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A physicist's approach to COVID-19 transmission via expiratory droplets

Pasquale Carelli\textsuperscript{a,b}

\textsuperscript{a} Istituto di Fotonica e Nanotecnologie, CNR, via Cineto Romano 42, 00156 Rome, Italy
\textsuperscript{b} Department of Physical and Chemical Sciences, University of L'Aquila, via Vetoio 67100 L'Aquila, Italy

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\textbf{ABSTRACT}

In this paper, a physicist's approach is given to support the necessity to wear surgical masks during the COVID-19 pandemic; they have become compulsory in Eastern countries, while in Western countries they are still an optional. My thesis is supported and described on the basis of a physicist's model which studies the droplets behavior when emitted by the respiratory apparatus of an infected person, symptomatic or not. The intermediate dimensioned droplets are proved to be changed into aerosol, losing their water content and becoming seriously contagious, but in their initial phase they could be easily caught by a simple surgical mask. The actual efficiency of FFP3 masks has been examined and found to be lower than expected.

\section*{Introduction}

While the COVID-19 pandemic is spreading around all over the world in a dramatic way, I think it is necessary to state a reference date in order to make any reflections, I chose the 3rd April 2020.

On that date in Italy there were 14,681 dead people and 119,827 infected, the situation was dramatically changing with a number of deaths higher than 500 a day. That rate (mortality) caused by the virus is of 0.11 (deaths/population).

At the same date in South Korea there were 120 dead people and 9037 infected, mortality was of 0.002\% with a lethality rate (deaths/infected people) of 1.3%. As the population in South Korea has a life expectation very similar to the Italian one (even if Koreans are younger than Italians\cite{1}), the Korean data about lethality is more plausible.

One of the reasons of such a serious pandemic in Italy and afterwards in many other western countries, could be the following: in Asian countries surgical masks have been widely worn for many years as a means to protect other people. This habit, strongly recommended by local sanitary authorities, started both from the epidemic of SARS-CoV which heavily hit the Asian world between 2002 and 2003 and from MERS in 2015. In Italy the epidemic of SARS-CoV caused just 4 infections and no deaths\cite{2}. At the moment, South Korea is affording the pandemic COVID-19, without locking-down the economy, with a program based on previous experience, combining massive screening and contact-tracing, in order to immediately find out the epidemic center of infection. Asian people still use to wear sanitary masks, even now that they are slowly coming back to normal life.

There are no doubts about the fact that expiratory particles transmit the pandemic, but we must make a coarse distinction among droplets and their dynamic evolutions when emitted by infected people. This paper wants to afford the problem from a physical point of view.

\section*{Droplets}

The airborne disease is caused by violent coughing\cite{3} and sneezing\cite{4}, but many infected people were minimally symptomatic or asymptomatic at all\cite{5-7} and transmission of virus from asymptomatic carriers has been identified\cite{8}. We always emit a large quantity of droplets\cite{9,10} even just breathing and speaking.

Whatever is the possible expiratory particle source, I assume that the smallest droplets are more numerous than the bigger ones and I won’t distinguish between speaking and any other more violent expiratory events.

A single initial very large droplet ($R_0 = 1$ cm radius, $V_0 = 4.2$ cm\textsuperscript{3} volume) containing a large viral load ($10^8$ virions for milliliters\cite{8}) splits in many smaller droplets (the largest droplets having a radius of $R_3 = 50$ µm). The model that I propose assumes that the number of fragments with a radius between $r_1$ and $r_2$ is given by:

$$N = \int_{r_1}^{r_2} \frac{A}{\pi r^2} dr$$

where $A$ is a dimensionless constant. $A$ is simply 3 times the cube of ratio between $R_0$ and $R_3$ because the volume of the initial droplet must be equal to that of all the smaller droplets; in this specific case A’s value is 24000.

Fig. 1 shows droplets’ distribution function with different styles.

We define $R_1 = 0.05$ µm the radius of the smallest droplets (radius of virions of SARS-CoV2\cite{6}), $R_1 = 2.5$ µm the aerosol upper limit\cite{11}. 

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The most numerous droplets are those called fine particle aerosol (dashed line, radius $R_c < R < R_1$). Their total number is $\approx 9.4 \times 10^4$ but being their total volume only $V_a = 1.25 \times 10^{-7} \text{ cm}^3$, their viral load is absolutely negligible. Those particles cannot be stopped by a surgical mask, but there is no reason to intercept them because they are just water or mucous. For the aerosol the gravity has a negligible effect, unless it is in an environment with brackish air.

The second group (dotted line in Fig. 1), is made of droplets with the biggest size, having a radius larger than 25 µm, they are a bit more than 15,000. They constitute almost the total volume of the initial large droplet and then they contain most of the viral load. They follow a parabolic trajectory and constitute what is called fomite [12], which can contaminate surfaces where they settle.

The third group (solid line in Fig. 1) is made of droplets with an initial radius between 2.5 µm and 25 µm, they are about 55,000. Their dynamic is strongly dependent from the Stokes law, that states that a spherical droplet of radius $R$, moving in the air, undergoes a drag force given by:

$$F = -6\pi\mu R \dot{V}$$

where $\mu$ [13] is the air viscosity.

At first they don’t behave like the aerosol, because the gravity action has an important role compared with the drag force; anyway at the end the two equal and opposite forces rapidly balance and the droplet reaches a descending speed limit. That movement is slow and it allows the evaporation of water, till the droplet is reduced to its particulate or virus and it has become aerosol.

These droplets have a substantial viral load, they are quite numerous, some thousands of them can contain just one single virion each and they are probably the most contagious and dangerous elements [14]; if not stopped on time, they constitute the real element of airborne infection [15]. Take note that at the starting phase, when they are larger, they could be easily caught by a common surgical mask. The evolution of those droplets has been roughly studied a long time ago by Wells [16]; more recently it has been deeply analyzed [17].

Of course the distinction of the three different typologies of droplets is purely as an indication, they are not exact measurements.

**FFP3 mask**

In the fluids dynamics we define fluidodynamical resistance the ratio between the gas flux (usually measured in liter/s) and the pressure difference. In a normal person breathing through the nose, the fluidodynamical resistance is about 250 Pa liter/s [18].

FFP3 masks [19] have very specific technical characteristics, they should have a fluidodynamical resistance lower than 63 Pa liter/s and filters at least 99% of airborne particles larger than 0.3 µm. We know that virions of SARS-CoV2 are about 0.1 µm.

Fig. 2 shows a drawing on scale of a filter (simulating the FFP3 mask filters) with holes of 800 nm diameter and a particulate with a 300 nm diameter (down, smaller than the canal): I presume that in 99% of the cases, whatever is the coming direction, it will hit the wall and it will be stopped. The other particulate with a 100 nm diameter, moving on the same direction and angle, goes inside in the same position, but it passes through the canal without being stopped. Therefore a filter able to stop particulates of 300 nm diameter in 99% of cases, can’t have the same efficiency for smaller particles.

Shortage of FFP3 masks has been considered a very bad event, but I don’t believe we need them so much: as a matter of fact, to be an absolutely safe protection they should cling to the face completely, which is impossible, especially when worn by bearded men.

**Conclusion**

Success in fighting against a virus depends on how deep is knowledge of its characteristics: to understand how the virus aerosol changes after being emitted from the otorhinolaryngological apparatus is important in order to recommend a widely spread use of surgical masks everywhere people speak, especially indoors. Moreover I underline how FFP3 masks are poorly efficient in preventing infection, considering the nature of infectious aerosol. Waiting for a new vaccine we could hope to extirpate the SARS-CoV-2 like it happened for Smallpox [19].

**Declaration of Competing Interest**

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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