A physicist view of the airborne infection

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To understand and prevent the spread of a virus like SARS-CoV-2, it is important to estimate the probability of airborne transmission as aerosolization with particles potentially containing the virus. Although there have been reports favoring the possibility of creating coronavirus aerosols [1], thus far no aerosolized coronavirus particles have been found in searches within the hospital rooms of SARS-CoV-2 patients [2]. In this brief report we provide an overview on the possible threat of SARS-CoV-2 airborne infection from a physics point of view.

In the presence of air resistance, compact heavy objects fall to the ground quickly, while light objects exhibit Brownian motion and follow the pattern of turbulent convection of the air. For aerosol particles containing the virus, the boundary between these two behaviors depends on the size of the particle. We begin with a simple question: how long does a virus float in the air under the influence of gravity? To answer this query we model the virus as a sphere of radius \( r \approx 90 \text{ nm} \) and mass \( m \approx 2.5 \times 10^{-9} \text{ kg} \) [3], and we assume that this spherical particle is suspended in a viscous fluid (the air) feeling the Earth’s gravitational field. Herein, gravity tends to make the particles settle, while diffusion and convection act to homogenize them, driving them into regions of smaller concentration. On the one hand, the convection mechanism provides particle macro-mixing within the fluid through the tendency of hotter and consequently less dense material to rise, and colder, denser material to sink under the influence of gravity. On the other hand, the diffusion mechanism acts on the scale of an individual particle (micro-mixing) slowly and randomly moving through the media.

Under the action of gravity, the virus acquires a downward terminal speed that follows from Stokes law and is given by

\[
\nu_{\text{down}} = \mu g \rho, \tag{1}
\]

where \( g \approx 9.8 \text{ m/s}^2 \) is the acceleration due to gravity and

\[
\mu = \frac{1}{6 \pi \eta r}, \tag{2}
\]

is the virus mobility in the fluid, and where \( \eta = 1.8 \times 10^{-5} \text{ kg/(ms)} \) is the dynamic viscosity of air [4]. Substituting (2) into (1) we find that the downward terminal speed of the virus in dry air is indeed negligible, \( \nu_{\text{down}} \approx 8 \times 10^{-8} \text{ m/s} \). It is therefore clear that gravity plays no role in the motion of an isolated virus through the air. Rather it follows a convection pattern in a manner similar to how smelly substances move through the air. The survival probability of the virus in the dry air is then given by the likelihood of survival outside its natural environment. The half-life of SARS-CoV-2 in aerosols has been found to be about 1.1 hours [1].

We have seen that the coronavirus can go airborne staying suspended in the air. However, the virus is transmitted through respiratory droplets produced mostly while sneezing and coughing. Then to ascertain whether airborne transmissible SARS-CoV-2 can survive and stay infectious in aerosols we must double-check that the falling time of a droplet from a height of about two meters is larger than its evaporation time scale. To this end, we assume that the drops are also spherical and hence the mass can be simply estimated as

\[
m = \frac{4}{3} \pi r^3 \rho, \tag{3}
\]

where \( \rho = 997 \text{ kg/m}^3 \) is the density of water and \( r \) the droplet radius. For large droplets whose diameters \( \geq 1000 \mu\text{m} \), the effect of air resistance is negligible and so the falling time can be directly estimated using Newton’s equations for gravitational settling. For smaller droplets whose diameters \( < 100 \mu\text{m} \), the falling times must instead be determined using the downward terminal speed given in (1) to account for the air resistance upon the falling droplets. It is now an instructive and

| TABLE I: Evaporation time of water droplets. |
|-----------------|----------------|
| Droplet diameter (μm) | Evaporation time (s) |
|-----------------|----------------|
| 2000            | 660             |
| 1000            | 165             |
| 500             | 41              |
| 200             | 6.6             |
| 100             | 1.7             |
| 50              | 0.4             |

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FIG. 1: Visual representation of airflow streamlines in an meeting room (left) and office space (right) colored to velocity magnitude from low (blue) to high (red). The convection pattern in the meeting room demonstrates how the infection can be persistently carried by the airflow between two chairs separated by 6 feet. The convection pattern in the office space illustrates how the infection can be taken by the airflow from one cubicle to the other. Simulation by SimScale [10].

straightforward exercise to show that the time for falling 2 m in saturated air is 0.6 s for droplets with \( r > 500 \mu m \), 6.0 s for those of \( r \sim 50 \mu m \), 600 s (about 10 minutes) for those of \( r \sim 5 \mu m \), and 60,000 s (about 16.6 hours) for those of \( r \sim 0.5 \mu m \). The droplet evaporation time scale as computed by Wells using droplet evaporation data collected by Whytlaw-Gray and Patterson is shown in Table I [5]. The assumption of pure water droplets in unsaturated air at 18°C was used for the evaporation calculations, such that the theoretical droplets are capable of complete evaporation. By direct comparison of the droplet evaporation and falling times we can conclude that somewhere between 100 and 200 \( \mu m \) lies the droplet size (i.e. the diameter) which identifies droplets of mouth spray that reach the ground within the life of the droplet as against droplets that evaporate and remain in the air as droplet-nuclei with attached SARS-CoV-2 infection. Several investigations have been carried out to continue improving the precision of Wells analyses and to study the various external environmental (such as temperature and humidity) factors that may alter his estimates; see e.g. [6].

The sizes of the droplets and droplet-nuclei produced by sneezing and coughing were studied by the microscopic measurement of 12,000 droplet stain-marks found on slides exposed directly to mouth-spray, and of 21,000 stain-containing droplet-nuclei recovered from the air on to oiled slides exposed in the slit sampler [7]. From this data sample it was found that the original diameters of respiratory droplets ranged from 1 to 2000 \( \mu m \) and that 95% were between 2 and 100 \( \mu m \) and that the most common were between 4 and 8 \( \mu m \). This suggest that, in principle, droplet-spray could drive direct airborne infection of SARS-CoV-2. The spread of a sneeze in the air has been studied by ultrafast imaging at MIT [8,9]. It was found that even the largest droplets from a sneeze can float in the air for up to 10 minutes, which allows them to reach the far end of a large room. This points towards convection in the air being the primary mechanism of the spread of the infection.

From the physics point of view, we cannot find a good justification for a stationary 6-feet separation in a situation when people spend long time together in a room. Droplets containing the virus move in the air via convection. The convection pattern in a room can be very complex; see Fig. 1. It depends on the location of air conditioners, radiators, windows, and all items in the room, as well as on people producing vortices by moving around. The existing vortices in the air can make a location far away from the source of droplets more dangerous than the location 6 feet away. This applies to meeting rooms, office spaces, supermarkets, department stores, etc. The airflow pattern should be studied for all such facilities to avoid the spread of infection to large distances from a single infected person. The safest rooms must be those equipped with the air sucking ventilator at the top, like hospital surgery rooms [11].

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