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EQUIVALENT ELECTRICAL MODEL CIRCUIT FOR COVID-19 ELECTROCHEMICAL DETECTION

Cesar A. Hernandez, Johann F. Osma*

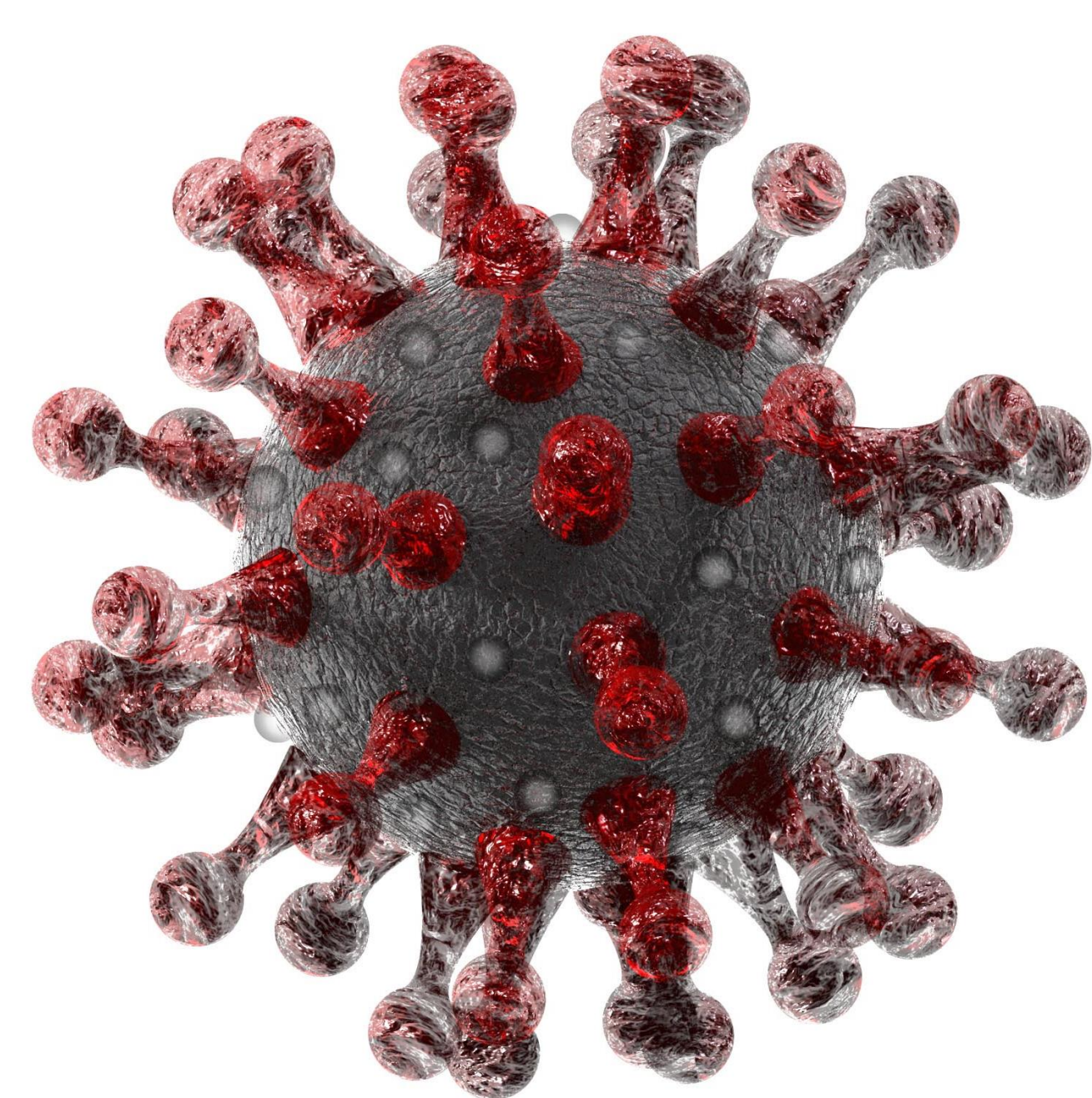
CMUA. Department of Electrical and Electronic Engineering, Universidad de los Andes, Carrera 1E # 19A-40, Bogota 111711, Colombia

* Author to whom correspondence should be addressed.

Motivation

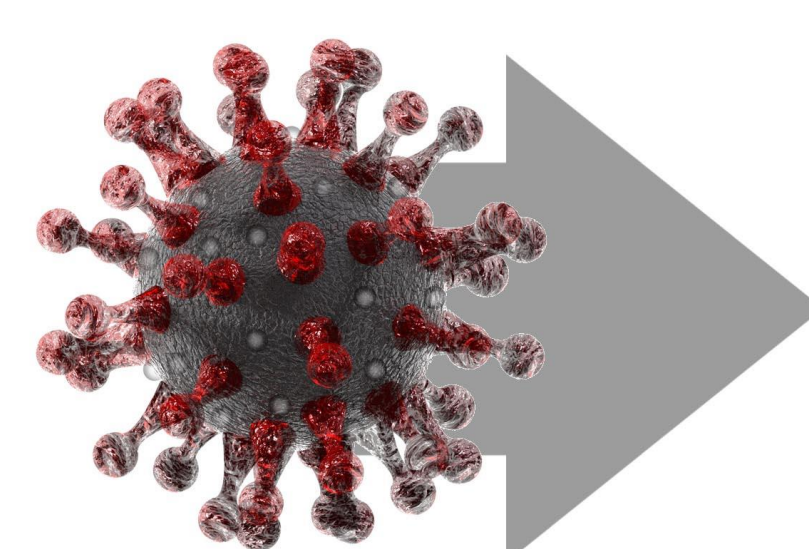
Electrochemical technologies have proven to accomplish the requirements for fast and economically amendable screening tools, with demonstrated applicability for sensing human influenza (H1N1) [1], rabies [2], human papilloma virus [3], among others. One of the main advantages of electrochemical detection is that it allows to obtain readily accountable results, which translates in market products that require little training, making them perfect candidates in emergency situations. On the other hand, the design and development of devices based in electrochemical technologies requires a careful understanding of each element that would partake in the final measurement. Motivated by the recent outbreak of the newly designated Coronavirus disease 2019 (COVID-19), this work presents the equivalent electrical model circuit for different electrochemical virus detection strategies focused in the COVID-19 related virus SARS-CoV-2 (severe acute respiratory syndrome coronavirus 2) viral particle (virion), ranging from the single particle electrical characteristics, to suspension dispersed virus (colloid) and immobilization. The basic model is based in the dielectric properties of the virion structure, represented by the single shell and the dual shell spherical model [4]. The results provide a simple capacitive representation which can be used for the more complex scenarios, in which the diffusive effect of the suspension medium and the immobilization molecules should be accounted for in order to avoid misreading and, correspondingly, misdiagnosis.

Physiology



The SARS-CoV-2 is a member of the viral family *Coronaviridae*, which contain positive-stranded RNA of around 30 kb in length, protected by a nucleocapsid protein covered by a lipid envelope, with a total diameter of 60-140 nm as observed under an electron microscope, with a crown-like appearance, given due to the spike proteins protruding out of the virus lipid membrane [5].

Electrical Models



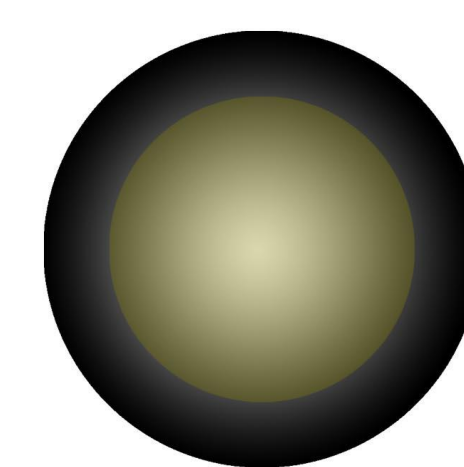
Maxell equation

For two concentric spheres $R_1 > R_2$ each with relative complex permittivity ϵ^*

$$\epsilon_c^* = \epsilon_1^* \frac{2(1-\varphi) + (1+2\varphi)\frac{\epsilon_2^*}{\epsilon_1^*}}{(2+\varphi) + (1-\varphi)\frac{\epsilon_2^*}{\epsilon_1^*}}$$

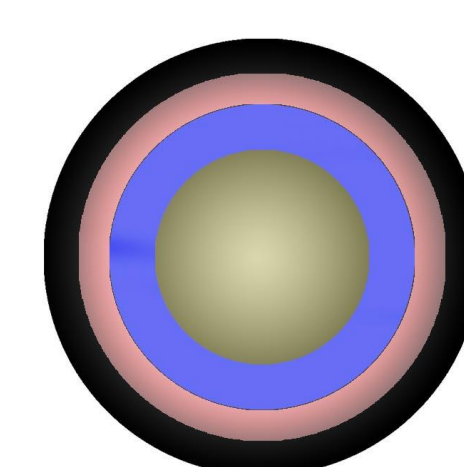
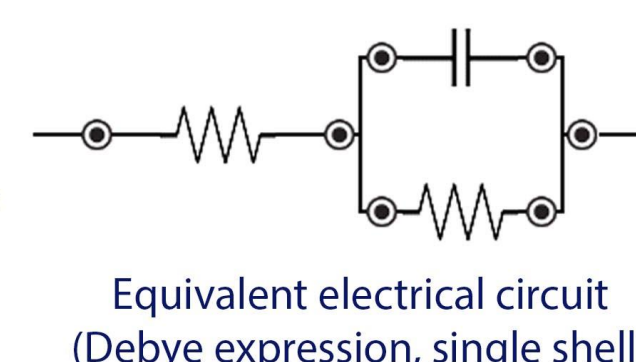
where

$$\varphi = \left(\frac{R_2}{R_1}\right)^3 \quad \text{and} \quad \epsilon^* = \epsilon' + i\epsilon''$$



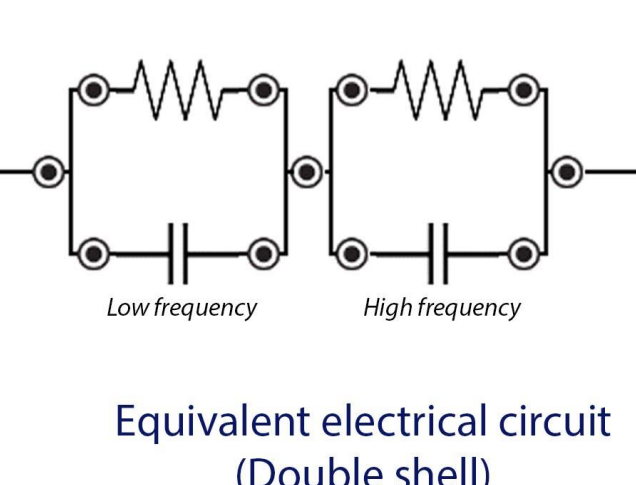
Model 1

- Core
 - R_c
 - ϵ_c^*
- Membrane
 - $a_m = R_{\text{virus}} - R_c$
 - ϵ_m^*



Model 2

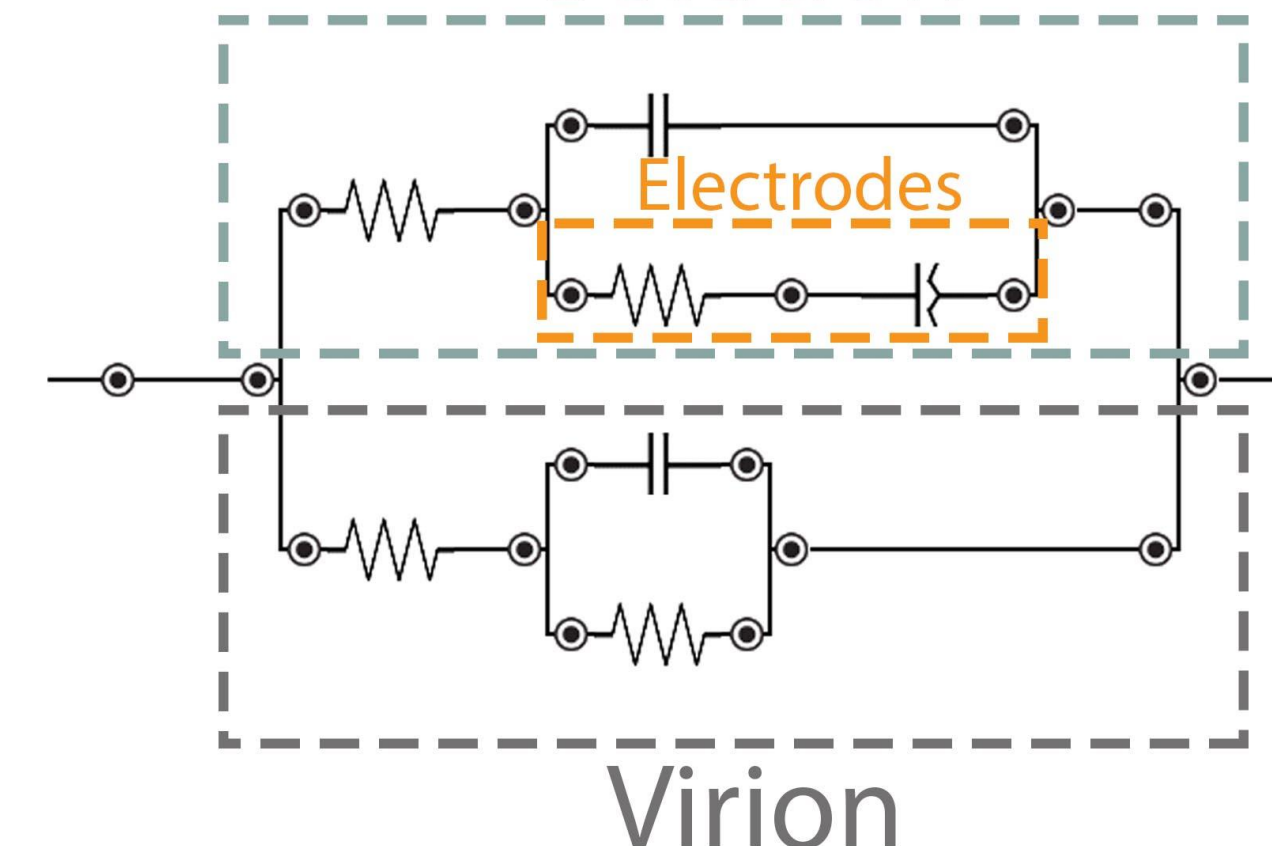
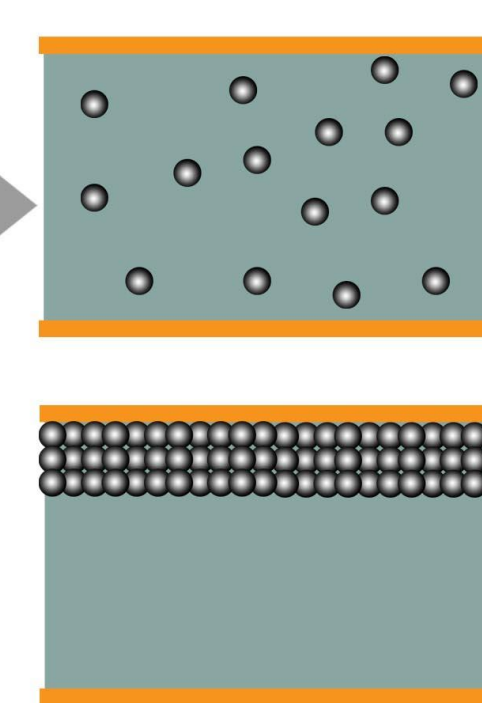
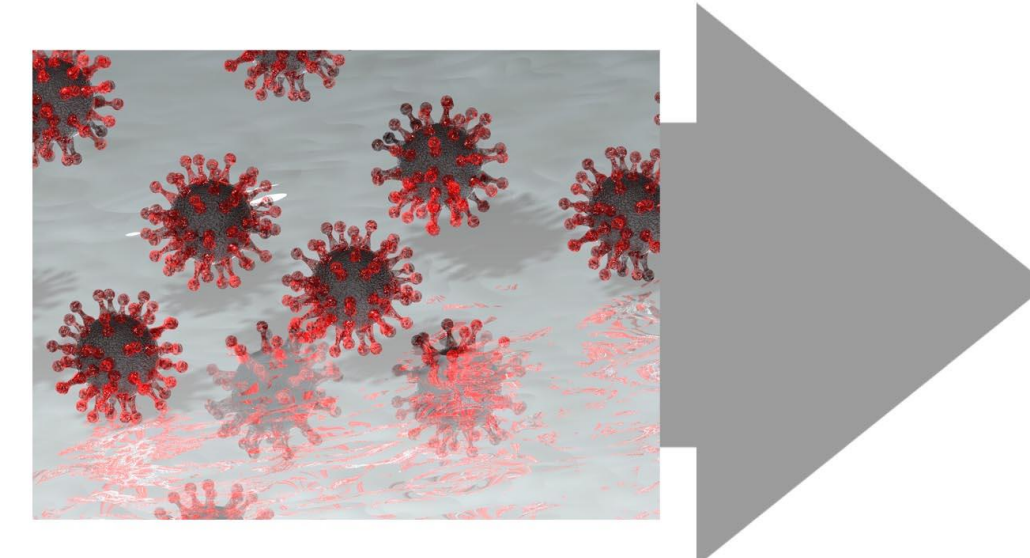
- Core
 - R_c
 - ϵ_c^*
- Capsid
 - a_{cs}
 - ϵ_{cs}^*
- Protein layer
 - a_p
 - ϵ_p^*
- Membrane
 - a_m
 - ϵ_m^*



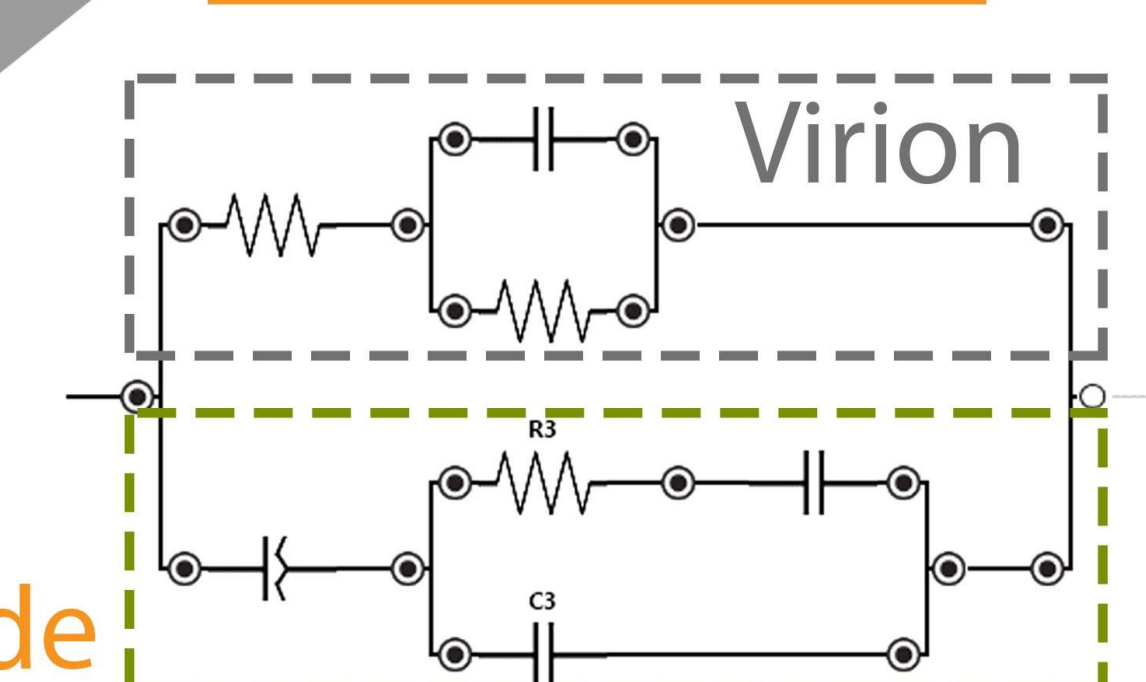
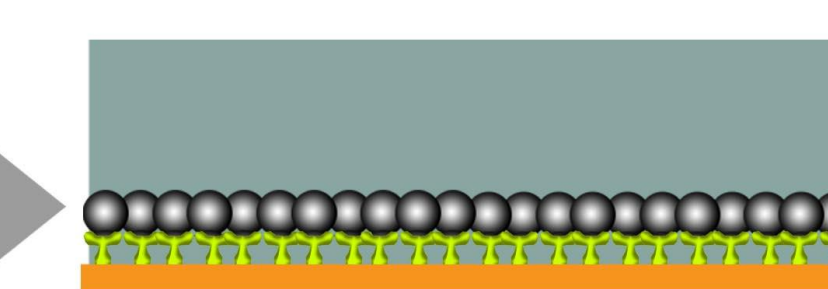
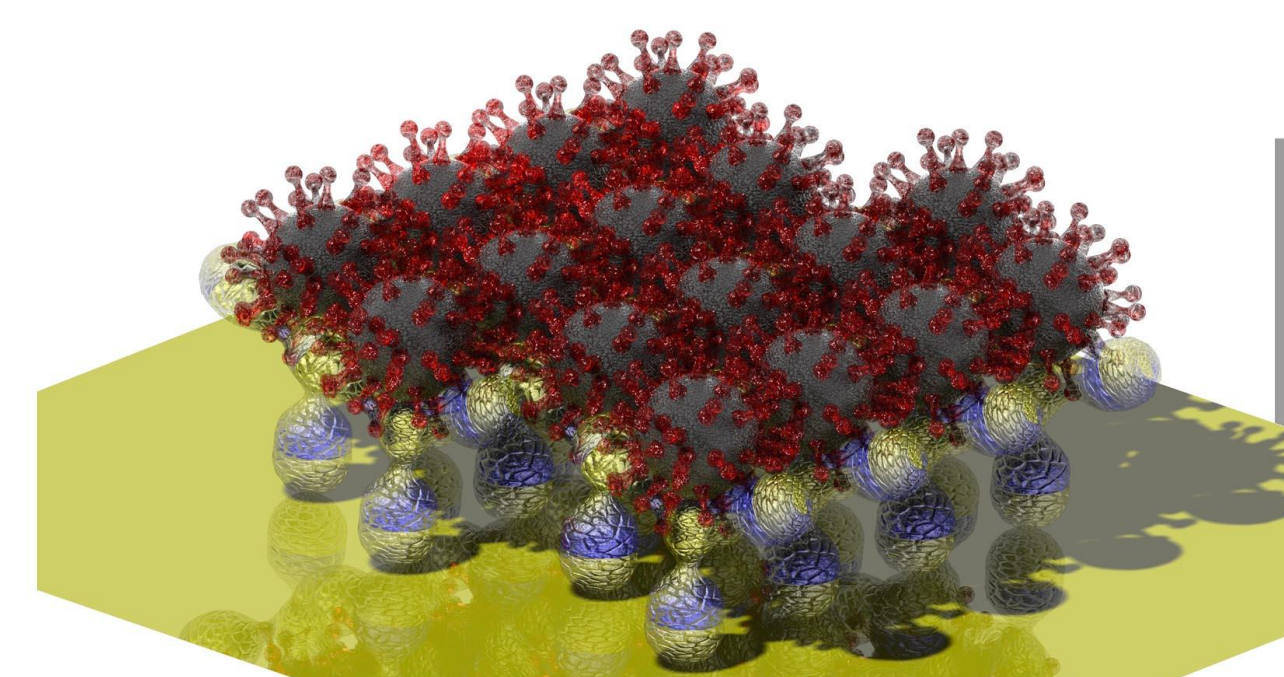
Virion

Suspension

Solution

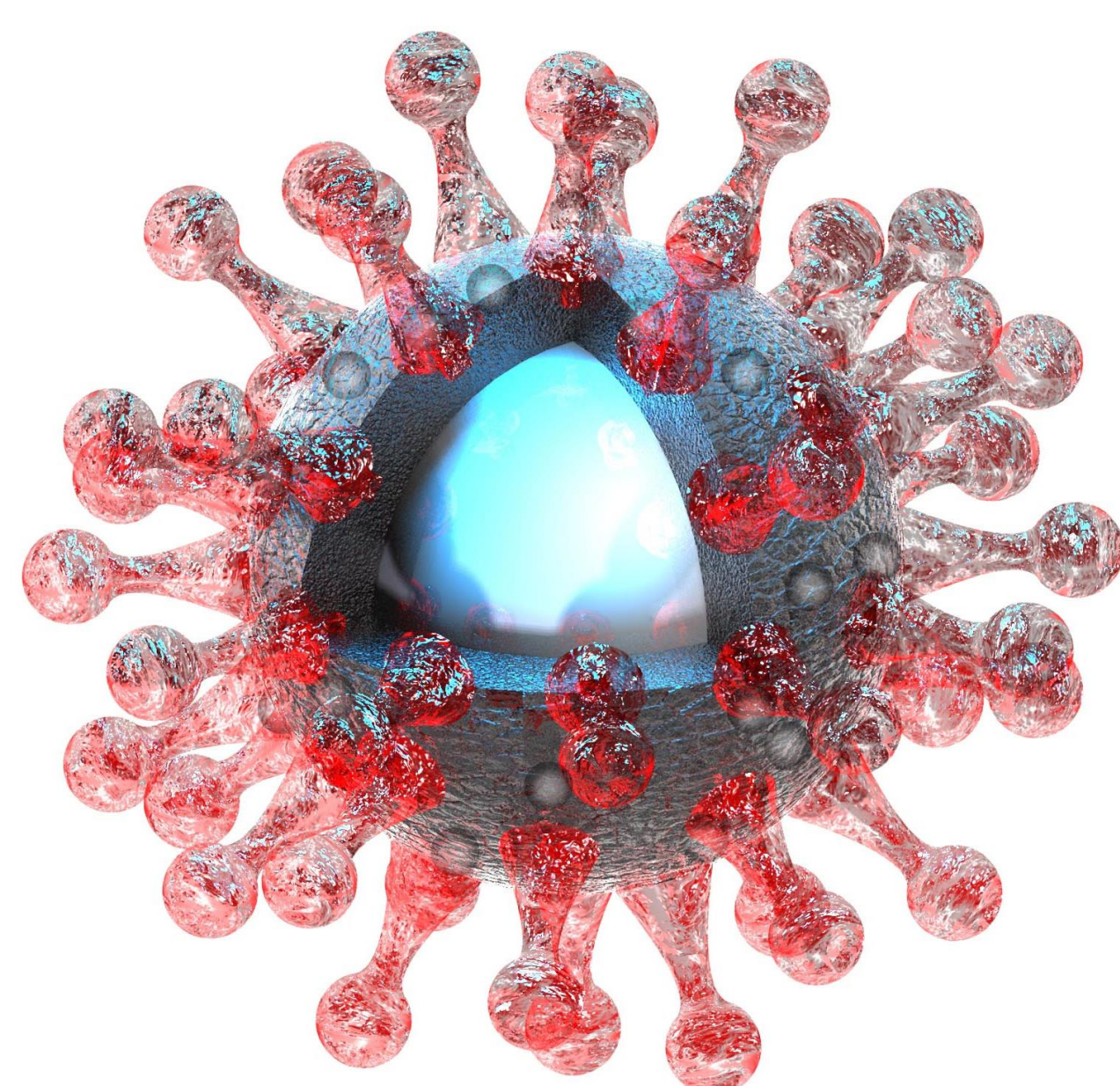


Immobilization



Antibody + Electrode

Electrical Structure



The contained RNA of SARS-CoV-2 contains phosphodiester bonds, which provides a partial negative charge to the virus, while the usual external envelope protein for CoV is usually composed of at least 17% negative charged lipids, influencing the ion selectivity of the membrane [6]. As such, SARS-CoV-2 virions behave as semi-conductive particles that can be modeled with a real and an imaginary impedance component. However, the small dimensions of virions require modeling that include physical interactions of various particles with different types of interactions.

CONTACT PERSON

Johann F. Osma
jf.osma43@uniandes.edu.co

Cesar A. Hernandez
ca.hernandez.edu.co

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