CDC, etc. downplay aerosol transmission.

Health agencies have been too slow to accept the obvious.
DEFENSA CONTRA VIRUS RESPIRATORIOS: EL MODELO DE QUESO SUIZO

RECONOCER QUE NINGUNA INTERVENCION POR SI SOLA ES PERFECTA PARA PREVENIR LA PROPAGACION.

CADA INTERVENCION (CAPA) TIENE IMPERFECCIONES (AGUIJEROS).
MULTIPLES CAPAS MEJORAN LA PROBABILIDAD DE EXITO.

Chapin on “Reasons for Belief” in Airborne Transmission

- The real reasons why people generally attach so much importance to this mode of infection are, first, the hearty belief in the general theory of aerial infection which has prevailed from remote antiquity, and, secondly, because infection so often takes place when there has not been any known contact. Contact is the most certain and obvious mode of infection, and other modes should not be assumed without good reason. The burden of proof rests on those who make the assumption.
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)