Basic notes: Staying safe from Sars-CoV-2 (SARS-COV-2) virus[1] and why the exposure controls work Version 5, 26th April 2021
by Dr Mark Piney

Good ventilation is key to COVID control

Good ventilation is key to COVID control – some evidence

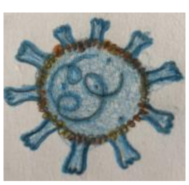
> *"… there were more than **500 outbreaks**, or suspected outbreaks, **in offices** in the second half of 2020 – **more than** in supermarkets, construction sites, warehouses, restaurants and cafes combined."* **link** **BBC 19th January** see also **link** (9.4.21) and **link** (23.10.20)

Good ventilation is key to COVID control – a song

***"Sometimes when the wind blows"* by Katy Bennett**

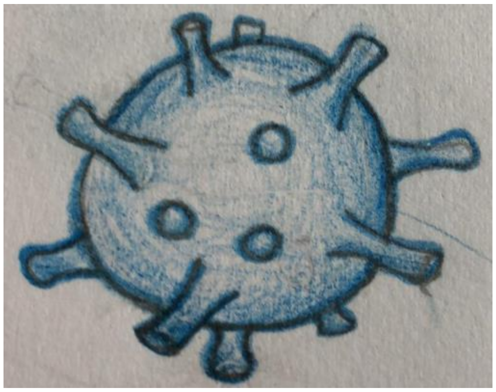
- ***"Sometimes when the wind blows,***
- ***I open every window in-the-house,***
- ***So I can feel it on-my-skin,***
- ***Cold air rushing in old-air-flowing-out"***

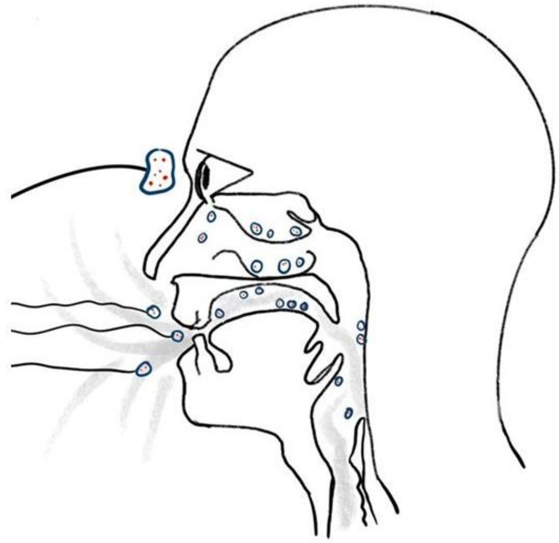
'When The WInd Blows' by Katy Rose Bennett - Acappella - YouTube



[1] The cause of COVID 19 disease

0.0 *Summary*





1. **Basic Notes, Version 1 & Version 5** These Basic Notes (Version 5) are shorter, more focused and accurate than Version 1 published by the British Occupational Hygiene Society (BOHS) about three months ago on 11th January 2021) **link**. The arguments, evidence and exposure control recommendations are more subtle and evidence–based in this Version.
2. **What is occupational hygiene?** Occupational hygiene is a specialist applied science focussed on exposure to, and control of, chemical, physical and biological health risks at work (and sometimes to the public in general).
3. **Audience(s)** There are three audiences for these Notes; those responsible for SARS-COV-2 policy, those responsible for SARs-CoV-2 exposure control management and interested members of the public.
4. ***"The dose makes the poison"*** The whole of applied sciences, such as occupational hygiene, all medical sciences and the science of toxicology are founded on the same idea. That if exposure to a contaminant/drug is "insignificant" then it follows that the risk is also insignificant. The problem with the new virus SARS-COV-2 (which causes Covid 19) is defining what is an **insignificant exposure zone** and therefore exactly what exposure controls are needed to get exposure well below this zone. **See pages 8 – 9**
5. **Scientific problems as jigsaw puzzles** Different sciences offer different insights and understandings of the world. Working out what is going on, and what to do about SARS-COV-2 virus, is a bit like trying to complete a jigsaw puzzle without the picture on the lid. Each science involved helps complete a bit of the puzzle **Pages 9 – 10**
6. **Virus key properties** Respiratory viruses cannot move by themselves, they need to be transported usually in saliva droplets. Even if these saliva droplets start out quite big all droplets rapidly dry out (in less than 3 seconds) and become a 'smoke' of dry virus-containing particles. **Page 10**
7. **Droplet/particle generation** There are four common human droplet/particle generating mechanisms. When our vocal cords vibrate when we talk, sing or shout, when we move our tongue, mouth and lips, when we cough or sneeze and

when the small bronchioles leading to the alveoli (air-sacs deep in the lungs) inflate and collapse on each breath. **Pages 11 - 21**

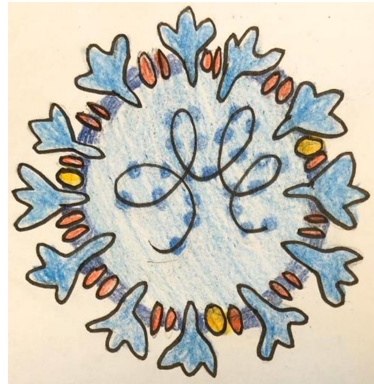
8. **Infectivity and routes/pathways to infection** There is a three-fold rank-order to droplet-particle infectivity (which wasn't appreciated at the start of the COVID-19 pandemic):

1. Smaller Airborne Droplets (SADs) and Smaller Airborne Particles (SAPs) – Main vehicle for SARs-CoV-2 transmission i.e. the main infection pathway (*"Far-field"*).
2. Larger Airborne Droplets both LAD_{spit} and LAD_{inh} - Far less important in SARs-CoV-2 transmission i.e. a secondary infection pathway (*"Near-field"*)
3. Direct skin-contact with contaminated surfaces with transfer to face or (perhaps) food – Highly unlikely to lead to SARs-CoV-2 transmission i.e. By far-and-away the least important pathway.

These facts took a while to work out and hampered early exposure control recommendations including the UK Governments. **Pages 13 - 22**

9. **Exposure control Measures** It would be handy if there was a similar simple rank-order of exposure control measures. Certainly, effective (or reasonable) ventilation is critical as is the wearing of face–masks or respirators. And physical distancing is very important too. But there are other layers of exposure control measures which can contribute to exposure control. Please Note: the exposure control measures apply to any country in the world, not just the UK. **Pages 23 - 35**
10. **Sciences and pandemics. Page 36**
11. **Acknowledgements Page 37**
12. **Dedication to Alan McArthur (3M). Page 38. Please give generously.**
13. **Appendices. Pages 39 – 58**
14. **Contents pages. Pages 4 - 5** Please use the Contents Pages as a guide to these Notes. There is a logic to the presentation of evidence and arguments, but each sub-section (Chapter) is relatively self-contained and intelligible.

"Basic Notes" Version 5 Introduction



1.0 Who am I and what is occupational hygiene?

I am 71 years old. Until I stopped work, I was a professional occupational hygienist for 38 years including 22 years working for the UK Health and Safety Executive (HSE) 1989 - 2011. As with any scientific (or other work) this isn't a solo effort. I have had lots of help, critical feedback and tons of support (see Acknowledgements)

Occupational hygiene is a specialist applied science focussed on exposure to, and control of, chemical, physical and biological health risks at work. The big emphasis is on getting the **exposure control measures[2]** right and maintaining them.

I have won various prizes for the professional quality and impact of my work. See more about the prizes and my career details in the Footnote[3] and associated links.

Much of my professional scientific work involved assessing risks from invisible dusts, vapours and gases, and working with people to develop **exposure control measures**.

A critical part of developing and applying **exposure control measures** is that:

1. They work well enough to effectively control exposure (in this case to SARS-COV-2 virus)
2. They are practical and doable over the long-term
3. They address and answer the question " Why *am I having to do this?".* This is a perfectly reasonable human question, and it needs answering covering the following issues:

[2] An *"exposure control measure"* is anything that reduces exposure to a contaminant. It could be a process change and behavioural change, and organisational change or the appliance of some form of active control such as ventilation or personal protective equipment (PPE). An *"exposure control measure"* can be anything. Once it's recognised and used then it needs to be included in the description of *"exposure control measures"* checked and maintained.

[3] Retired Member of the British Occupational Hygiene Society (BOHS) Faculty of Occupational Hygiene and retired Health and Safety Executive (HSE) Principal Specialist Inspector in Occupational Hygiene (Details **here** (Linked-In) & **here** See particularly ***Professional*** ***"About"*** and ***"Further Information – HSE Publications"*** and ***Further Information – Some Other Publications***) and ***Further Information – Presentations***). Recently (March - July 2020) Member of BOHS RPE Working Group

a. If people know how the exposure control measures work they will have confidence in them and will do what's needed to protect themselves and others.
b. They need to believe that the measures, even if they're a bit of a palaver, will work.
c. It helps to understand some of the details of why and how the measures work so that people can trust and apply them in their own circumstances.

1.2 Pandemic response

At the start of the pandemic in the UK, and in many other countries, people including many of the scientists asked to help, were confused as to how SARs-CoV-2[4] spread from person to person. Initially, for instance, the UK's government's advice (from about February 2020) was to rigorously keep our skin, especially our hands, clean.

It was only later that it was realised that the airborne routes (pathways) were the main routes and face-mask wearing, physical distance and the importance of good ventilation became clearer, and part of governmental advice. Almost bizarrely nowadays some scientists **still** down-play the airborne routes, **link**

These Notes do two things:

1. They summarise what's been learnt by the sciences involved especially the insights that the applied science of occupational hygiene can offer.
2. They go a bit further and explain not only why the SARS-COV-2 exposure control measures work, but what we might do differently, and better, next time there is a pandemic.

1.3 Audiences for these Notes

There are three audiences for these Notes.

1. Those responsible for SARS-COV-2 policy in government and other organisations.
2. Those in management responsible for control of exposure to SARS-COV-2 virus.
3. Interested members of the public.

The British Occupational Hygiene Society (**BOHS**) will illustrate and extend the key messages in these Notes. I've also put them on my **Website** but please go principally to the Society's **Website**

[4] The cause of COVID 19 disease

1.4 ***"The dose makes the poison"*** **and SARs-CoV2 infectious dose zone**

Every day we make judgements based on risk. With medicines for instance, we read the instructions and take enough to ease our symptoms but not too much so as to cause bad side-effects. Two paracetamols (500 milligrams/per tablet) may ease our headache or maybe we need four or six or eight over the day if we have a migraine. If the migraine continues over several days, we may take up to eight paracetamol every day. If you took a week's dose[5] of paracetamol in one go it would be fatal. Spread over a week it isn't[6].

We are **all** following the old rubric that, *"The dose makes the poison"*. We apply the same idea to, for instance, alcoholic drinks and some foods.

The whole of the applied science of occupational hygiene, indeed all medical sciences and the science of toxicology are founded on the same idea, that if exposure to a contaminant/drug is insignificant (however that's defined) then it follows that the risk is also insignificant,

> *"The dose* (does) *make the poison".*

The problem with the new virus SARS-COV-2 (which causes Covid 19) is defining what is an insignificant exposure zone and therefore exactly what exposure controls are needed to get exposure below this zone.

What dose of SARS-COV-2 is required to cause an infection in man?

Virologists use the term HID50 (human infectious dose 50%) to indicate the dose of virus which will cause illness / infection in 50% of persons exposed to the dose. Another, looser, term is MID (minimum infectious dose).

There are several estimates of the HID50 for SARS-COV-2 which are in the range 100-1000 virions. This is provisional and experimental work in human volunteers will soon provide better data. The influence of the route of administration is, as yet, unknown.

Influenza and the common cold have been studied more intensively and the HID50 does depend on the route of administration and the strain of virus

- For flu HID50s can be anything from 3500 – 10,000,000 viral particles by nasal administration
- But by aerosol administration it can be much lower about three-fold
- For the Common cold (Rhinoviruses) from 10 - ~700,000 virus particles.
- And for noroviruses (the one's that cause Winter Vomiting) apparently only one virus particle can set off a full-blown infection.

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[5] For a week the paracetamol dose would be (8 X 7 X 500) 56 tablets or 28 grams of paracetamol.

[6] Although anyone with a migraine which lasts a week would be well advised to see their GP if they were driven to take this amount of paracetamol

(Yezli and Otter, 2011 **link**).

For SARs-COV-2 virus some tissue culture work recently reported suggests the HID50 lies between 300 – 650 SARS-COV-2 viral particles (Tang et al 2020 **link**). This is in the same ball-park as the estimate from the Science Media Centre[7] (SMC) 26th March 2020 **Link**[8], about a year ago. See also Nature 23.3.21 **link** Royal Free 25.3.21 **link** and The Lancet 15.4.21 **link**.

If we can keep exposure to SARS-COV-2 well below the Infectious Dose Zone (IDZ loosely the amount of virus to cause illness) then we can probably stay reasonably safe (see Figure 6). Which thinking leads to a critical point:

> One SARS-COV-2 virus **cannot,** in all but extraordinary circumstances cause COVID 19 infection i.e. **We can be exposed to some small number of SARS-COV-2 viruses** and yet **not be put at meaningful practical risk**.
>
> One viable SARS-COV-2 virus particle **does not normally**, *"…make the poison".*

1.5 Science problems as jigsaw puzzles

> *"The variability of transmission among respiratory pathogens appears to be less dependent on the physical particle size emitted by the diseased person…but more by biological factors such as the size of the emitted inoculum, the ability of the pathogen to survive desiccation and other stresses on aerosolisation and air transport, and environmental factors such as air movement, temperature and humidity, and host defences".* Fennelly 24th July 2020 **link**

Different sciences offer different insights and understandings of the world. The applied science of occupational hygiene offers unique, useful, additional understanding of exposure and what can be done to limit the spread of, and danger from, SARS-COV-2 virus.

Working out what is going on, and what to do about SARS-COV-2 virus, is a bit like trying to complete a jigsaw puzzle without the picture on the lid.

Each science involved helps complete a bit of the puzzle. Over time the picture becomes clearer. The problem is, if the urgent practical problems to work out are, that there a lot of times, the picture/puzzle solution is bit hazy but recommendations have to be made. The US National Academies of Sciences, Engineering and Medicine came to a similar conclusion about the need for multi-science problems needing many sciences working together:

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[7] That I used in Version 1 of this guidance 11th January 2021

[8] The SARS-COV-2 virus is evolving, and different variants are appearing but all of them will have a IDZ. For some this will be lower than the original SARS-COV-2 variant. In future pandemics perhaps it will be possible to model or predict how the "spike proteins" (and other virus properties) that affect how it's transmitted through the air or via surfaces change the infectiousness IDZ of a virus? For instance, there was something about the virus properties of the Spanish Flue which hit humankind in 1918 that meant that it could infect the lower lungs SARs-CoV-2 clearly transmits differently. At a guess it would seem that the 1918 Spanish Flu virus could survive drying out better than SARS-COV-2 which allowed transmission into the deep lung.

"These questions and more (about SARS-COV-2 transmission, meant) *that* (the Academies) *convened* ***experts in aerosol science and atmospheric chemistry, building engineering, epidemiology,, environmental health, infectious disease, pulmonary medicine, public health and virology****…"* from *"Droplets versus aerosols during coughing and talking"* **Link**

The need for and strengths of seeing problems to be solved by sciences (in the plural) rather than *"Science"* (singular) is further discussed in sub-section 5.3 and Appendix 3.

1.6 *"And now relax…"*

Being on-edge and fearful all the time grinds us down, affects our mental health and may stop us thinking clearly. It is difficult, if not impossible, to stand back and get some perspective when you are chronically frightened. These Notes explain how and why the SARS-COV-2 exposure control measures work and it is OK to have confidence that they **do** work. Enabling you to do what you need to do to control the COVID 19 risk. To relax and get on with your work and social life. To be a bit less fearful, more relaxed and more social. At a societal level, if we can have confidence in the exposure control measures, we all use, we can then better balance the risks from SARS-COV-2 and other risks we, as a society face. Risks such as delayed cancer operations[9], or joblessness, or lost educational opportunities, or the mental health challenges[10] that chronic fear can cause amongst adults, young people, and children.

1.7. Some policy implications

These Notes spell out what exposure control measures are needed and make it clear that some measures are unnecessarily strict. For instance, physical distancing outside could be reduced to 1.0 metre safely allowing more people to attend weddings, christenings, funerals and other outdoor events. If all the people attending a funeral are vaccinated and stick to the 1.0 metre rule, then it's more-or-less completely safe. The need to routinely clean all touched surfaces and regard the surface-skin-face pathway as significant could be eased. Likewise, the requirement of some organisations, for instance, not to touch pens used by other people.

There is a tendency in a rules-based risk control system for rules to accrete when, if possible, rules should be rank-ordered and perhaps some explicitly dropped when it's clear that they really aren't needed or their ranking has changed. Difficult to do but it makes the remaining rules more credible and likely to be followed.

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[9] See, for instance, this recent report by Macmillan cancer charity potential cancer-deaths and suicides link

[10] This is an extract from a FB Message *"…a summer lockdown was bad for people… with mental health, a winter one may well be …worse…The relapse and overdose rate has increased by 30% since March 2020 … the pandemic are especially hard for people with depression* **link** . Resources include - Samaritans **link** and recently set-up Shout **link**.

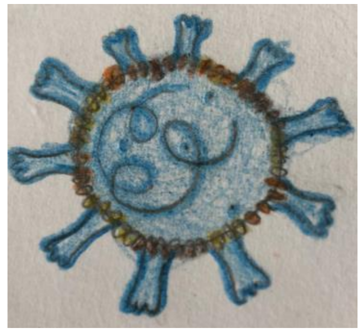
2.0 Viruses

Respiratory viruses cannot move by themselves, they need to be transported usually in saliva droplets. Even if these saliva droplets start out quite big all droplets rapidly dry out (in less than 3 seconds) and become a 'smoke' of dry virus-containing particles

2.1 Key virus properties

1. They cannot move by themselves.
2. They can only multiply inside a living cell
3. They are transported to another living cell in bodily fluids such as saliva or blood or faeces.
4. Usually, they are carried in droplets of saliva.
5. They don't survive long on some surfaces (e.g. copper) especially if the surface is exposed to bright sunlight.
6. They can survive for hours or even days on some surfaces (e.g. cardboard).
7. They are damaged, but not completely, when the droplets, in which they are being transported dry out.
8. The amount of damage caused by desiccation varies from virus to virus **link**
9. All but the largest airborne droplets dry out within a few seconds to become truly airborne. They move within the air in which they are suspended
10. Truly airborne droplets-particles travel suspended in the air
11. Whether by rapid drying of airborne droplets, bright sunlight, or hand cleaning, viruses are relatively easily disabled and made unviable (unable to reproduce).
12. Viruses are relatively easily destroyed by soapy water or hand-cleanser.
13. All viruses have an infectious dose zone (IDZ). Sometimes it appears to be as low as one virus particle (Norovirus, the cause of the so-called Winter Vomiting Bug). For SARs-CoV-2 it's probably great than 100 virus particles or maybe more than 100 (see sub-section 1.4)

3.0 Droplet/particle generation, travel, landing-sites and infectivity



This sub-section is probably the most complex in these Basic Notes. So, by way of a bit of light relief here's something light-hearted but, in its own way, serious.

3.1 "*Coughs and Sneezes spread diseases"*

Tony Hancock (the comedian) sung ***"Coughs and Sneezes spread diseases"*** **link** how to stop the spread of the Common Cold virus (see Appendix 1 for more detail).

SARs-CoV-2 virus spreads in a similar, but not exactly the same way to the Common Cold virus and exposure control measures are therefore similar, but not exactly the same.

3.2 The Wells diagram/curve (1934)[11]

The Wells diagram/curve (Figure 1) seems to have been almost forgotten about by microbiologists and public health scientists. Yet it's critical to understanding how SARs-CoV-2 spreads and infects people.

This is what Wikipedia says:

> *The Wells curve …is a diagram, developed by WF Wells in 1934, which describes* what he thought might happen to small droplets once they have been *exhaled… (from) coughing, sneezing, and other violent exhalations (which) produce high numbers of respiratory droplets derived from saliva and/or respiratory mucus, with sizes ranging from about 1 µm to 2 mm.*
>
> *Wells' non-experimental guesses included that such droplets have* ***two distinct fates****, depending on their sizes.*
>
> 1. *The interplay of gravity and evaporation means that droplets larger than a humidity-determined threshold size might fall to the ground due to gravity,*
>
> 2. *while droplets smaller than this size quickly evaporate, leaving a dry residue that drifts in the air.*
>
>   *Since droplets from an infected person may contain infectious bacteria or viruses, these processes influence transmission of respiratory diseases".* **link**

[11] See Wiki reference to the "Wells Curve" here **link** and this WHO text on ventilation **link**

There is a lot of information and ideas in the Wells Curve/Diagram and it takes some time to work out all the things it's 'saying'. No doubt there are more to be found and used.

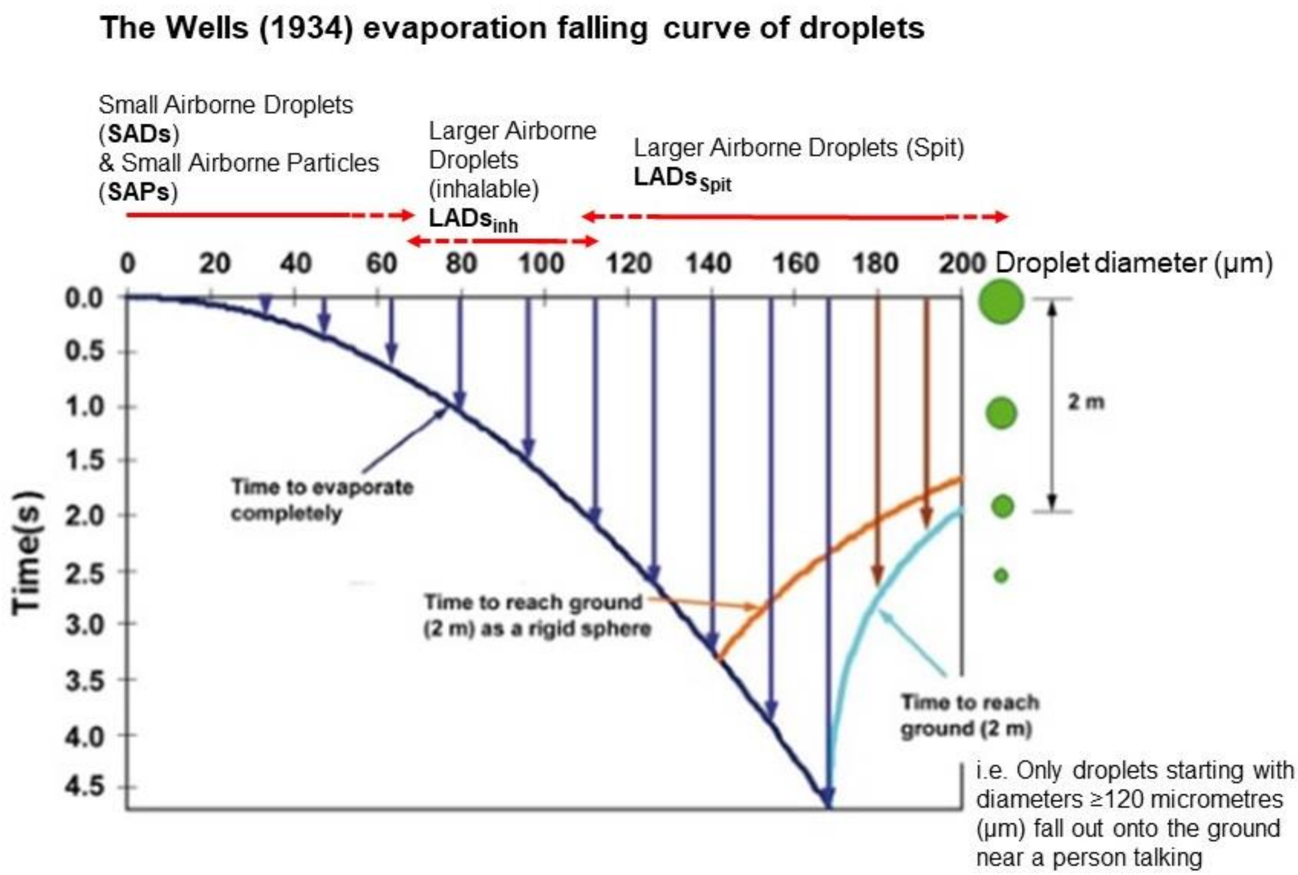


Figure 1 The Wells diagram (1934) link and link

3.2 Key Messages of the Wells Diagram and these Basic Notes (Version 2)

3.3a Dimensions of Droplets/Particles

Using the Wells diagram, it is roughly possible to bracket the approximate dimensions of four 'types' of droplet/particle and where they land on the body/ground and respiratory tract. The

Four 'types' are:

1. Larger Airborne Droplets (Spit) $LADs_{spit}$,
2. Larger Airborne Droplets (inhalable) $LADs_{inh}$,
3. Small Airborne Droplets (SADs)
4. And Small Airborne Particles (SAPs)

Their rough dimensions are included in the Wells Diagram and in Table 1 below.

Table 1 Dimensions of Droplets/Particles		
Droplet/Particle	**Droplet/particle dimensions (approx)** **in (micrometres) µm Wells Diagram (1934)**	**Where do Droplets & particles land?**
Larger Airborne Droplets (Spit) **$LADs_{Spit}$**	≥ 110 – Several hundred µm	Eyes, nose and perhaps the mouth
Larger Airborne Droplets (inhalable) **$LADs_{inh}$**	>70 to ≤ 110 - 120µm	Nose and throat and tracheo-bronchial region
Small Airborne Droplets **(SADs)** & Small Airborne Particles **(SAPs)**	>0.0 to ≤ 70µm	Alveolar region

a1 **Only the largest projectile spit droplets and** ($LADs_{spit}$) land near i.e. about 2 metres or less (within 2 -3 seconds) from someone talking, singing, shouting or coughing (Figure 2 for $LADs_{inh}$ also see Figure 2a; what might be called in occupational hygiene parlance (*"Near Field"*[12])

a2 **Within 1 second all small airborne droplets** (SADs) have evaporated to dryness. SADs rapidly become small airborne particles (SAPs) or *"condensation nuclei"* (Figure 2b)

a3 **All SADs, SAPs and $LADs_{inh}$** are fully airborne i.e. they have little-or-no momentum of their own separate from the parcel of air into which they were first released (Figure 2b). What might be called *"Far Field".*

[12] The terms *"Far-Field"* and "*Near Field"* are used in occupational hygiene to describe the human breathing-zone and where the personal sampling head should be located ((~30 centimetres from the nose/mouth). Far-field is any sampling position not in the Near-field (i.e. >30 centimetres)

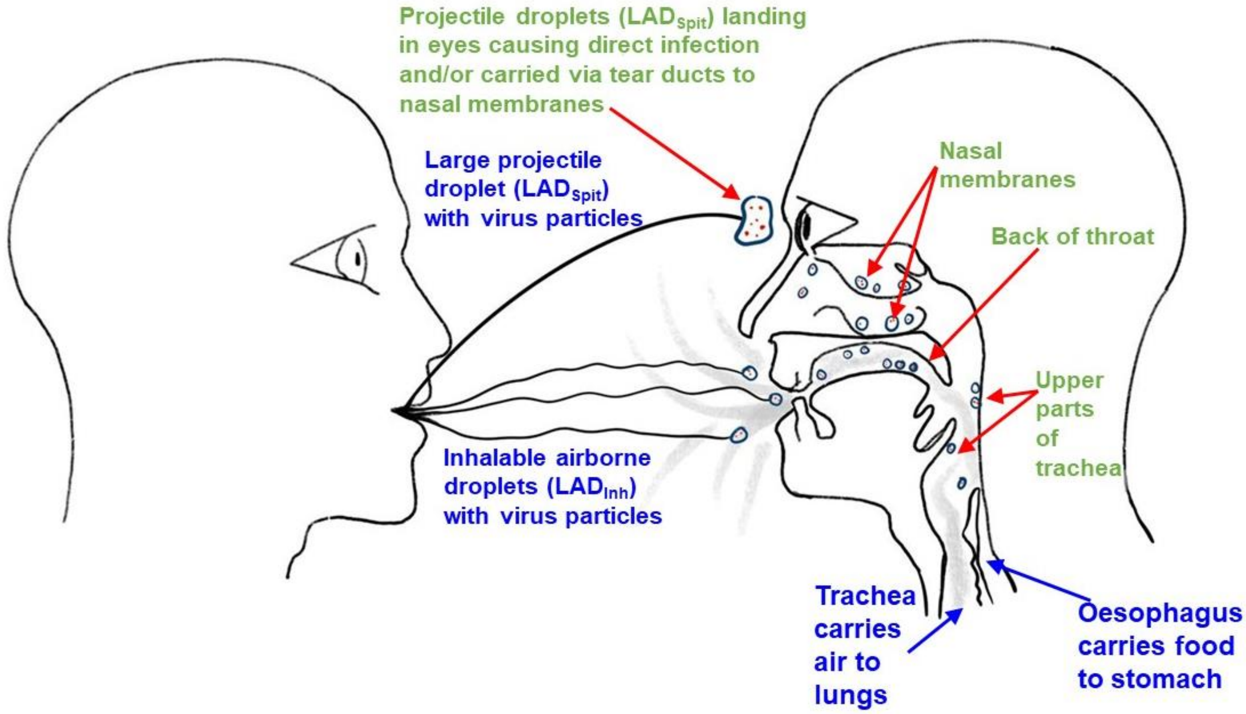
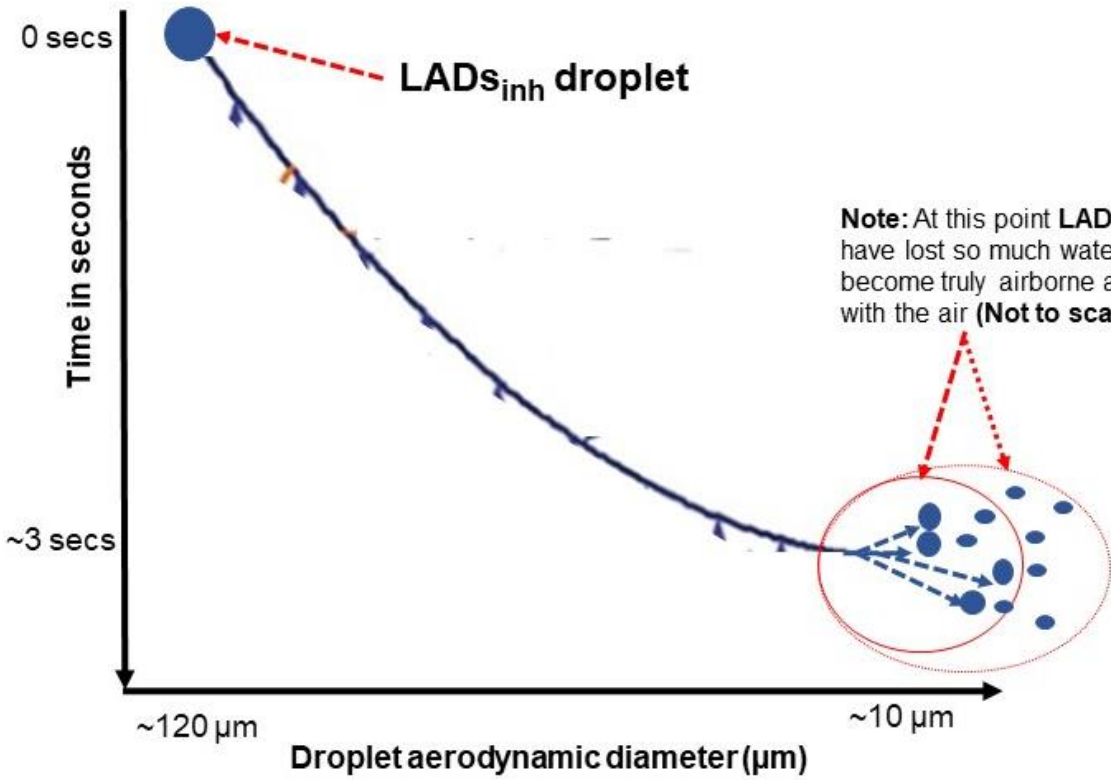


***Figure 2** **Main landing sites of inhalable airborne (**LAD$_{inh}$**) and projectile droplets (LAD$_{spit}$)** Note: Smaller airborne droplets (SADs) and Smaller airborne Particles (SAPs) not shown. When very close (maybe less than 25 centimetres) and, e.g. talking, wet flying spit droplets can land on someone's face. When singing wet flying spit droplets probably travel further. Whether created by talking or singing the very large flying spit droplets LAD$_{spit}$ can land on the eyes. From here the SARS-COV-2 viruses can infect the eyeball directly or be carried to the nasal membranes via the tear-ducts. The largest (still wet) inhalable airborne droplets can be inhaled and most land on the nasal membranes, back of the throat and top of the trachea (wind-pipe).*

Figure 2a
Falling trajectory of Larger Airborne Droplets (inhalable) i.e. $LADs_{inh}$ adapted from The Wells Diagram/ Curve



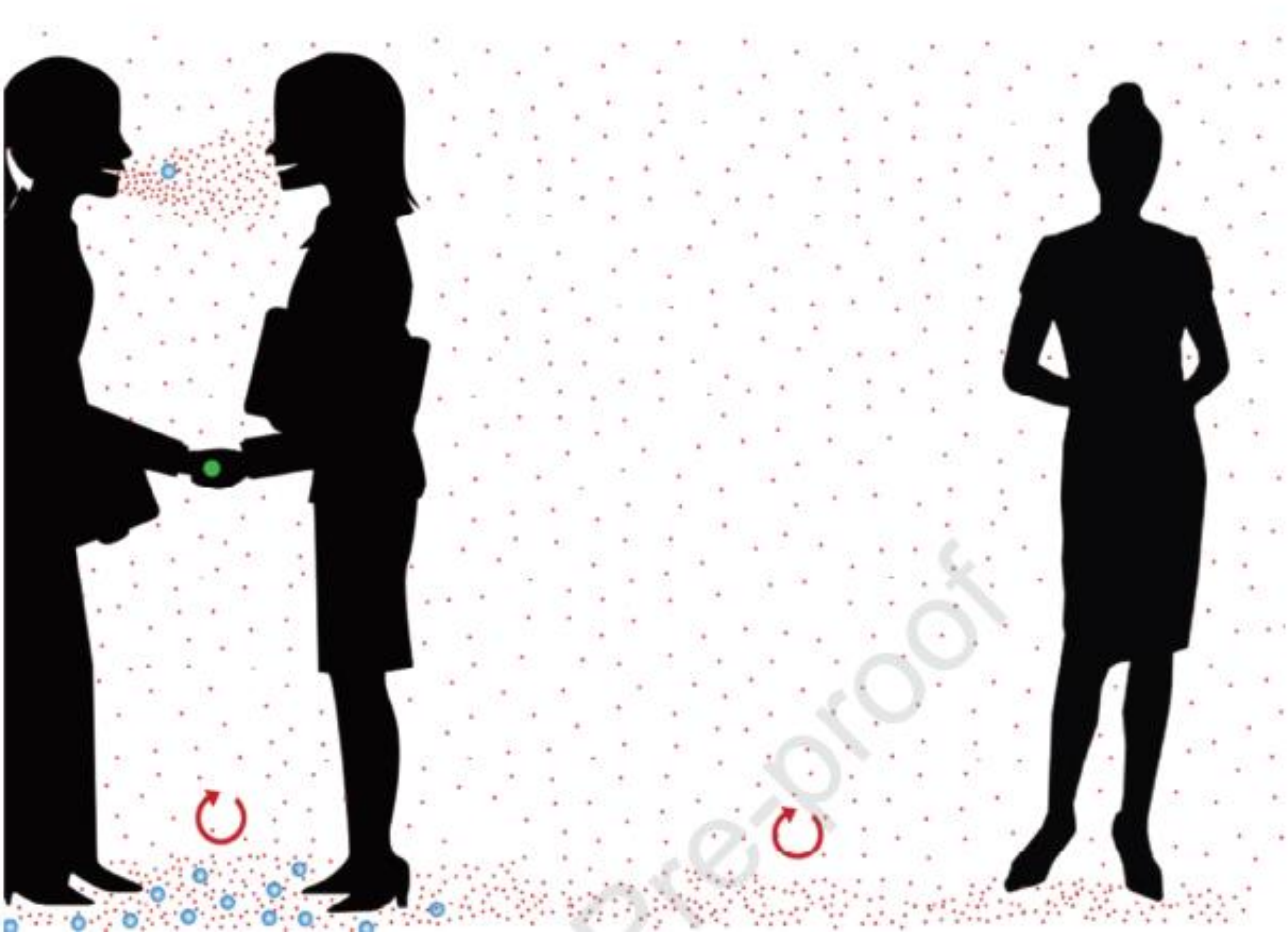


Figure 2b *Shows* **"…the range of respiratory particles and potential spread over distance"** *Tang et al 13th January 2021* ***link****.* Figure 2a covers the four pathways in less detail but reinforces two critical points:

1. That being physically close, talking, not wearing a facemask, is risky
2. Transmission, via SADs and SAPs can occur at a distance (this is the third transmission pathway)

3.3b Droplet/particle generation

Airborne droplet creation requires generating mechanisms. In human beings there are four common mechanisms.

Four common human droplet/particle generating mechanisms:

1. When our vocal cords vibrate when we talk, sing or shout.
2. When we move our tongue, mouth and lips droplets are created

3. When we cough or sneeze. When this happens air 'explosively' erupts from our lungs and throat and the turbulent 'air-blast' creates droplets.
4. When the small bronchioles leading to the alveoli inflate and collapse on each breath[13]. This action generates ultrafine[14] airborne droplets/particles. These move almost like a gas and hardly settle

1 The first two mechanisms and the fourth probably account for the reported size distribution of airborne droplets/particles **Link**.

2 The vibrating moving lips and tongue generating the larger droplets and the vibrating vocal cords and the collapsing/inflating bronchioles the sub-micrometre (ultrafine) airborne droplets.

3 The tongue, lips and mouth also create the flying spit droplets (LAD_{spit})

4 The evidence of SARS-COV-2 viral RNA detected in the breath of people simply breathing is almost certainly the ultrafine droplets/particles. **Note:** It's worth noting that while SARS-COV-2 RNA is detectable the ultrafine airborne droplets behave almost like a gas and do not easily land on surfaces including the respiratory tract. In the context of smoking they are of interest[15].

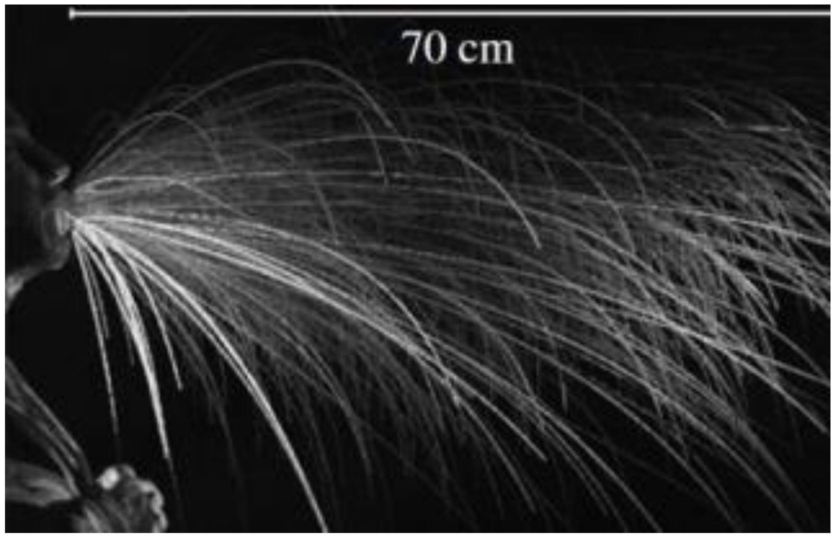


Figure 3 Large flying (projectile) spit droplets (LAD_{spit}) fall in a flying (ballistic) curve towards the ground after being emitted from the mouth. Most fall-out of the air close to us. They land still-wet on surfaces including the face of someone very close by – See also Figures 1 & 1a (Taken from Brosseau et al (2020) **link**)

3.3c Breath-Air *("Respiratory plume")*

***"Breath-air"* description**

The *"Proceedings of a Workshop: Airborne Transmission of SARS-COV-2 "* **Link** refer to breath-air as *"respiratory plumes"* but the terms mean, and refer to, the same thing.

Apart from when we deliberately blow out air, such as when we blow out the

Dramatically positive effect of wearing a face-mask

Small low-powered puffing 'steam engine'

Smaller low-powered wispy puffing 'Roman Candle'

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[13] See Fennelly June 2020 **here**

[14] Less than a micrometre in aerodynamic diameter

[15] A smoker's breath is full of such ultrafine airborne particles which can be smelt on their breath for sometime after they've stubbed out the cigarette.

candles on our birthday cake, our breath-air air puffs gently out of our mouths as if we were little low-powered puffing steam engines. Our breath-air puffs when we speak, sing, laugh or cry.

The range of *"breath-air"* is very limited. The air in the puffs moves fairly slowly and a face-mask dramatically reduces the distance the breath-air travels.

See the excellent video link in Figure 4 and Tables App 1 and Summary Table App 2 and the detail of the breathing, speaking and singing tests in Appendix 2.

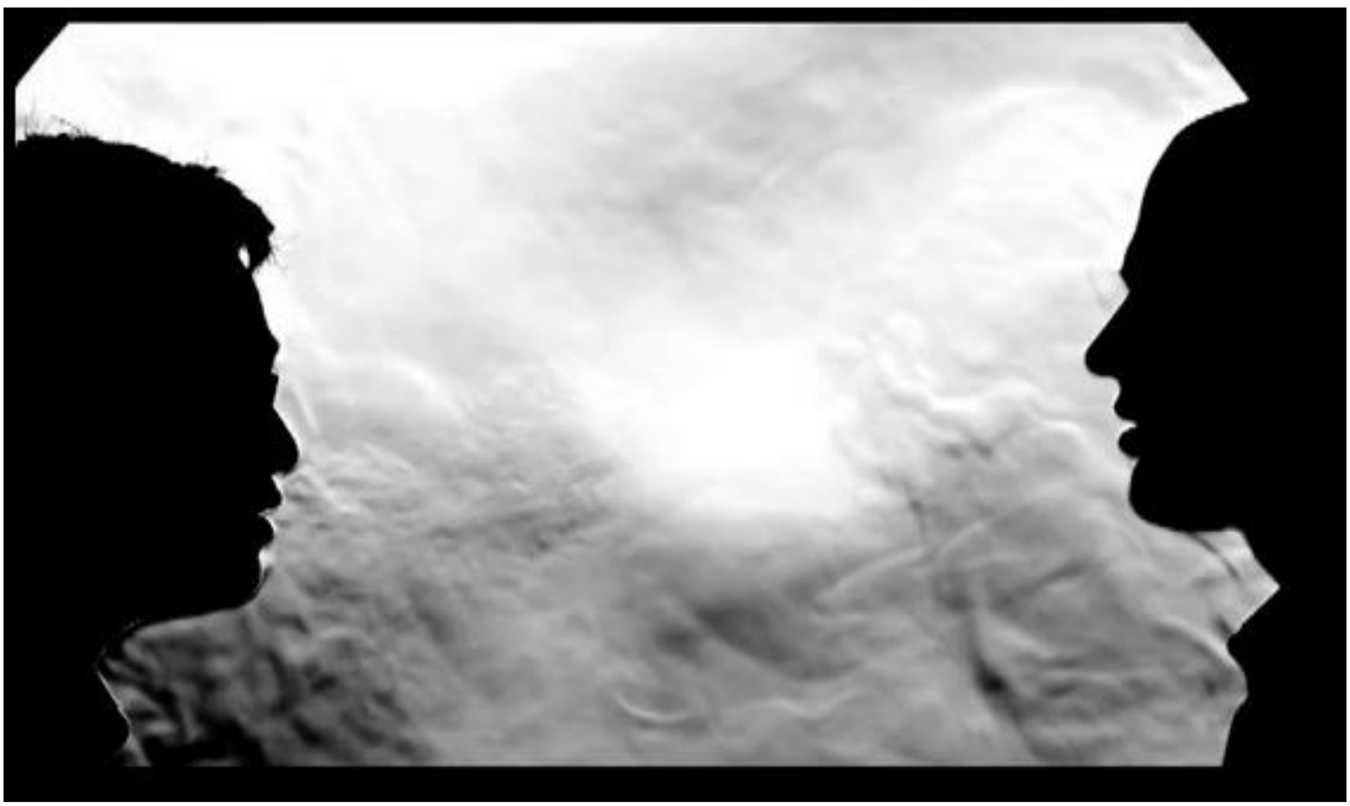


Figure 4 Talking breath-air range (photo) in quiet room air. Schlieren still-photo shows talking breath-air shape and range. This shows up best in the video **link**

Breath-air carries the airborne droplets/particles

1. Airborne droplets and particles (LAD_{inh},SADs and SAPs) are carried suspended in our breath-air
2. We puff out our breath-air like small low-powered puffing steam engines
3. You can measure your own breath-air range (See simple DIY test in Table 1) and see breath-air ranges illustrated in Appendix 2 Tables 5a, 5b and 5c. Talking breath-air range (in poor ventilation) is about 50 centimetres

4. All breath-air ranges fall to 1 – 2 centimetres if you wear a face-mask – see Tables 3a, 3b and 3c) and Appendix 2 Summary Table 4. We all become gently smoking 'Roman Candles'.

3.3d Droplet-Particle travel

1 Flying spit droplet $\mathbf{LAD_{spit}}$ release and spread

Spit droplets (**$\mathbf{LAD_{spit}}$**) are projectile droplets, created by the movement of the tongue and lips they fly out of our mouths and quickly land on nearby surfaces including sometimes the face of someone we're talking to, (see Figure 2 and 2a). The LAD_{spit} droplets lose water as they fly falling through the air. There's enough water in them to mean that they are still wet when they hit nearby skin/surfaces. This wetness probably means that the viability of the viral particles being carried is maintained.

2 **Airborne droplets ($\mathbf{LAD_{inh}}$, SADs and SAPs) travel in and with the *"breath-air"***

Separate from flying spit-droplets (LAD_{spit}) all other droplets/particles (LAD_{inh}, SADs and SAPs) are, what might be called, **truly airborne.** They flow out of our mouths and noses suspended in the "breath-air" and move and travel with the parcels of air in which they are suspended

The larger airborne droplets ($LADs_{inh}$) and the smaller airborne droplets (SADs) have so little mass they do not move independent of the "breath-air". They move in the parcels of air into which they are released. The larger LAD_{inh} (see Table 1)are, for the first seconds of their existence partially projectile (Figure 1 Wells' Diagram)

3.3e Droplet-Particle main tissue landing sites

$\mathbf{LAD_{spit}}$

$\mathbf{LAD_{spit}}$ can land on the faces of people being talked to. If they land in someone's eye they may cause COVID 19 infection directly to and through the eyeball. Another route is where the LAD_{spit}, together with its viral load, is swept by the tear film onto the nasal membranes (Figure 2). This is how the protective effect of wearing glasses works. They stop LAD_{spit} (or inhibit) landing in the glass-wearers eyes (**link** and **link**)

$\mathbf{LAD_{inh}}$ can LAD_{inh} if the person you are speaking to is close-by (about 25 centimetres) probably the majority of the LAD_{inh} land in the listeners nose and throat. Some of the smaller LAD_{inh} will become SADs and land further down the respiratory tract probably mainly in the trachea-bronchial region.

SADs and SAPs can land anywhere in the respiratory tract. The majority will land in the lower lung airways including the alveoli (air-sacs).

3.3f Droplet/particle infectivity

Ultrafine[16] airborne particles are unlikely, in most circumstances, to deliver SARs-CoV-2 viruses above the IDZ. Although laboured breathing, during for instance running, is highly likely to create more than just ultrafine airborne particles. In which case runners should pass others at a good physical distance.

And, of course, sneezing generates huge quantities of SADs and SAPs and does lead to SARS-COV-2 infection as Figure 3 shows how our breath-air jet carries all airborne droplets and particles (SADs, SAPs and LAD_{inh} and LAD_{spit}) further than 2 metres. Probably at least 3 metres and maybe further.

SARS-COV-2 viral infection can occur via the arrival of all four sizes of droplet/particle (LAD_{spit}, LAD_{inh}, SADs and SAPs).

The chances of a large dose of SARS-COV-2 virus being delivered to a small area of respiratory tract (RT) tissue is greater if the airborne droplet started off as a LAD_{spit} or $LAD_{inh,}$. Why would this be?

For two reasons:

1. LAD_{spit} and LAD_{inh} have a larger volume than SADs and SAPs and **can carry** more SARS-COV-2 particles
2. LAD_{spit} and LAD_{inh} dry out slower than SADs and SAPs so it's likely that their load of SARS-COV-2 viruses stay viable longer

[16] Very crudely – less than 1 micrometre (um, = 1 millionth of a metre) in aerodynamic diameter

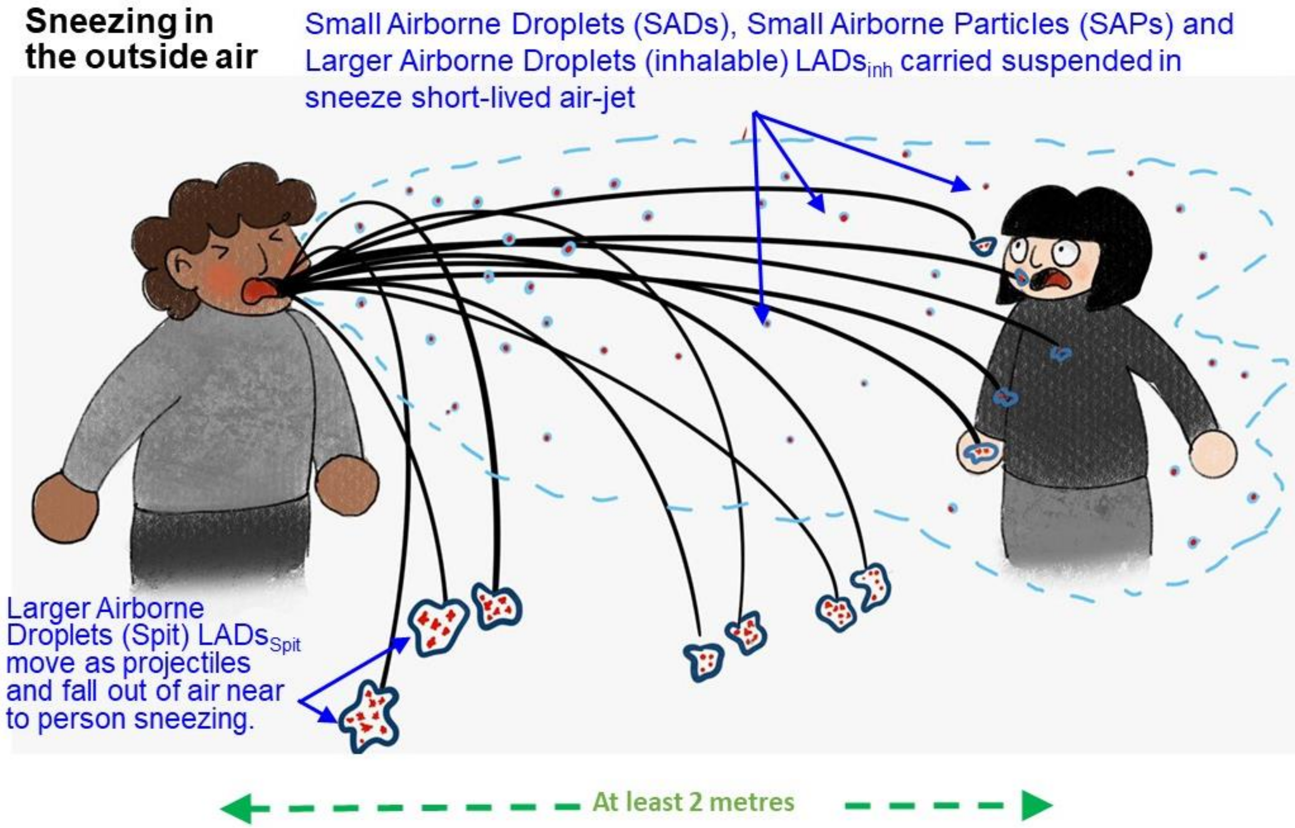


Figure 3 Sneezing

3.3g Rank Order of infectivity

Put simply there is a rank-order to droplet-particle infectivity:

1. Smaller Airborne Droplets (SADs) and Smaller Airborne Particles (SAPs) – Main vehicle for SARs-CoV-2 transmission i.e. the main infection pathway (*"Far-field"*).
2. Larger Airborne Droplets both LAD_{spit} and LAD_{inh} - Far less important in SARs-CoV-2 transmission i.e. a secondary infection pathway (*"Near-field"*)
3. Direct skin-contact with contaminated surfaces with transfer to face or (perhaps) food – Highly unlikely to lead to SARs-CoV-2 transmission i.e. By far-and-away the least important pathway.

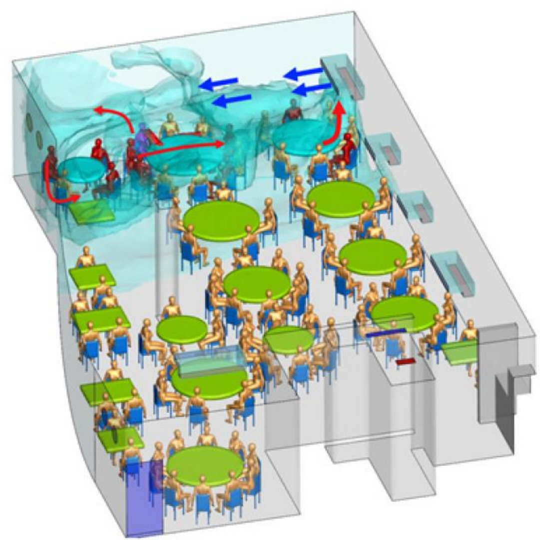
4.0 SAR-COV-2 virus exposure control measures[17]

4.1 Breath-air and ventilation

LADs$_{inh}$ and SADs and SAPs are carried, suspended in "breath-air". They spread in the "breath-air" which flows and mixes with the surrounding air. The mixing dilutes the airborne droplet/particle numbers. How rapidly (time) and how far (distance) can be divided into two questions:

i. *"How **rapidly** is the "breath-air" diluted* before mixing reduces the SARs-COV-2 numbers below the IDZ*?"*
ii. *"How **far** does the "breath-air" travel before mixing with clean air* reduces the SARs-COV-2 numbers below the IDZ

4.2. Ventilation and ***"Super-spreading"*** events



All of the *"super-spreading"* events have happened indoors in places with poor dilution and dispersion of the room air or where the ventilation simply recirculates stagnant air in a restricted area of a room (see *"Proceedings of a Workshop: Airborne Transmission of SARS-COV-2 "* **Link**)**.** People's breath-air 'smoke' wasn't diluted enough and airborne viable SARS-COV-2 virus concentrations rose to and exceeded the IDZ and some people got COVID-19.

The "super-spreading" events indicate that it's vital that people's breath-air 'smoke' is well diluted and dispersed. This is much more easily achieved if everyone is wearing a face-mask or face shield.

Breath-air dilution and travel

Dramatically positive effect of wearing a face-mask

Small low-powered puffing 'steam engine' — Smaller low-powered wispy puffing 'Roman Candle'

Given our size our breath-air volume is small, for adults (between 600 millilitres in men and 500 millilitres in women[18]) and even smaller for children, about 250 millilitres. We really are, in effect, small steam engines puffing out our breath-air. Outdoors these small 'puffs'

[17] These Basic Notes do not cover the ins-and-outs of vaccination except to say everyone should be vaccinated
[18] Called the *"tidal volume"* – the amount of air we inhale and exhale at rest

of breath-air are diluted in fresh air as are the airborne droplets/particles being carried in the 'puffs'.

4.3. Ventilation is a critical control layer

Figure 6 shows what happens to physical separation distances and exposure times assuming the Infectious Dose Zone (IDZ) spans a certain range.

Note: In practice the IDZ doesn't have hard top and bottom boundaries and peters out at both the top and bottom of the IDZ range for a host of reasons.

Figure 6 Physical distances (and times) to get below different Infectious Dose Zone values

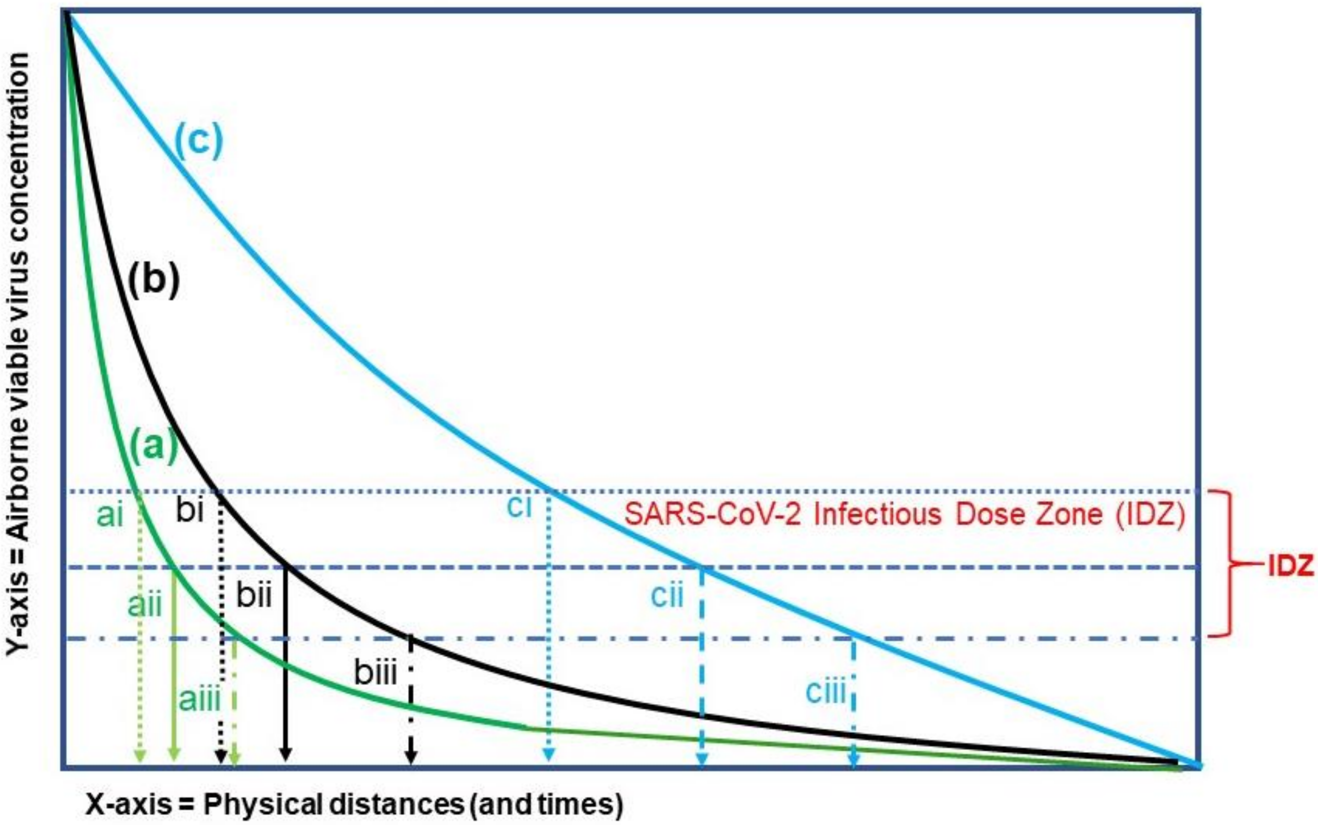


Figure 6 has three curves, one **green** labelled "Curve a", another in **black** labelled "Curve b" and a third labelled "Curve c" in **blue**.

a. ai, bi and ci represent the top of the IDZ
b. aii, bii and cii represent the middle of the IDZ
c. aiii, biii and ciii represent the bottom of the IDZ

But these are all conceptual approximations see the **Note** above Figure 6

In Figure 6

1. **"Curve a"** falls steeply and then slowly approaches zero on the distance x-axis.
2. **"Curve b"** falls less steeply but eventually approaches zero at the same point as **"Curve a"** on the distance x-axis.
3. **"Curve c"** falls even slower and eventually approaches zero on the distance x-axis.

"Curve a" shows that in well ventilated spaces it takes shortest time for SARS-COV-2 viable virus concentration to fall below the IDZ and the necessary physical separation distances are the smallest.

"Curve b" shows what happens in some of the better, fairly effectively ventilated, indoor spaces. That it takes longer for the SARS-COV-2 viable virus concentration to fall below SARS-COV-2 IDZ and the physical separation distances are smaller than for **"Curve a".**

"Curve c" shows what happens to airborne viable virus concentration in poor-ventilated spaces. It shows how slowly the SARS-COV-2 virus concentration falls below the SARS-COV-2 IDZ and how large the physical separation distances need to be.

But, a very important exposure control point is that, however effective or ineffective the ventilation is, viable virus concentration fall below SARS-COV-2 IDZ **eventually**.

The curves and three different points on the X-axis (i, ii and ii) showing the top, middle and bottom of the IDZ really punch home the critical part of the graphs that;

a. Outdoor spaces increase the effectiveness of separation distances (and exposure times) dramatically.
b. Indoor well-ventilated spaces are less effective than being Outdoors.
c. Indoor poorly-ventilated spaces are less effective than being indoors in well-ventilated spaces.

The conclusions from Figure 6 are clear:

1. There's a rank order of ventilation effectiveness from outdoors to indoors (well-ventilated) to indoors (poorly ventilated).
2. Even in poorly-ventilated spaces the physical separation distances (and exposure times) are finite. They span ranges but none of them are zero.

4.3a Outdoors

The most effective dilution and dispersal of breath-air occurs outdoors. Outside air is in constant large-scale movement. Ideal for dilution and dispersal of breath-air 'smoke'. Even a slight wind will rapidly dilute and disperse our breath-air 'smoke' (See **"Curve a"** in Figure 6)

4.3b Large well-ventilated spaces

Next in terms of effective dilution and dispersal, comes large well-ventilated spaces (e.g. supermarkets). The volume and external surface area of large rooms tends to lead to greater air-infiltration and dilution ventilation compared to a small room.

Apart from greater air infiltration the air in large rooms, such as supermarkets, is kept in constant turbulent motion by air conditioning fans and all the fans in open-fronted food chillers and freezers. Ventilation effectiveness in such well-ventilated rooms probably looks like **"Curve b"** in Figure 6.

4.3c Poorly-ventilated spaces

Last but not least comes poorly ventilated spaces (**"Curve c"**) which tend to be physically small (hence less air-infiltration) and, if fresh air and air movement are not well planned and executed, result in the need for the greatest physical separation distances (and exposure times).

4.4 Defining reasonable ventilation

Reasonable (effective) ventilation is key and is coupled with other exposure control measures including facemasks, barriers between check-outs (in supermarkets and similar places) and physical distancing. With all these exposure control measures in place the chances that breathing-air 'smoke' from a COVID-19 infected person reaches and stays above the SARS-COV-2 IDZ is small.

Defining *"reasonable ventilation"* is difficult. Outside air is the benchmark. Inside ventilation will dilute and disperse breath-air 'smoke' less effectively but in many cases is probably good enough. Any airborne droplets carrying SARS-COV-2 viruses are diluted to the point where they cannot deliver SARS-COV-2 numbers greater than IDZ.

1. Our puffing staccato breath air is of very limited range so physical distancing works
2. A simple face-mask reduces our breath-air range to almost nothing and significantly reduces airborne droplet/particle emission
3. Reasonable general ventilation dilutes and disperses SARS-COV-2 emitted in our breath-air

4.5 Improving ventilation in rooms[19]

See Appendix 6 for more details of qualitative and quantitative assessment methods.

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[19] Smoke is good but exact measurement is better. The Health and Safety Executive (HSE) used to publish an MDHS (Methods for Determining Hazardous Substances) on using trace gases to empirically measure room ventilation rates. It doesn't seem to be in-print which is a pity as it was useful guidance which I've used myself in the dim-and-distant past.

4.5a. Our bathroom

Using a Concept Engineering machine **link**, I filled our bathroom full of smoke to show the effectiveness of:

1. Poor ventilation (Doors and window closed)
2. Some ventilation (Window open)
3. Better ventilation (Door and window open creating a through draft)

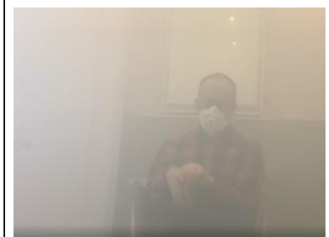
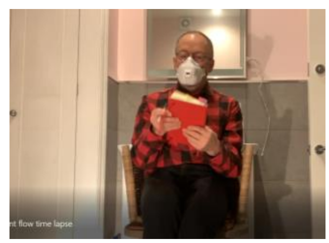
I videoed the smoky air and did time-lapse videos with my iPhone over five minutes for each test.

Table 2 shows stills taken from the videos which summarise the effectiveness of the ventilation improvements to our bathroom.

1. With poor ventilation there is hardly any discernible dilution and dispersal of the smoke.

2. With some ventilation (window open) the smoke is diluted and dispersed quite well but some is still present at the end of the five minutes.

3. With better (through-draft) ventilation, after five minutes, the smoke has been completely diluted and dispersed

Table 2			
Ventilation	**Start**	**~1½ minutes**	**~5 minutes**
1. Poor (Doors and window closed)			
2. Some (Window open)			
3. Better (Door and window open creating a through-draft)			

4.5b. Small rooms

At home or in, for instance, small shops and offices simply opening the windows and/or doors will dilute our breath-air 'smoke'. Creating a through-draft is even more effective. And 'stirring the air with a fan or fans improves mixing and dilution. If the 'stirring' fans filter the air too, so much the better.

4.5c. Face-to-face meetings in fairly large rooms

The risk of SARS-CoV-2 transmission can be minimised by:

a. Having the meeting in a 'fairly'[20] large room
b. Keeping a reasonable physical distance apart (1 – 1½ metres)
c. Arranging through-draught ventilation e.g. open a window/doors either side of the room
d. 'Stirring' the room air with a simple fan or fans (**Note**: It is probably better if at least one of these fans includes a HEPA (High Efficiency Particulate Air) filter[21])

[20] Not sure how to define "fairly large" probably at least 4 by 5 metres i.e. at least 20 square metres

e. Wearing either a face-mask (some transparent face-masks are coming on the market) OR, if the ventilation is reasonable, (e.g. you can feel air flowing from outside on your naked skin (listen to Katy Bennett's song **link**) OR smoke release shows good fresh-air input and mixing) face-shields will probably be god enough
f. Limit the meeting time to, for instance, one hour

4.5d. Ventilation in Moseley (B13 9RN) *"One-Stop Shop"*

This is our local One-Stop shop. All customers wear face-masks.
The doors regularly open as customers come and go. Each time this happens some fresh air enters the shop.
The open-front fridge food chiller units run almost down one side of the shop. The fans in these units 'stir' the shop air creating constant turbulent mixing of the air. These simple (inadvertent) ventilation arrangements, plus the face-masks and physical distancing, make it very unlikely that the SARS-COV-2 IDZ will be exceeded and COVID-19 infection will occur.

I would make only two additional exposure control recommendations to One Stop staff:
a. Open a door or window at the back of the shop to create a through-draught.
b. Turn on the ceiling air conditioning unit fan to increase 'stirring' of the air

4.6 Face-masks[22]

At the start of the COVID-19 pandemic, in the early 2020s, the World Health Organisation (WHO) and UK authorities were not sure that face-masks were much use or were needed. The main emphasis was on surface and skin hygiene. You still see remnants of this emphasis on public transport and elsewhere today.

Since then, the UK (and other national authorities) positions have changed.

Face-masks do, in fact, if worn correctly offer a useful additional layer to exposure control measures. They work in four main direct ways, and another, indirect way, five ways in all:

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[21] Some have suggested using Ultra-Violet (UV) light to sterile air running through ventilation systems. I'm not sure this would have much benefit over and above a HEPA filter as all airborne viruses are carried in droplets/particles. UV sterilisation of surfaces is another thing
[22] The British Standards Institute has a standard in development *"Community Face Coverings - specification"* that can be downloaded for free **here**

1 Face-masks filter air Probably most importantly and perhaps most surprisingly face-masks are quite good at filtering airborne droplets and particles from the air. Particularly the Larger airborne Droplets which are inhalable (LAD_{inh}) and many of the SADs and SAPs.

> *"Masks substantially reduce exhaled respiratory droplets and aerosols* (exhalation source) *from infected wearers and reduce exposure of uninfected wearers to these particles"* 10th February 2021 **link**

Dramatically positive effect of wearing a face-mask

Small low-powered puffing 'steam engine' — Smaller low-powered wispy puffing 'Roman Candle'

2 Face-masks cut breath-air range When we are close together (especially in poorly ventilated places) face-masks turn us from small low-powered steam engines into smaller wispy puffing Roman candles (exhalation sources). The changes in puffing range of our breath air reduces the concentration of airborne droplets/particles we deliver to people close-by[23].

3 Face-masks stop flying spit Face-masks are very good at stopping us emitting flying spit droplets (LAD_{spit}), which can land on nearby surfaces and on people close-by. People we're talking or singing to, Figure 1.

4 Face-masks (may) remind And maybe there is a fourth indirect ways that face-masks help protect. They remind other people, not wearing face-maks to get out their face-mask and put it on.

There's a bit more detail on how face-masks work in sub-section, mainly taken from the recent US Centre for Disease Control (CDC) reference **link**

5 The breath-air range for Blowing is the breath-air benchmark (Table **2**???). All other common human activities have breath-air ranges less than blowing. The breath-air ranges are summarised in Table 3. The detail is in Appendix 1, for quiet breathing (Appendix 1 Table 1a), for talking (Appendix 1 Table 1b) and for singing (Appendix 1 Table 1c).

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[23] The protective effect of face-masks due to their impact on our breath-air range is limited to close-range meetings and is minimal when people are further away, for instance, 2, 3 or 4 metres away in a supermarket

4.7 Source control

In workplaces there is a common hierarchy of exposure control measures[24]. A similar hierarchy can be used for SARS-COV-2 with some critical amendments. These amendments are needed because **we are the source(s)** of airborne contaminant – airborne droplets/particles containing SARS-COV-2 viruses.

In the industrial settings the sources of airborne contaminant are work processes. These may be fixed or mobile, close to workers or far away, strongly emitting or weaker but they are separate from the people involved.

With SARS-COV-2 virus, and other viruses and microbes, we are the sources of airborne contaminant. As sources we move around, there may be one of us or a number. We move through the environment outdoors and indoors always emitting airborne droplets and particles in our breath-air.

Exposure controls[25] start with changing the process to reduce emissions and/or reducing the number of sources. A similar approach works here by the use of face-masks to reduce our source emission rate.

Normally personal protective equipment (PPE) is towards the bottom of the exposure control options hierarchy but, in this case, the rigid application of the hierarchy can be put on one side. Because we are the source(s) of airborne contaminants and face-masks reduce our 'source strength' a lot. Face-masks, it turns out, are critical to effective source control.

4.8 Respirators[26] give more protection than face-masks

a. Well-fitting respirators, designed and manufactured to recognised standards, will provide better protection than facemasks
b. They **could** be used by vulnerable people instead of face-masks and **should** be used by people exposed to huge numbers of smaller airborne droplets (SADs), for instance, health care workers in Intensive Care Units (ITUs) [27].

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[24] Starting with changing the processes to reduce emissions and moving onto controls that are applied to processes and workplaces, such as ventilation (local and general) and behavioural controls which may include the use of personal protective equipment (PPE).

[25] Andy Gillies (see Acknowledgements) brought my attention to **Professor JVT** and his useful acronym CCC+D&V. The professor's idea of risk factors to consider in trying to reduce infection he sums up as ***"three C's plus D and V"*** i.e. (avoid) **C**lose contact with people in **C**ramped indoor environments, **C**rowded with lots of people, (and minimise) **D**uration of exposure and places with high noise **V**olume (meaning people have to raise their voices or shout to be heard

[26] To be called a "respirator" a device has to meet an agreed test standard. These usually rank respirators into 'protection factor' categories which indicate whether the device is likely to reduce exposure by, for instance, 5-times or 10-times or 40-times. Respirator standards vary across the world, but they are comparable. The respirator test standard tests use clouds of small airborne particles (SAPs). Protection against larger airborne droplets ($LADS_{inh}$) by respirators is likely to be greater than the standard 'protection factor' categories suggest.

4.9 Face shields

Face shields stop flying spit droplets (see Figure 1). They are worn by themselves as a substitute for a face-mask. They will not restrict the range of our breath-air as much as a face-mask but they will restrict it. This is likely to be good-enough outdoors and maybe good-enough in well ventilated rooms/shops indoors.

They should **not** be used in poorly ventilated spaces or for prolonged periods by workers in, for instance, offices and supermarkets.

4.10 Physical distancing between people

The graphs in Figure 6 show how important physical distance is as one of the key layers of exposure control

4.11 Physical barriers

Barriers such as the plastic transparent ones now found in shops reduce the range of breath-air 'smoke' not as much as visors and certainly not as much as face-masks but probably reasonably well. They make a useful additional exposure control layer and should be used in combination with other 'layers'

4.12 Summary of SARS-COV-2 exposure control principles The same principles apply to any room at home or in, for instance, an office:

1. **Open window**(s) and/or door(s) to create a through-draught
2. **'Stir' the air** in the space with a fan or fans
3. **Use an air-cleaner** as one of the fans in a small office/room (fan-filter example is not an endorsement) and always have the air-con fresh air input set at maximum
4. **Wear** a face-mask, respirator or face visor, the latter only in very well ventilated areas/spaces
5. **Keep to the** physical **distancing rules**
6. **Limit the number of people** in the space
7. **Put up physical** (transparent) **barriers** to limit breath-air spread
8. **Good surface and skin hygienic** behaviour and management - The surface-skin transmission pathway is far less likely than inhalation of airborne droplets/particles. Even so good surface and skin hygiene are part of the layered SC" exposure control[28].

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[27] Tight-fitting respirators are difficult to wear for a long time. Where high protection factors are needed for length periods people could be supplied with and wear powered air purifying respirators (PAPRs)

[28] Picking up a lot of SARS-COV-2 viral particles from letters and parcels etcetera is an even more unlikely transmission pathway. Nevertheless, it may be worth washing your hands after opening letters and parcels especially if this reduces your anxiety.

(9. Sing Katy Bennett's song! – see lyrics on the Cover page of these Notes and here's the tune **link**)

4.13 Meeting other people safely outdoors and in other well-ventilated spaces

Table 3 covers common things we all do and experience, how to do them safely and why it is safe to do so.

Table 3 Meeting, and passing-by other people safely outside		
Meeting circum-stances	**Advice/ Options**	**Why this approach is relatively low risk**
Passing someone when you are both silent Walking towards someone walking towards you	Smile, walk past the other person at, say, 1.0 – 1.5 metres separation.	If neither of you is talking, your breath-range is up to or less than 50 centimetres. Although you are both emitting ultrafine droplets/particles, they don't settle to any extent and are unlikely to pose infection risk (see main text sub-section 3.1 for a bit of detail) If you're both wearing face-masks, it's highly unlikely you pose a risk to each other, and 1.0 metre distancing should be completely fine. Smile, nod, greet and pass on your way
Passing someone (adult) who is talking Walking towards an adult walking towards you who is talking	Smile, say *"Hi!"* or similar, walk past the other person at, say, 1.0 – 1.5 metres separation. .	Saying *"Hi!"* or *"Good morning"* will produce a puff of breath-air which is rapidly diluted. The chances of you or the other person receiving a the Minimum infectious Dose (MiD) of SARS-COV-2 from such a brief encounter is unlikely
Talking to another adult Meeting a friend and talking to them	Keep at least 1.5 – 2.0 metres apart	Air puffs out of our mouths when we speak as if we're small low-powered small puffing steam engines (See Table 1 for the DIY *"Breath-air"* test and Table 3b for results of talking breath-air range tests) Our voices are very directional and carry a long way. You'll still be able to hear your friend at 1, 2 or more metres so step back a bit if you want. The risk of receiving more than the infectious Dose Zone (IDZ) number of SARS-COV-2 talking outside at least 1.5 – 2.0 metres physical distancing is very unlikely

Table 3 **Meeting, and passing-by other people safely outside**		
Meeting circum-stances	**Advice/ Options**	**Why this approach is relatively low risk**
Passing a small child who is talking Walking towards children (talking intently) who are walking towards you	Smile and try to pass the children with, perhaps, 1.0 metres separation.	Children talking continuously will produce flying spit droplets that fall out of the air below adult head-height. A child's *"breath-air"* volume is about half of an adults[29] and their breath-air range will be smaller too. If we're small low-powered puffing steam-engines then their puffing is even smaller. Their breath-air is diluted rapidly
Singing to another person or in a choir outside	Keep at least 2.0 metres apart	See App 4 Table 3 for the DIY *"Breath-air"* test summary results. There are singing-face-mask designs which stick out from the face. In a choir they should probably be worn if the choir is singing in large(ish) numbers. Just to be on the safe side. 
Someone runs towards and past you	Keep at least 1.0 – 1.5 metres apart	Air flows out of runner's mouth with more momentum than quiet breathing. His/her breath contains ultrafine droplets/particles (see sub-section *"b1 Droplet/particle generation"*). Ultrafine particles don't settle to any extent and are unlikely to pose an infection risk
A friend wants to hug you	This can be done relatively safely if the following applies: (see next column)	1. If you are both wearing effective well-fitted face-masks and you don't speak then it should be **relatively safe** 2. If you are both wearing effective well-fitted respirators and you don't speak then it should be **safe** 3. If you are both wearing effective well-fitted respirators and you've both been fully vaccinated and you don't speak then it should be **more-or-less completely safe** **Please Note[30]: This advice is not sanctioned by the UK government but, for the reasons outlined in these Basic Notes, it should be safe to do this especially if both people have been vaccinated. And are wearing face-masks**

[29] About 250 millilitres compared with about 500 millilitres

[30] The exact degree of risk will depend on several factors including the COVID-19 prevalence, the degree of protection given by a vaccine and a lot of environmental and biological factors

5.0 Final comments

5.1 Breath-air

In Version 1 of these Notes (11th January 2021 **link**) I thought, like many, that projectile droplets (LAD_{spit}) and inhalable airborne (LAD_{inh}) spread the SARS-COV-2 virus more than Smaller airborne droplets (SADs) and Smaller airborne Particles (SAPs), When we are very close (around 25 centimetres) this maybe true (Figure 2)

At distances greater than 25 centimetres the details of exactly which airborne droplets or particles carry how many SARS-COV-2 viruses don't matter as much as how our breath-air is emitted and is diluted. The answer is more subtle and nuanced than I first understood.

Unless we're blowing out the candles on our birthday-cake we don't produce classic air-jets (Appendix 2 Table 3). Our breath-air comes out in staccato puffs when we talk or sing. When we do our breath-air range is about 50 centimetres when talking. And further for singing at about 70 centimetres. This is reduced to 5 to 10 centimetres if we wear a face-mask when talking or singing.

It's now clear that keeping a reasonable physical distance, wearing facemasks or respirators in shops, coupled with effective ventilation reduces the risk very significantly.

5.2 Sciences and the SARS-COV-2 and the COVID-19 jigsaw puzzle

The jigsaw puzzle metaphor, of the relevant sciences working on 'their-bit' of the puzzle that is SARS-COV - COVID 19 works quite well.

Eventually more hard scientific work, in individual sciences and with different combinations of sciences working together, will clearly show the whole picture, on the jigsaw puzzle lid, in crisper detail.

5.2.1 The jigsaw puzzle metaphor also reminds us that to get the full picture of what is going on you need a mix of views, a mix of sciences. A point that was very well made in the US National Academies October Workshop **Link**

> *"The discussants noted that making progress on remaining unknowns will require interdisciplinary research…"* (and some areas covered by different sciences are listed)

And this raises another interesting thought - One person or science cannot 'speak for Science' because the problem demands the input of the relevant sciences (plural). It needs the noisy voices of all the relevant sciences working together and thrashing out a credible reasonably true jigsaw puzzle picture.

The applied science of occupational hygiene does illuminate part of the SARS-COV-2 and COVID 19 jigsaw puzzle and helps particularly with practical exposure control measures.

5.3 Sciences and the next pandemic
There will be another pandemic; that's for sure. When it happens, and governments and others dust-off the old 2020-2021 COVID-19 pandemic plans and actions, the key lesson, the exhortation to put in big shiny letters on the front cover as the US National Academy of Sciences said,

> "(this), *will require interdisciplinary research"*

The governmental job next time is to ensure that the right mix of sciences work noisily together playing to their different strengths, so that the picture on the pandemic jigsaw-puzzle box becomes clear-enough so that practical exposure control measures can be developed and applied as quickly as possible.

5.4 Occupational hygiene and other scientific research needed

In Appendix 4 I've had a stab at some of the multidisciplinary scientific research that's probably needed to prepare us for the next pandemic and also commented a bit on what different sciences bring to the multidisciplinary 'party'.

5.5 Final (final) comments

I hope you find these *"Basic Notes"* (Version 5) make sense and are useful to you. They apply not just in the UK but across the world.

Best wishes and good luck in the pandemic.

Mark Piney
26th April 2021

6.0 Acknowledgements

Thanks to:

- Julie Bellot, Alan McArthur's sister, for the photos of Alan and his nieces and permission to use them.
- Simon Wallis for useful discussions, references and forensic critical thoughts throughout the process of writing *"Basic Notes"* Version 2
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- Adrian Hirst and Alvin Woolley for keeping me going when I thought I was getting nowhere
- Kevin Bampton for gentle consistent support
- Kelvin Williams for raising the critical issue of vehicle ventilation and helping hugely with Appendix 6
- Trevor Ogden for reminding me of all the aerosol-physics I thought I sort of knew but didn't and some key references (via his Facebook Posts)
- Liz Stafford (my wife) for endless care, patience and repeat proof-reading
- Rowena Clayton for her long friendship, deep public health knowledge and our mutual interest in the history and philosophy of science
- Last but not least Emma and Lea Lucor would drew the lovely (almost cuddly) SARS-COV-2 viruses and Figures 2 and 3.

7.0 Dedication to Alan McArthur

These Basic Notes are dedicated to the memory of Alan McArthur[31]

7th March 1971 – 28th February 2018

(3M Technical Supervisor Respiratory Protective Equipment (RPE))

Please donate to **[this fund,]** set up by Alan's colleagues at 3M, in support of Mind, the mental health charity

[31] Alan took his own life on 28th February 2018. He was 47 years old. I knew him quite well and it is a great sadness that I didn't know that he suffered from deep depressive moods. Modern psychotherapies, like Compassion Focused Therapy (CFT) do work.

Appendix 1

SARS-COV-2 virus spreads in a similar way to Common Cold viruses

Figure 2 *"Coughs and sneezes spread diseases, trap the germs in your handkerchief"* Tony Hancock

SARS-COV-2 virus, which causes COVID 19 disease, spreads in a similar way to the Common Cold viruses[32]. Unlike the Common Cold perhaps 40% to 45% of those infected with SARS-COV-2 virus **don't have any tell-tale symptoms** (*"Proceedings of a Workshop: Airborne Transmission of SARS-COV-2 "* **Link**) Whereas with the usual Common Cold symptoms are a runny nose and a sore-throat. These are not the standard symptoms of COVID 19 which seems to have a range of early symptoms.

Although the health effects and tell-tale symptoms are different, the Common Cold virus and SARS-COV-2 virus routes of exposure and exposure control measures are similar.

Tony Hancock in *"The Blood Donor'* sketch (1961) plays a hopeless buffoon character pompous, sad and almost always wrong. In this sketch[33] he sings a song based on an old government World War 2 poster (Figure 2) ending with *"Trap the Germ in your handkerchief".*

We need to do more than what Tony Hancock sang about in the sketch. It's important not so much to just *"Trap the Germs in your Handkerchief"* as do **that plus use other layers of control** such as wearing face-masks, face-shields, physical distancing, good general ventilation etcetera. It is clear that the recent evidence is *"strongly indicative of **airborne transmission**"* (*"Proceedings of a Workshop: Airborne Transmission of SARS-COV-2 "* **Link** from 10.20 onwards) Coughs and sneezes **do** spread diseases.

[32] Which include Rhinovirus, Corona virus RSV and parainfluenza are some of them, perhaps 30% of Common cold viruses, are not identified **link** and **link**

[33] But you don't have to sing it to the tune Tony Hancock uses but it fits in with the song lyrics rather well.

Appendix 2 Breath-air (or "respiratory plume")

<table>
<tr><td colspan="3">App2 Table 1
Do-it-yourself (DIY) breath-air range test</td></tr>
<tr>
<td>Human "Breath-air"

Puffs out of our mouths</td>
<td>Try the DIY test yourself


</td>
<td>DIY "breath-air" test in four-simple-steps

1. Wet your hand and make it damp

2. Hold it in front of your face and blow at your hand. Move your hand away until your arm is at full stretch. You will feel the blown air at every distance

3. Do the same but this time speak or sing. You will find that you cannot feel your breath past about 50 centimetres (0.50 metres)

4. Repeat the simple DIY tests described in (3) wearing a facemask

DIY test conclusions:

a. Breath-air" is real and has a limited range of about 50 centimetres (0.5 metres)

b. Facemasks dramatically reduce the range to a few centimetres at most[34]</td>
</tr>
</table>

[34] *"Proceedings of a Workshop: Airborne Transmission of SARS-COV-2 "* Link refers to the same effect on *"respiratory plume"* travel

App 2 Table 2 Blowing – The breath-air range benchmark

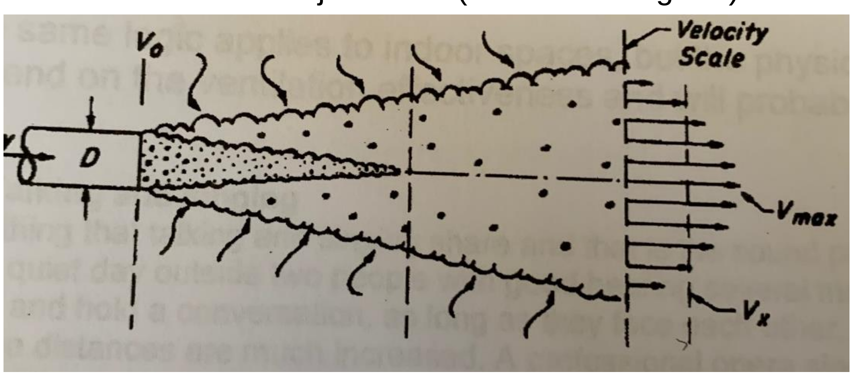
Classic air-jets are created by:

1. Continuous airflow
2. Which have **time** to entrain (draw-in) surrounding air (see Hemeon's diagram below the photo)
3. This increases the jet volume, momentum and range
4. Air-jets **take a little time to develop** but once they do, they can travel many metres
5. My blowing breath-range in still air was over 3 metre (not shown)

We only produce classic air-jets when we **blow air** (e.g. blowing out the candles on our birthday cake) or **when we sneeze or cough.** Quiet breathing, talking and singing do not produce classic air-jets with anything like the same range (See Tables 3a, 3b and 3c)

- The metre-rule on the wall provides some scale
- My blowing breath-air range in my unventilated study was over 3 metres (not shown)

Hemeon's[35] beautifully simple diagram showing jet core-air, air-entrainment in the jet and jet-air expansion with travel from the jet-orifice (D – in the diagram)



[35] Taken from WCL Hemeon's "Plant and Process Ventilation" 1955 See Review of Jeff Burton's re-print and edit here: (11) (PDF) Hemeon's Plant and Process Ventilation, Third Edition (researchgate.net)

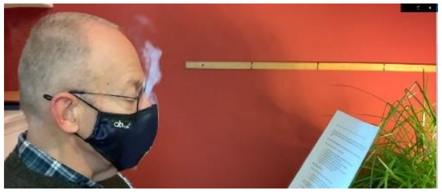
Appendix 3 Breath-air ranges: summary and key comments

Appendix 2 Table 3

	Quiet breathing without mask	**Quiet breathing** with mask	**Talking** without mask	**Singing** without mask	**Talking & singing** with mask	Key comments
Indoors poor ventilation	25 – 75[36] centimetres	~5 – 10 centimetres	25 – 50 centimetres	~35 - ~70 centimetres	~5 – 10 centimetres	1 The breath-air ranges of **talking and singing are similar** at roughly 25 – 50 centimetres although singing can be 10 – 20 centimetres more becoming ~35 - ~70 centimetres 2 The **maximum breath-air range**: quiet breathing indoors is 75 centimetres (see Footnote 12)
Indoors good ventilation	25 – 50 centimetres	~5 – 10 centimetres	25 – 50 centimetres	~35 - ~70 centimetres	~5 – 10 centimetres	3 All **breath-air ranges fall when face-masks are worn** Using the DIY test and the vaping smoke test all breath-air ranges fall to about 1 to 2 centimetres (0.01 – 0.002 metres). **But Note:** These ranges are approximate and take no account of how the breath-air flows once it's left your mouth. Almost certainly the breath-air range when wearing a mask is greater than 1 to 2 centimetres, perhaps **in the region of 5 to 10 centimetres**.
Outdoors good (variable) ventilation	25 – 50 centimetres	~5 – 10 centimetres	~25[37] centimetres	~25 centimetres	~5 – 10 centimetres	**4 Facemasks offer protection in 2 ways;** They filter out exhaled LADspit, LADinh are quite effective for SADs and SAPs. And, secondly, they **dramatically reduce** our *"breath-air"* range

[36] Perhaps it's surprising that quiet-breathing breath-air range is greater than talking or singing. In fact, it illustrates the range impact of classic air-jets (see Table2 for some details). During quiet breathing my exhalation was slow and prolonged through my nostrils (see Table 3a). There was time for the two nostril-air-jets to be established. Talking and singing are far more staccato and there's little or no time for classic air-jets to form. Their breath-air ranges are therefore less.

[37] This is a bit lower than indoors good ventilation. Probably it was due to a gust of wind

Blowing, the breath-air benchmark (see App 3 Table 2 for details)			
Where?	**Quiet breathing**	**Quiet breathing**	**Quiet breathing conclusions: Breath-air range**
Indoors poor ventilation, without mask			**Without mask** *"breath-air"* range 50 – 75 centimetres (approx) **With mask** *"breath-air"* range 1.0 – 2.0 centimetres (approx)
Indoors good ventilation without mask			**Without mask** *"breath-air"* range 25 – 50 centimetres (approx) **With mask** *"breath-air"* range 1.0 – 2.0 centimetres (approx)
Outdoors good (variable) ventilation without mask			**Without mask** *"breath-air"* range 25 – 50 centimetres (approx) **With mask** *"breath-air"* range 1.0 – 2.0 centimetres (approx)

Appendix 3 Table 1b Talking breath-range ranges

How to interpret the images in this table:

1. See Table 1 for more on blowing breath-air benchmark
2. The smoke shows my *"breath-air"* range
3. Ignore the **density** of the smoke, it is the breath-air range that matters

Focus just on the range of my breath-air as shown by the smoke

Blowing, the breath-air benchmark (see Table 1 for details)

Where?	Talking	Where?	Talking & mask	Talking conclusions: Breath-air range
Indoors poor ventilation, without mask		**Indoors** poor ventilation, With a mask		**Without mask** *"breath-air"* range 25 - 50 centimetres (approx) **With mask** *"breath-air"* range 1.0 – 2.0 centimetres (approx)
Indoors good ventilation without mask		**Indoors,** good ventilation, With a mask		**Without mask** *"breath-air"* range 25 - 50 centimetres (approx) **With mask** *"breath-air"* range 1.0 – 2.0 centimetres (approx)
Outdoors good (variable) ventilation without mask		**Outdoors** good ventilation - With a mask		**Without mask** *"breath-air"* range 25 centimetres (approx) **With mask** *"breath-air"* range 1.0 – 2.0 centimetres (approx)

Appendix 3 Table 1c Singing breath-air ranges

How to interpret the images in this table:

1. See Table 1 for more on blowing breath-air benchmark
2. The smoke shows my *"breath-air"* range
3. Ignore the **density** of the smoke, it is the breath-air range that matters

Focus just on the range of my breath-air as shown by the smoke

Blowing, the breath-air benchmark (see Table 1 for details)

Where?		Where?		**Singing conclusions:** **Breath-air range**
Indoors poor ventilation, without mask		**Indoors** poor ventilation, With a mask		**Without mask** *"breath-air"* range 25 - 50 centimetres (approx) **With mask** *"breath-air"* range 1.0 – 2.0 centimetres (approx)
Indoors good ventilation without mask	**Video lost – no still image available**	**Indoors,** good ventilation, With a mask		**Without mask** Video lost – no still image available **With mask** *"breath-air"* range 1.0 – 2.0 centimetres (approx)
Outdoors good (variable) ventilation without mask		**Outdoors** good ventilation - With a mask		**Without mask** *"breath-air"* range 25 centimetres (approx) **With mask** *"breath-air"* range 1.0 – 2.0 centimetres (approx)

Appendix 4 Thoughts on occupational hygiene and other scientific research

The right mix of sciences
In sub-section 1.5 it was clear that multidisciplinary problems, like the COVID-19 world-wide pandemic require the right mix of sciences to arrive at the right mix of practical and practicable exposure control and other problem solutions.

Once the multi-science nature of the problems to be solved is accepted the next question is, *"Which mix of sciences do we need?"*. I hope I've demonstrated in this guidance that the specialist applied science of occupational hygiene has something to add to *"Staying safe from Sars-CoV-2 (SARS-COV-2) virus"* and why the exposure controls work and the *"What exposure control measures are likely to work?"* question.

The USA Academy of Sciences **link** are quite clear about the range of sciences needed in tackling the COVID-19 pandemic. But problems can arise if such multidisciplinary/multi-science issues are treated as something that can be solved by one science or the wrong mix of sciences is chosen. In a nutshell the strengths of individual sciences can also be the cause of their weaknesses. By saying this I'm not picking on a particularly 'bad' or 'good'science, the issues are inherent to the nature of sciences and their working together.

Sciences and technical language/paradigm translation
Each science works to its own paradigm that overlap with but is not the same as other sciences. Thomas Kuhn (who popularised the term in his book the Structure of Scientific Revolutions,1962) describes how a scientist learns a paradigm. He or she does this by becoming imbued with the ideas and techniques special to your science especially the solved exemplary problems. It's a form of apprenticeship. Part of the apprenticeship is learning the definitions and concepts of your science and how to apply them. The specialist language needed to communicate to other scientists in your field of study.

When two or more sciences try to work together the specialist language can need translating. One science may have used a term differently from another science. Good enough as a working definition but not for another science. Good examples are the terms aerosol and droplet. Tang et al 2020 **link** explain that physicians and aerosol scientists (and occupational hygienists) use the same terms but they mean something different.

Term used	Physician	Aerosol scientist (occupational hygienist)
Aerosol	Particle smaller than 5um that mediates airborne transmissions produced during aerosol generating procedures and also requires N95 respirator	Collection of solid or liquid particles of any size suspended in a gas
Droplet	Particle larger than 5 um that falls rapidly to the ground within a distance of 1-2 metres from source; requires a surgical mask for infection control	Liquid particle

The first thing that multi-science groups, trying to solve a joint problem, need to do is to compare their definitions of common terms. Tang et al 2020 **link** explain why this is necessary using a series of Myths. One science needs to translate its technical language to another and all need to agree a common definition or joint term. Otherwise, sciences will tend to talk through each other using the same word but meaning different things. It's inherent to the nature of scientific paradigms (Kuhn 1962).

Occupational hygiene (OH) and other scientific research - a few thoughts			
Research question(s)	**Description**	**Discussion points**	**Sciences comments**
How much does surface and skin contamination play a part in SARS-COV-2 (and other virus) transmission?	It's pretty obvious with SARS-COV-2 that the **primary transmission pathway** is through the air. It's not clear how much surface-skin transfer plays in transmission. It would be useful to roughly quantify this pathway.	SARs-like cold viruses can be transmitted from nose to skin to nose/mouth especially in young children (who can be very snotty). SARS-COV-2 will be transmitted this way but, probably, not a lot. Finding out how much surface-skin contributes matters in terms of public fear and economic costs.	OH research into surface and skin contamination will be relevant but also virology in examining virus viability on surfaces and skin and the most cost-effective ways of cleaning surfaces and skin. Pathway quantification will be difficult but is worth doing.
What difference do different physical distances make to infection risk?	I've assumed that larger airborne droplets (LADs) can carry more viable virus than smaller airborne droplets	Current airborne virus sampling methods damage viruses collected. Although their RNA is detected, it's not clear what %	Airborne droplet/particle sampling focussing on inhalable, thoracic and respirable fractions will be

Occupational hygiene (OH) and other scientific research - a few thoughts			
Research question(s)	**Description**	**Discussion points**	**Sciences comments**
	(SADs) because they dry out more slowly. And the infection risk is greatest in the "near field" close to someone infected with COVID 19.	of viruses are viable and able to infect. Gentler methods of sampling are needed.	relevant (OH and aerosol physics). But how to measure the viability of viruses is the province of virology.
Cold and hot environments and climates appear to affect SARS-COV-2 transmissibility. What are the mechanisms(s) which cause these differences?	Some UK outbreaks have been associated with food/meat-packing warehouses which are kept cold. It appears that some countries e.g. Rwanda have had far less COVID-19 death[38]. Increases or decreases in transmission will be due to multiple factors. It's likely that temperature and UV light intensity will be important	The factors increasing or decreasing SARS-COV-2 transmissibility will be multiple. Colder environments are likely to increase virus viability and higher levels of UV light are likely to decrease it. And perhaps warmer environments mean that doors and windows are left open automatically increasing ventilation effectiveness. The demographics of different countries has an impact on mortality.	Sciences involved could include: Ergonomic human factors, occupational hygiene, physics, virology, epidemiology
Quantification of ventilation effectiveness	The term *"reasonable ventilation"* needs to be defined experimentally using tracer gas empirical work[39] and CFD modelling used together. Smoke testing is all very well but it is not quantitative.	As long as airborne droplets/particles carrying SARS-COV-2 viral particles are diluted and dispersed effectively, COVID-19 infection is prevented. But exactly what poor, good and very good dilution and dispersion ventilation means needs to be defined.	Sciences involved could include ventilation engineering, and occupational hygiene.
Quantification of face-mask	EN standards are in	The main impact of face-masks	Physics (aerosol science),

[38] Recent broadcast of *"More or Less"* on BBC World Service showed that Rwanda had 300 times less COVID-19 deaths compared with Belgium which has a comparable sized population to Rwanda

[39] The HSE Method for Determining Hazardous Substances (MDHS) explaining how to measure ventilation effectiveness seems to be out-of-print. It would be well worth updating and republishing it

Occupational hygiene (OH) and other scientific research - a few thoughts			
Research question(s)	**Description**	**Discussion points**	**Sciences comments**
effectiveness	development but world-wide standards are needed.	is on breath-air range filtration, especially of the Source air. Quantitative ways of measuring filtration effectiveness at different airborne droplet/particle sizes and the impact of different breath-air range are needed.	physiology including (probably) Ear Nose and Throat (ENT medical specialist consultant, OH and probably ergonomics on wearability and comfort of face-masks. Textile technology on options and their breathability.
Respirators are designed for industrial use and, usually, intermittent exposure when, and for some time after, a process has stopped running. In health-care environments respirators maybe worn for hours on end. These conditions demand more of the wearers and the RPE.	Some tight-fitting RPE may be fine but this needs properly checking. Where people have to wear RPE for long periods it should be a PAPR (Powered Air Purifying Respirators).	The most comfortable tight-fitting RPE is probably FFP devices with exhalation valves[40]. Industrial PAPR can noisy for the wearer and some are heavy. There's design work to do to make them quieter and improve PAPRs so that wearers can communicate. They probably need to be lighter than current 'industrial' designs.	Sciences involved: PPE engineering, ergonomics, social psychology, occupational hygiene (others?).
Which lung tissues get infected by SARS-COV-2 virus – upper respiratory tract or upper and lower respiratory tract.	Figure 2 suggests that flying spit droplets and the larger inhalable large airborne droplets (LADs) lead to infection of the upper respiratory tract. In circumstances where smaller airborne droplets/particle (SADs and SAPs) are large in number (e.g in poorly ventilated	Deep lung direct infection by SARS-COV-2 is likely to be more serious than infection of the upper respiratory tract. How infection difference airborne droplet/particle size fractions are likely to be and where they preferentially land maybe important determinants of the severity of COVID-19.	Sciences involved: Aerosol physics (OH), lung physiology, virology and immunology.

[40] There maybe increased leakage of SAR-CoV-2 viruses if the wearer has COVID-19

Occupational hygiene (OH) and other scientific research - a few thoughts			
Research question(s)	**Description**	**Discussion points**	**Sciences comments**
	spaces or where Aerosol Generating Processes (AGPs) are used in a medical setting, it's possible that the tissues of the lower respiratory tract are infected too.		
How and why does the SARS-COV-2 HID50 (or Minimum infectious Dose, MiD) vary with age and underlying health conditions and SARs variants.	It's likely that the SARS-COV-2 MiD is different for different groups and different variants of the virus. It would be useful to better understand the mechanisms underlying these differences to better bracket likely Minimum infectious Doses (MiDs).	Why Minimum infectious Doses (MiDs) vary could be due to less effect respiratory tract clearance, or a weakening of the immune system or other factors.	Sciences involved could include aerosol physics, lung physiology, immunology, virology, genomics (and others?).

Appendix 5 How do face-masks work?

I know a fair bit about the design and effectiveness of respirators (as defined in EU and other standards). Until the COVID-19 pandemic I regarded face-masks as more-or-less useless (a sort-of occupational hygiene scientific prejudice if you will. Over the course of the pandemic, I've changed my mind not because face-masks offer any useful protection against, say, respirable crystalline silica (RCS) dust for which task they are truly useless, but because airborne transmission of SARs-COV-2 virus happens via airborne droplets and particles most of which are much larger that RCS. Face-masks, it turns out, do work quite well against airborne droplets and particles but, like respirators, they need to fit the users face, be made of the right material and be worn correctly.

Two key scientific research papers This sub-section leans heavily on a recent US Centre for Disease Control (CDC) reference publication (snappily) entitled *"Maximizing Fit for Cloth and Medical Procedure Masks to improve Performance and Reduce SARS-CoV-2 Transmission and Exposure, 2021"* **link** (called MMWR research in this guidance). And another ground-breaking piece of occupational hygiene scientific research, *"Efficacy of face masks, neck gaitors and face shields for reducing the expulsion of simulated cough-generated aerosols"* by Lindsley et al (2020) **link**

MMWR research The MMWR research was done using two artificial hollow plastic human heads which could create airborne droplet/particle clouds simulating coughing and talking. One head was used as the *"Source"* and one as the *"Receiver"*.

Three experimental set-ups are reported:
1. Unknotted medical procedure mask (or surgical mask in the UK)
2. Double mask (where one mask is worn on-top of another)
3. Knotted/Tucked medical procedure mask (where the straps holding the mask to the face are tightened)

The results are summarised in MMWR Figure 2 which is Figure XX in this document.

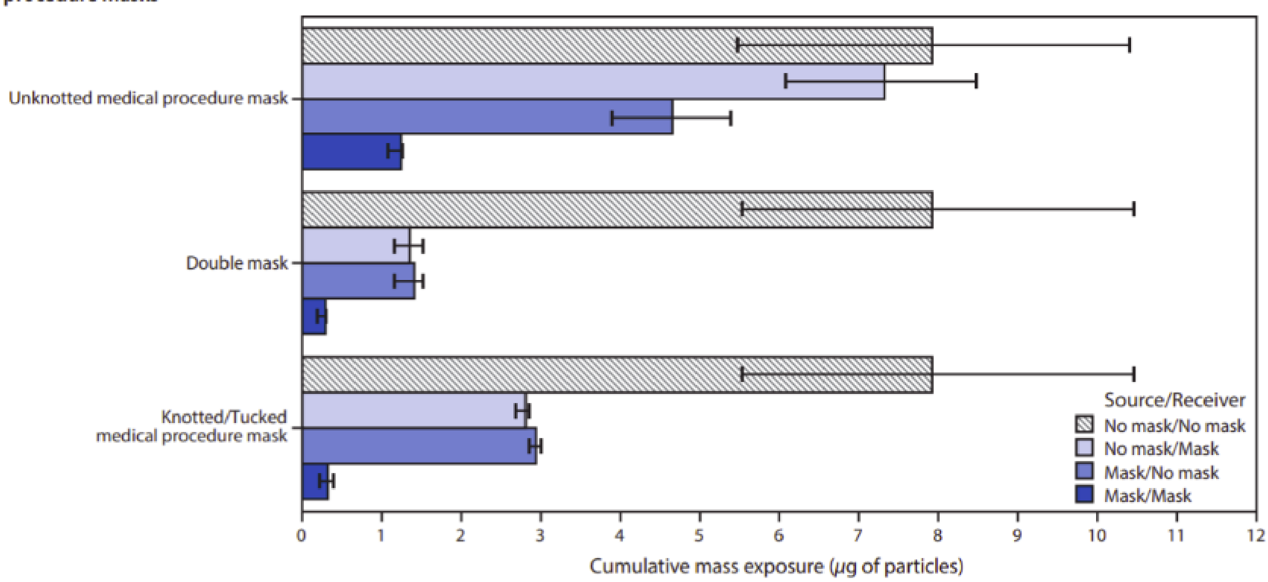
The medical procedure (called "surgical" in the UK) mask has some effect and it's performance is improved by knotting the ties pulling it against the wearers face. But the greatest reduction in test aerosol exposure comes from double masking.

I've crudely estimated "mean cumulative aerosol" exposures from MMWR's Figure 2 for four circumstances, in Table XX.

Appendix 4 Table 1				
Test arrangements	**Exposure level**	**% effectiveness against aerosol challenge**	**% protection**	**Comment**

Appendix 4 Table 1				
Test arrangements	**Exposure level**	**% effectiveness against aerosol challenge**	**% protection**	**Comment**
No masks	8 ug/m^3	-	-	Control test result
Receiver wearing surgical-mask	7.7 ug/m^3	94%	6%	
Source wearing surgical-mask	4.75 ug/m^3	60%	40%	If the Source wears the surgical mask % protection is 40% compared to 6% if the Receiver wears the mask
Both Source and Receiver whear knotted and tucked surgical masks	1.5 ug/m^3	20%	80%	

FIGURE 2. Mean cumulative exposure* for various combinations of no mask, double masks, and unknotted and knotted/tucked medical procedure masks†



Lindsley et al 2020 research

Device	Receiving (ug) approx	% Receiver protection	Source (ug) approx	% Source protection	Comment(s)
None	~500	0.0%	~500	0.0%	
3M1860 respirator	10	98%	10	98%	No exhalation valve
Face-mask	200	40%	300	60%	
Cloth mask	250	50%	250	50%	
Neck gaitor	200	40%	300	60%	
Face shield	500	0.0%	250	0.4%	

Discussion of MMWR 2021 research findings

It's alluded to in the MMWR report but I wanted to bring out a key point explicitly by crudely using the results reported in MMWR Figure 2.

Why does a face-mask only reduce Receiver aerosol challenge by about 6% whereas if the same type of face-mask is worn by the Source the reduction is about 40%, about a 7-fold greater reduction?

The answer I think is to do with the labile nature of airborne droplet clouds. The liquid (mainly spit) droplets we all generate when we talk, sing, cough or sneeze – the larger airborne droplets (LAD_{inh}) and the smaller airborne droplets (SADs) all become either SADs or small airborne particles (SAPs) within a few seconds of being released. In these circumstances the surgical masks filter, and reduce the immediate breath-air spread, of the LADs, SADs and SAPs because many of the particles are bigger at the start of their flow out of the mouth (and nose) than even a few seconds later.

The Source aerosol is filtered (and confined) far better than the Receiver because the aerosol has rapidly evaporated water and the whole droplet/particle size distribution has shifted downwards.

These facts, in turn suggest that SARs-COV-2 virus particles are carried and transmitted most efficiently in airborne droplets/particles **larger than the classic definition of "respirable"** i.e. <5.0um. Together with the conclusions of Tang et al (2021) **link**, it strongly suggests that it's probably the larger airborne droplets/particle fractions that do the majority of SARs-COV-2 virus particle delivery.

In certain very specific medical settings (e.g. Aerosol Generating Processes or AGPs) the "respirable" size fraction maybe important. Note: Sneezing is the one human action that generates sufficient SADs and SAPs.

Appendix 6 Assessing ventilation effectiveness in rooms and vehicles[41]

Qualitative assessment can be summed up as; if ventilation follows good design principles, looks to be effective and feels effective then it is very likely to be effective

There are two broad ways of assessing ventilation effectiveness, qualitative and quantitative. Please also refer to subsection 4.0 – in the main text of these Basic Notes.

Some general ventilation history

The early UK Factory Inspectorate (FI) used to measure CO2 levels in factories to assess general ventilation effectiveness. I think that this started somewhere around 1870 – 1880. They used a kit that was designed by a Professor Haldane which involved bubbling factory atmosphere through a solution which developed a colorimetric reaction (don't know details). The depth of the solution colour was a measure of the CO2 level. At the time factories were gas-lit and most of the CO2 came from the gas-light flames. But the method is still perfectly valid nowadays.

Personal experience of general ventilation assessment

I have used CO2 levels to assess fresh-air input into an HSE conference room (in Masshouse Circus offices Birmingham) and some other HSE offices[42]. The method was all written down in the Drager Tube Handbook of the time and used Drager CO2 tubes.

Exactly the same method can be used nowadays to assess fresh air input into a room or a vehicle, such as a bus.

Ventilation Assessment Methods

Qualitative assessment

Start with a qualitative assessment of current general ventilation arrangements. Are they likely to be good-enough and/or can they be improved fairly easily. For instance, if the room/vehicle is quite large (e.g. >20 square metres (m^2)) and there are large windows which can be opened to create a throughflow of air, it should be relatively safe to meet in that room. As to how many people can meet that will depend on being able to maintain a minimum physical distancing.

If the room/vehicle is smaller and it's not possible to set-up a crossflow of fresh air the occupancy will have to be less, and simple quantitative methods, such as release and observation of smoke tracer, may be used for assessment purposes.

---

[41] Thanks particularly to Kelvin Williams **link** who raised a really interesting occupational hygiene problem with me a few days ago – *"How to work out the safe COVID-related occupancy levels of a bus?"*

[42] I have also used sulphur hexafluoride (SF_6) gas as a tracer-gas but SF_6 has been banned under the Montreal Protocol

Quantitative assessment

As mentioned earlier CO2 is probably one of the easiest ways to quantitatively assess general ventilation (see these links[43])

Fresh air input guidance levels, the CO2 benchmark and SaRs-CoV-2 airborne risk

The $64,000 question is really, *"What CO2 level do we use to say ventilation is satisfactory?"* HSE Northern Ireland (HSE NI) and others provide the following advice;

> ***"****A* ***poorly ventilated area*** *can be described as one that has movement of air that is below 5 Ltrs/sec/person or above* ***1500ppm of Carbon Dioxide (CO2)****.*
>
> *An* ***adequately ventilated area*** *can be described as having a movement of air that has 8-10 Ltrs/sec/person or* ***below 800ppm of CO2****. In communal areas such as offices* ***around 1000ppm of CO2*** *is widely regarded as an indicator of sufficient per person ventilation rate"* Ventilation and COVID-19 | Health and Safety Executive Northern Ireland (hseni.gov.uk) **HSE NI**

The obvious benchmark of effective ventilation is to get conditions in the room or a vehicle as close to outdoor air as possible. The CO2 level in the general atmosphere today runs at just over 400 parts per million (ppm). Although it is an obvious benchmark in practice ~400 ppm CO2 is rarely achieved in occupied rooms and vehicles. This is reflected in the advice provided by HSE NI (see above).

While CO2 is a good indicator of fresh-air input, strictly speaking it's not entirely what you are interested in when it comes to general ventilation and Covid infection risk. For example, it takes no account of the level of infection or immunity in a local population.

Various agencies are exploring the use of exhaled CO2 as a Covid 19 infection risk proxy but how CO2 levels relate to SARs-CoV-2 infection risk remains unknown.

[43] There's quite a bit online information, for instance, on CO2 measurement - **Part 1** Carbon dioxide and Ventilation Part I - YouTube **Part 2** Carbon dioxide and Ventilation Part II - YouTube **How to measure CO2 in air** How to Measure Carbon Dioxide (CO2) Levels, Indoor Air Quality (lukeskaff.com) Nowadays there will be continuous monitors and clever ways of link these to fresh-air input, for instance, in air-con systems.

Bare bones of an assessment of room/vehicle ventilation

1. Start with a **qualitative assessment** of current general ventilation arrangements. Are they good-enough and/or can they be improved fairly easily? If so, make the changes and reassess. If good through-flow of air is clear and/or occupancy is low, then general ventilation is likely to be adequate.
2. If you're not sure perhaps use a simple qualitative assessment test such as smoke-tracer release
3. If the numbers of people at risk are quite large (e.g in a coach or bus) consider quantitative testing CO2 measurements. Some noteworthy principles for monitoring CO2 are provided by *"Role of Ventilation in Controlling SARS-CoV-2 Transmission"* by SAGE-EMG 23rd October 2020 **link**
   Note:
   a. If there are only small numbers of people in a room/vehicle and there are large spaces CO2 measurements will be a bit erratic. It's best to average the CO2 measured values over a number of measurements.
   b. Where air is cleaned of airborne particles (e.g. by air filtration or ultra-violet light cleaning) CO2 levels will not be a reliable proxy. But they will be a good indicator of fresh air input.
   c. The person doing the CO2 measurement is interested in the fresh air dilution of CO2 in the occupied space. Measurements should be done in the occupied space and not near open windows, ventilation grilles etcetera. It's probably best to take an average measurement over at least an hour. Also be on the look-out for other sources of CO2 such as open fires etcetera.
   d. Continuous CO2 monitoring is not likely to be a reliable proxy for transmission risk in most environments. However preliminary research suggests that in spaces where the same group of people regularly attend (e.g. offices, schools), continuous monitoring may be possible to use as a transmission risk indicator.

I suggest the following approach:

a) Start the testing with maximum general ventilation and room/vehicle occupancy.
b) Vary the fresh air input and see what happens to CO2 levels
c) Increase the air-con fresh-air and volume flow rate to maximum and see what happens to CO2 levels
d) If the vehicle/room ventilation system has filters take them out to decrease ventilation flow resistance and increase air flow rate.
e) It should become pretty clear, pretty quickly whether it's possible to use the room/vehicle at maximum occupancy. If maximum occupancy is not possible, when setting occupancy numbers be cautious.
f) As an additional layer of control in vehicles such as coaches where people have to pass close to each other all occupants should wear face-masks for the journey. And perhaps the vehicle drivers and attendants should wear respirators (just to be on the safe side)
g) Many workplaces / vehicles have installed Perspex screen barriers. While well intentioned and useful for reducing "near-field" virus transmission, they will impede the mixing of fresh and room/vehicle air and the far more important control measure of

ventilation. It may be best to remove Perspex screens - apart from those that, for example, separate drivers from passengers, or customers from staff in shops.

Conclusions

If occupancy of the room/vehicle is low then there is probably no need to do any quantitative measurement. In such circumstances the easiest way to assess whether the general ventilation is effective enough is a check on the ventilation set-up, for instance, this includes open windows/doors so there's a clear through flow of air. If you can honestly say that you 'can feel-the-*"cold air on-my-skin"* **link**, and there are few people in the space (room/vehicle) it's likely that general ventilation will be effective enough.

Use the qualitative/quantitative methods if you are not sure.