

18.03.2021

(1)

Bundesministerium:

4. COVID-19-Schutzmaßnahmenverordnung:

ABSTAND  $\longleftrightarrow$  2 Metern

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Why The distance rule? It seems pretty obvious: it has to do with the distance that is travelled by a droplet which is emitted during sneeze/talk/cough...

BUT, how it is calculated? or is it calculated at all?

Here we will see how we can simply calculate these numbers and if these numbers make any sense.

History:

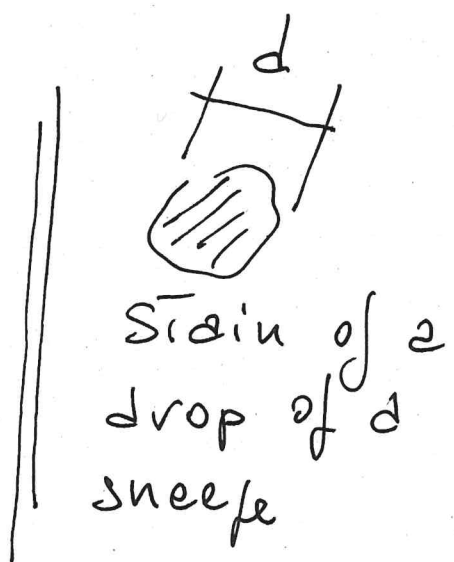
The "Spanish fever" pandemic of about 100 ~~1/2~~ years ago [1918, vor einhundertere Jahren], prompted studies on how viruses are transmitted between human beings.

A famous experiment by Dr. Duguid in years 1930 - 1940, is the basis for our current estimates on the size of droplets emitted during respiratory acts (also violent as sneezes).

1. Dr. Duguid made patients (people) sneeze and breathe in front of a celluloid slide

2. He measured the stains of the drops

3. He computed the diameter of the drops emitted.



# The size and duration of air-carriage of respiratory droplets and droplet-nuclei

(3)

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473

carrying droplet-nuclei which remained airborne after sneezing was found to decrease geometrically with time; only 4% remained airborne after 30 min. and 2% after 40 min.

In the present investigation, the droplet-nuclei produced in speaking, in coughing and in sneezing have been measured by a new technique, namely, by direct micrometry after their recovery from the air on to oiled slides. The sizes of the smaller respiratory droplets have been calculated from the sizes of these droplet-nuclei. The sizes of the larger respiratory droplets have been estimated from measurements made of stain-marks found on slides exposed directly to mouth-spray. By appropriate combination of these two sets of findings, the formulation of a comprehensive size distribution for the respiratory droplets has been attempted. The duration of aerial infection by droplet-nuclei has been observed by examination of the air at intervals after droplet-spray production, for the presence both of bacteria-carrying droplet-nuclei and of all microscopically visible droplet-nuclei.

## THE MEASUREMENT OF DROPLETS AND DROPLET-NUCLEI

The following expiratory activities were tested: (1) *sneezes*, induced by snuff or by tickling the nasal mucosa with a throat swab; (2) *coughs with the mouth initially closed*, voluntarily performed with the lips, or with the tongue and the upper teeth, approximated at the start of expiration; (3) *coughs with the mouth open*, voluntarily performed with the mouth kept well open and the tongue depressed; (4) *speaking loudly one hundred words*, by counting from 'one' to 'a hundred'.

### A. The measurement of stain-marks on slides exposed directly to mouth-spray

In order that even the smallest droplet-marks might be readily visible, some dye was introduced into the mouth just prior to each test. A little congo red, eosin or fluorescein powder was applied with a throat swab to the surfaces of the mouth and fauces; the heaviest application was made to the tip of the tongue, to the front teeth and to the lips, for droplet-spray originates largely from the secretions of the anterior mouth. Following solution of the dye, droplet-spray was produced by sneezing, by coughing or by speaking; it was directed at a celluloid-surfaced slide held 3 in. in front of the mouth in tests of speaking, and 6 in. in front of the mouth in tests of coughing and sneezing. The slide was examined under the microscope, and the diameters of the first few hundred droplet-marks encountered were measured with aid of a micrometer eyepiece. In the case of each type of expiratory activity, a number of tests, from 10 to 22,

were carried out, involving the measurement of 3000 droplets.

In order to ascertain the relationship between the diameters of the droplets while in their original spherical state, and the diameters of the stain-marks which the droplets leave on evaporation after impinging and flattening upon a slide, the experiments of Strausz (1926) were repeated. With the low power of a microscope and a micrometer eyepiece, large drops of saliva (1-3 mm. in diameter) were measured, first while they hung from fine glass capillaries and then again after they had fallen, flattened and evaporated on a slide. When a glass slide was used, it was found, as it had been by Strausz, that the

Table 1. The size distribution of the larger droplets

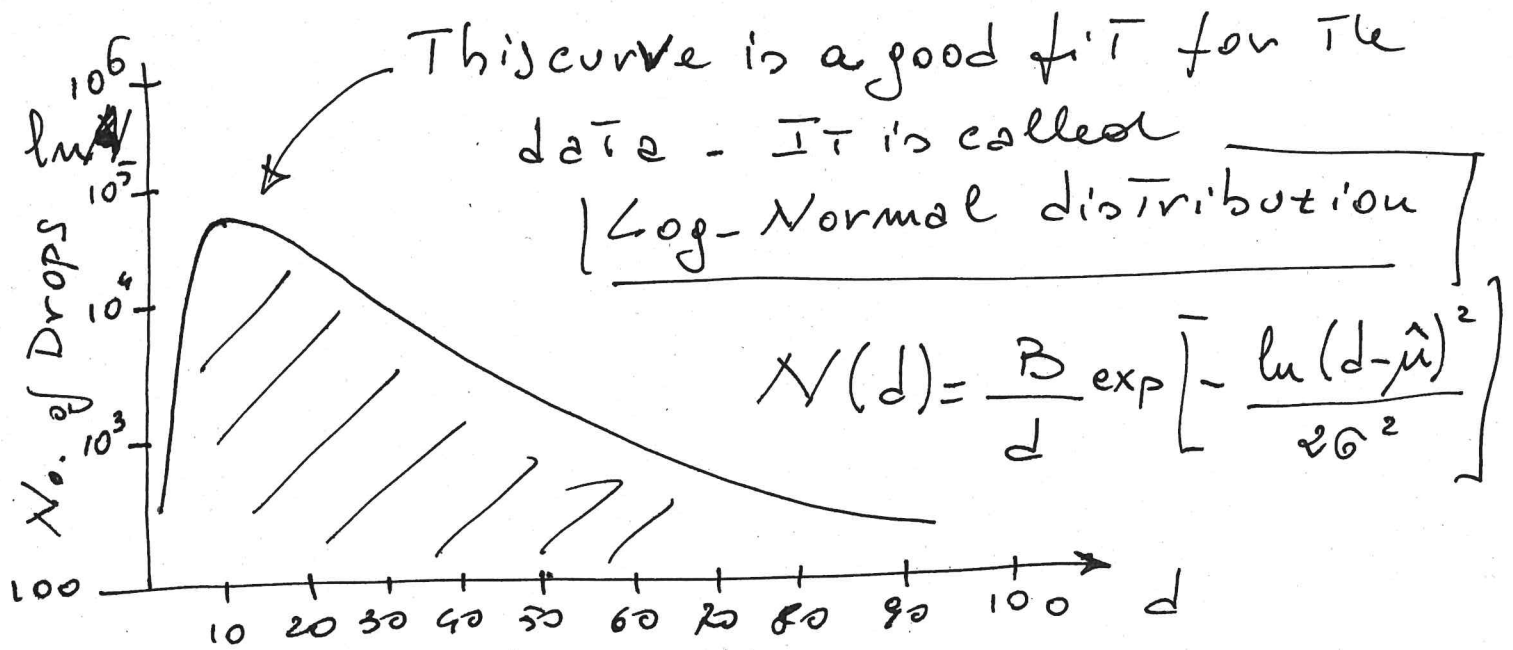
Showing for each type of expiratory activity the diameters of 3000 droplets calculated as half the measured diameters of the stain-marks found on celluloid slides exposed a few inches in front of the mouth.

| Diameter in $\mu$ | Sneezes | Coughs with mouth 'closed' | Coughs with mouth open | Speaking loudly |
|-------------------|---------|----------------------------|------------------------|-----------------|
| 0-5               | 0       | 0                          | 0                      | 0               |
| 5-10              | 36      | 24                         | 8                      | 20              |
| 10-15             | 94      | 119                        | 39                     | 84              |
| 15-20             | 267     | 337                        | 127                    | 200             |
| 20-25             | 312     | 346                        | 189                    | 224             |
| 25-50             | 807     | 767                        | 577                    | 597             |
| 50-75             | 593     | 468                        | 593                    | 531             |
| 75-100            | 260     | 285                        | 341                    | 352             |
| 100-125           | 144     | 160                        | 231                    | 260             |
| 125-150           | 105     | 125                        | 202                    | 214             |
| 150-200           | 115     | 115                        | 253                    | 179             |
| 200-250           | 82      | 96                         | 165                    | 99              |
| 250-500           | 118     | 113                        | 213                    | 197             |
| 500-1000          | 59      | 40                         | 52                     | 41              |
| 1000-2000         | 8       | 5                          | 10                     | 2               |

← Table 1

diameters of the original droplets were about one-third those of the stain-marks. When a celluloid-surfaced slide was used, the diameters of the original droplets were about half those of the stain-marks. Celluloid slides were used throughout the present investigation, so the original droplet diameters have been calculated as half the measured diameters of the stain-marks. The size distribution so found for the droplets expelled in the different expiratory activities, is shown in Table 1. It will be noted that few droplets were found of less than 10  $\mu$  in diameter and none of less than 5  $\mu$ . It is presumed that droplets smaller than this possessed such a small mass, or evaporated rapidly to such a small mass, that they were carried past the slide in the deflected air stream.

If we plot The dots by Douvois, we can obtain a "Probability Distribution", which tells us how <sup>many</sup> ~~many~~ droplets per diameter we have @ emission [Sheep]



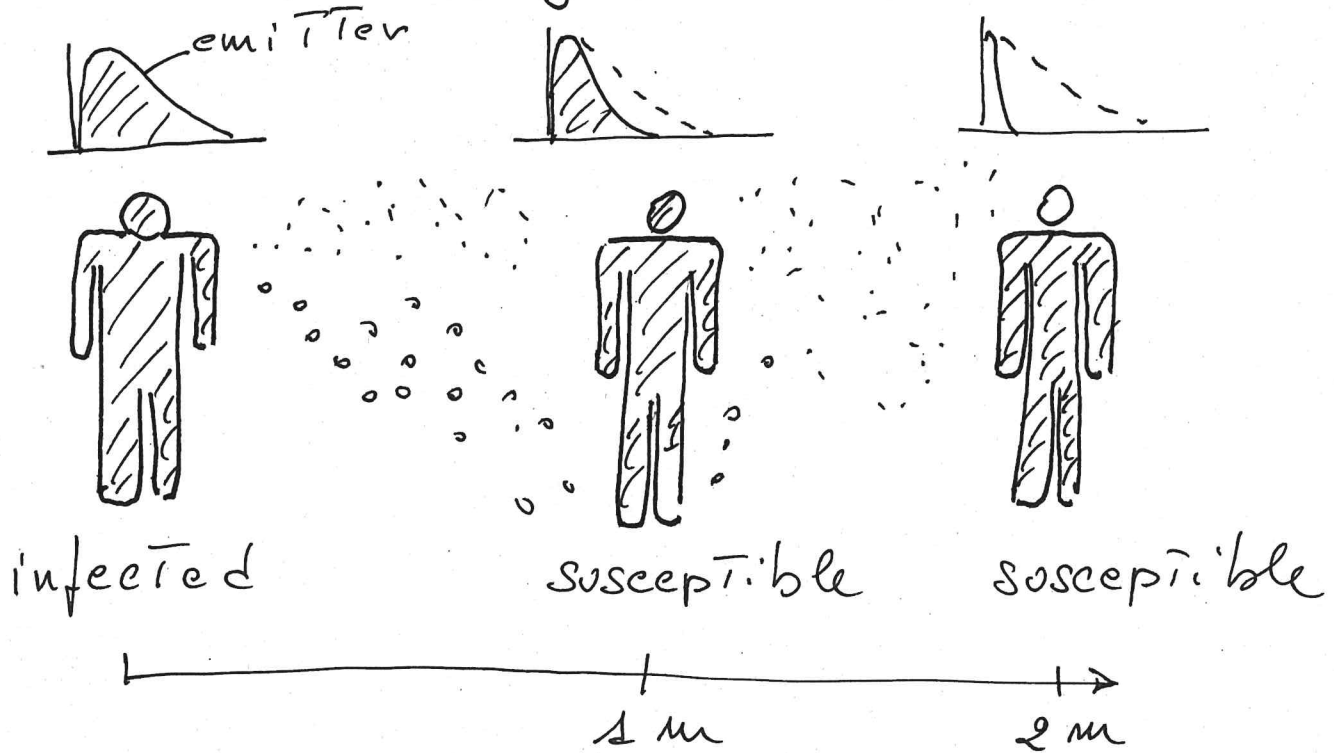
where  $d$  = diameter ;  $\hat{\mu}$  = average diameter  
 $\sigma$  = r.m.s. (standard deviation)  
 $B$  = constant

~~Once we know~~

Of course There are questions relative to The accuracy of the experiments of Douvois - In 100 years, more accurate experimental Techniques have been developed.

On these data are based the current guidelines for safety!

⑤



So, the question is now the following.

Assuming that larger drops contain more copies of the virus,

• How many and how big droplets can reach the two susceptible individuals?

In other words, how does the PDF of the droplet change with the distance (or time)?

Once airborne, droplets can do only two things:

1. They can fall
2. They can evaporate

### Droplets That fall

In lecture II, we have computed the free-fall velocity of a small droplet as:

$$v_s = \frac{[\rho_p - \rho_f] g d^2}{18 \mu}$$

in the hypothesis of the Stokes eqns,

$$Re_p = \frac{\rho_f \cdot d_p \cdot v_s}{\mu} < 1$$

$\rho_p$  = density of a drop  $\approx 1000 \text{ kg/m}^3$  This eq. is valid.

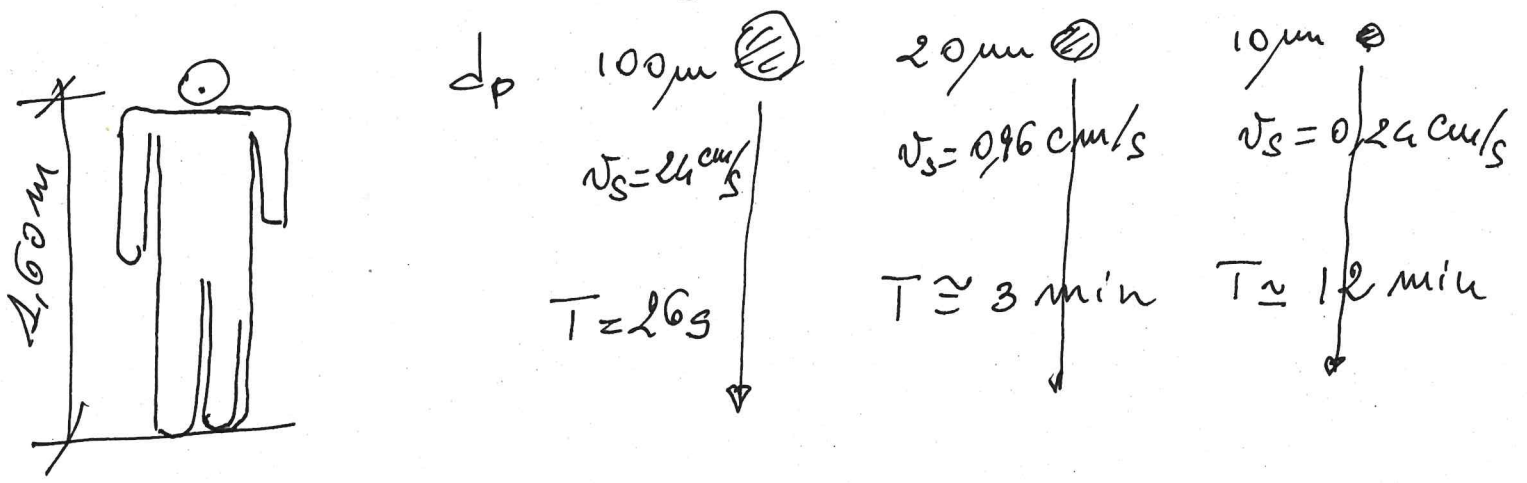
$\rho_f$  = " of air  $\approx 1,2$

$\mu_f$  = viscosity "  $\approx 2 \cdot 10^{-5}$

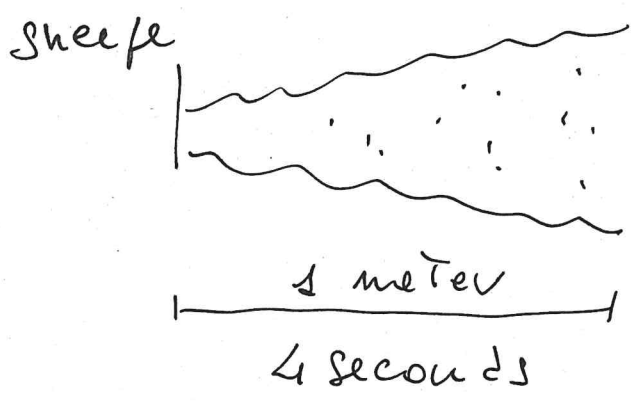
$g = 9,81 \text{ m/s}^2$

| $d_p$ [mm] | $v_s$ [cm/s] |
|------------|--------------|
| 100        | 24           |
| 50         | 6            |
| 20         | 0,96         |
| 10         | 0,24         |
| 5          | 0,06         |

So, it turns out that for a drop with diameter  $d_p = 10 \mu\text{m}$  [ $10^{-5} \text{m}$ ] it takes about 666 seconds to reach the ground if emitted at about 1.60 m height [mouth level]



During a sneeze, droplets are emitted at about 5 meters per second (also much faster) - The jet (the sneeze) slows down very quickly - In average, to set up our model, the jet travels 0.5 m in only 1 second, and about 1 m in 4 seconds.



Small drops, smaller than  $50 \mu\text{m}$ , will peacefully travel with the jet.

But, when particles travel, they evaporate. They are exposed to ambient air which is in general dry compared to the droplets! Therefore, to compute

(8)

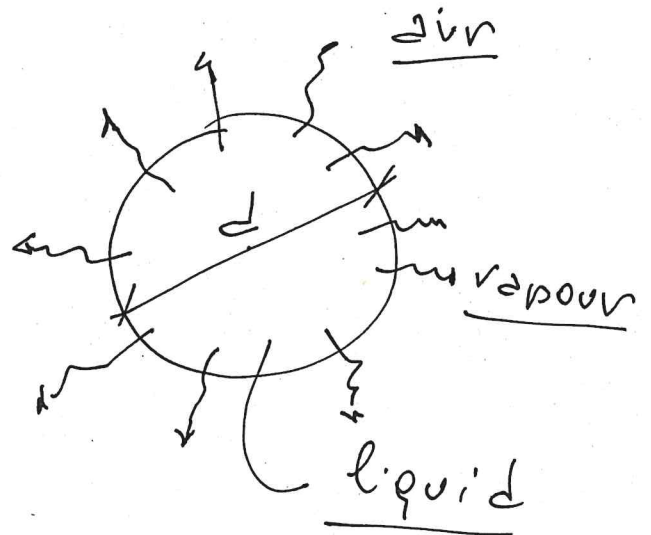
The evaporation rate of droplets, we rely (and current safety measures also)

on a research by Wells (1939), which is in turn based on a paper by Langmuir (1918)

The way in which a drop loses mass by evaporation is as follows [Langmuir, 1918]

$$-\frac{dm}{dt} =$$

$$= \pi d D \rho \frac{N_u}{Pr} [1 + B_m]$$



$d$  = drop diameter

$D$  = diffusion coefficient of vapour in air

$N_u$  = Nusselt number [Transfer properties]

$B_m$  = coefficient [how humid is air]

We can rewrite:

(9)

$$m = \rho \cdot \frac{\pi d^3}{6}$$

↑  
drop density

$$\frac{d \left[ \frac{\pi \rho d^3}{6} \right]}{dt} = - \pi d D \rho V_u \ln[1 + B_m]$$

$$\cancel{\frac{\rho \pi}{6}} \cdot d^2 \cdot 3 \frac{d(d)}{dt} = - \cancel{\pi} \cancel{d} D \cancel{\rho} V_u \ln[1 + B_m]$$

✱ Simplifying

$$d \frac{d(d)}{dt} = - \underbrace{2 D V_u \ln[1 + B_m]}_k$$

It is an equation with separable variables

$$d \, d(d) = - k \, dt$$

$$\frac{d^2}{2} = - k t + \text{Const} \quad \text{and}$$

$$d(t) = \sqrt{d_0^2 - k' t}$$

where  $d_0$  is the initial droplet diameter.

The major effect of  $k'$  is to consider different environmental humidity -

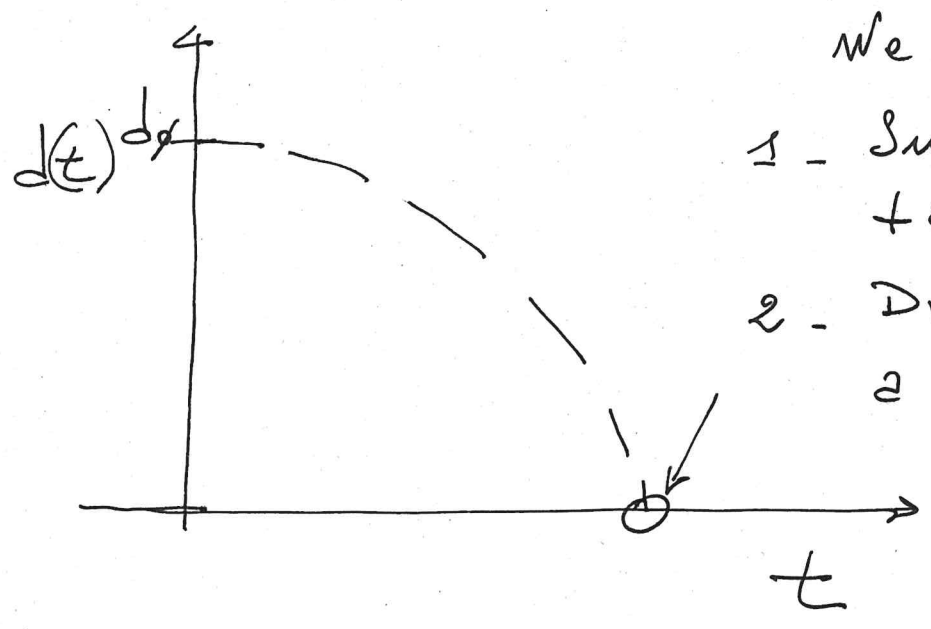
The evaporation is slower if the air is more humid -

Application

Air humidity = 98%

it is extremely humid - Today in Vienna [17. March. 2021] air has 44% humidity

The Behaviour of  $d(t)$  is as follows



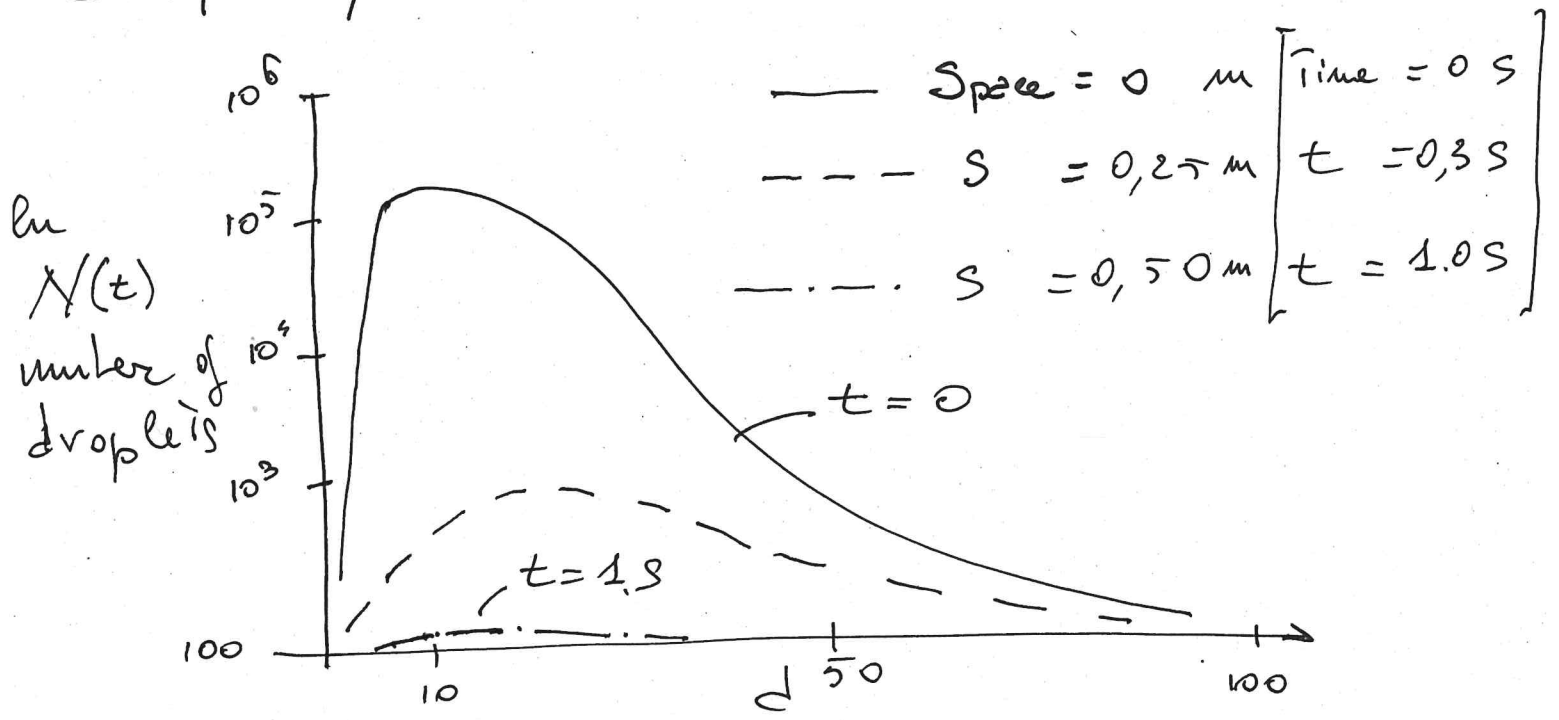
We observe that :

- 1 - Small drops evaporate faster
- 2 - Drops vanish in a finite time

There are two big questions -

- 1 - Can it be acceptable that drops evaporate down to disappear?
- 2 - What is the effect of evaporation on the distribution of diameters?

# Effect of evaporation on drop size distribution



$S$  = Space covered from mouth

$t$  = Time elapsed from sneeze.

So, if we use the model, after 1 second ALL Drops have disappeared. Even in 98% humidity!

So, why are all worried?

One important point is that Droplets contain matter that cannot evaporate. Mucos, proteins, and the virus itself, which is a big protein [ ~ 80 nanometers ]

Question 1 -

If a drop contains only 0,1% non volatile matter, what will be its final size?

$\phi = \text{fraction of N.V.M. [non volatile matter]}$

$\phi = 0,1\% \text{ [almost pure water]}$

$d_{\text{final}} = 0,1 d_{\phi} \quad \nabla$

$\phi = 3,0\%$

$d_{\text{final}} = 0,3 d_{\phi} \quad \nabla$