Theoretical Analysis of the Induction of Forced Resonance Mechanical Oscillations to Virus Particles by Microwave Irradiation: Prospects as an Anti-virus Modality

Nikolaos K. Uzunoglu

National Technical University of Athens

Abstract

The induction of acoustic-mechanical oscillations to virus particles by illuminating them with microwave signals is analyzed theoretically. Assuming the virus particle being of spherical shape, its capsid consisting primarily of glycoproteins, a viscous fluid model is adopted while the outside medium of the sphere is taken to be ideal fluid. The electrical charge distribution of virus particle is assumed to be spherically symmetric with a variation along the radius. The generated acoustic-mechanical oscillations are computed by solving a boundary value problem analytically, making use of the Green's function approach. Resonance conditions to achieve maximum energy transfer from microwave radiation to acoustic oscillation to the particle is investigated. Estimation of the feasibility of the technique to compete virus epidemics either for sterilization of spaces and/or use for future therapeutic applications is examined briefly.

1.   Introduction

The study of physical properties of various type viruses has attracted significant interest by several interdisciplinary research groups during the last 10 years[1]. Mechanical properties of virus particles with diameters of 10-300 nm, in particular the capsids enclosing the virus gene structures (DNA,RNA both single or double stranded), have been studied

experimentally using Atomic Force and Electron Microscopy(AFM)[2,3]. Also, Elasticity Theory methods applied to draw conclusions on the mechanical properties of virus particles[4]. Electric charge distributions of virus have been also studied by several researchers[5,6,7,8,9]. It is observed that under physiological conditions of salinity and acidity, virus capsid assembly requires the presence of genomic material that is oppositely charged to the core proteins[10]. Furthermore, few researchers have focused their research on the possibility of inducing photon-phonon interactions[11] in virions, which are the virus causing infections[12,13,14,15,16,17]. Already resonance phenomena of the H3N2 and H1N1 viruses have been demonstrated experimentally[18] , leading to high rate extinction of them at a resonance microwave frequency near 8 GHz. The physical phenomenon attributed to this interaction is the separation of positive – negative electric charges on the body of the virus particles and the coupling of microwave energy through the interaction with the three dimensional bipolar electric charges distributions, generating mechanical oscillations at the same frequency. At specific microwave frequencies depending on the diameter and other properties of the particle[19,20], primarily the dipole acoustic mode, have been claimed and strong coupling leading to high level virus killing rates have been demonstrated recently (ref. 19 and 20). The effects of hydration levels on the bandwidth of microwave resonant absorption induced by confined acoustic vibrations has been also studied[21]. It should be stated that the involved phenomenon is of non-thermal nature related to non-ionizing radiation, in this case being the I band microwaves (6-10 GHz). Raman scattering phenomena[22] have also verified the existence of acoustic-mechanical resonance phenomena in virus particles[23].

The recent ongoing Covid-19 worldwide pandemic[24] and its severe consequences, makes attractive to investigate the possibility of utilizing the above-mentioned resonance phenomenon either in sterilization of spaces[25] such as clinics, public venues, hospitals etc. and in future as a therapeutic modality in some cases. Along this direction, the possibility of utilizing similar methods used in microwave induced hyperthermia, to raise the temperature of malignant tumors inside the human body, could be envisaged as therapeutic modality. In fact, contrary to hyperthermia where usually lower frequencies 27-2450 MHz are used[26] in this case much higher frequencies (6-8 GHz) needed to be used. In some cases, ultrasound and laser radiation modalities have been also used, in clinical hyperthermia, along the low frequency microwaves radiation using endo-cavitary radiators. However in present case, the interaction of non-ionizing radiation with tissues will be entirely different of the hyperthermia, to compete the virus populations. The rather high frequencies used in the present resonance phenomenon poses a challenging problem to penetrate with high intensity electric fields inside the human body such the case of lungs. However, in case of larynx and throat and even some parts of lungs endo-cavitary radiators[27], as done in hyperthermia could be used. Finally since in present case, the action of microwave radiation having the character of a resonance interaction, it foreseen not needing long time irradiation, contrary to hyperthermia which in order to raise the tissues to 43 - 45° C, needs usually 45-60 minutes. This principle allows, to propose in present case short duration pulsed - periodic high intensity microwave signals[28,29]. This is expected to alleviate to some degree the penetration problem of electromagnetic energy to human body.

In all the mentioned publications of this resonance phenomenon, the virus particle is assumed of being an elastic particle, as was modelled by H. Lamb in 1887[30] for the oscillations of an ideal spherical isolated in space. In present article, the mathematical analysis is carried out also considering the surrounding medium of the virus particle and taking into account the interaction of external microwave radiation with the electric charge distribution of the virus particle. Based on the recently published data on the structure[31] of the Covid-19 virion of being of 100-150nm in diameter, because of its reach liposome capsid with few proteins on it, in the present work lead us to adopt the model the spherical virus particle as a viscous fluid while the outer space is taken to be an ideal fluid, with different acoustic characteristics of the spherical particle. Furthermore, vortex phenomena in modelling the viscous virus structure are neglected, since it assumed these are very weak and they have no effect on the resonance phenomenon to be studied.

2.   Mathematical Formulation of the Phenomenon.

A spherical particle of radius α, shown in Fig.1, is assumed to poses a continuous electric charge distribution with spherical symmetry defined with the equation

$$\rho_q(\mathbf{r}) = \frac{Q}{\sigma} \ (1 - \frac{5}{3} \ (\frac{r}{\alpha})^2) \qquad\qquad (1)$$

Where Q is the total positive electric charge in the center of the sphere, $\sigma = 8\pi\alpha^3(3/5)^{3/2}/15$ is a normalization constant. The term 5/3 in the
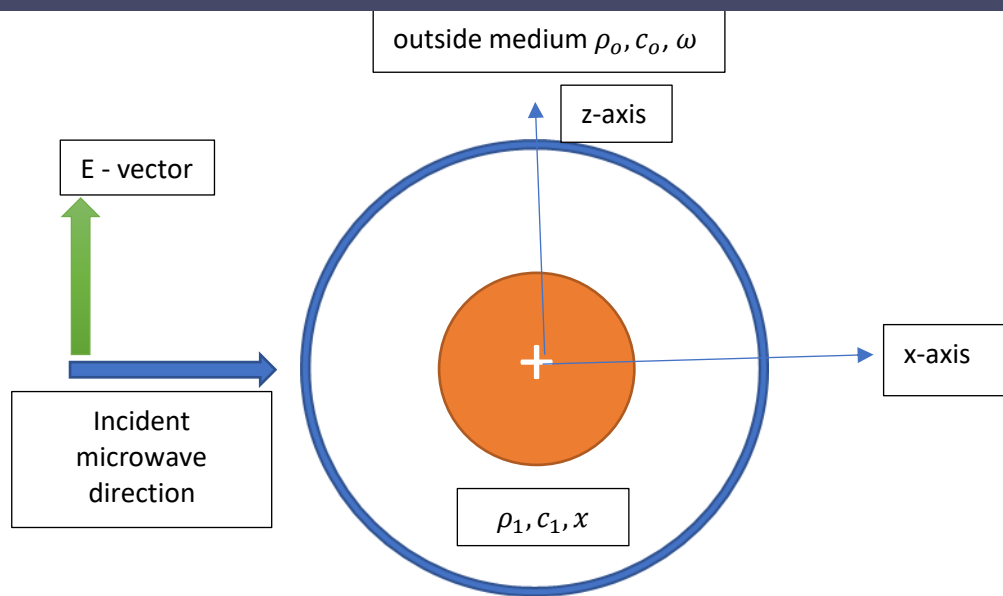
Fig.1. Spherical model for the virus particle.

above eq.(1) was selected to have the total charge of the particle to be zero, that is to have a balance between the positive (inner $r<\alpha(3/5)^{1/2}$ region) and negative (towards the external surface) charge distributions. It is evident that the particle could have the opposite charge distribution and the same analysis is valid. The proposed method is extendable to the case of non-symmetric charge distribution, then higher order modes will be excited.

The spherical model of the virus is assumed to be a compressible fluid, characterized with its homogenous mass density ρ_1 acoustic wave propagation speed c_1 and total viscosity constant (dynamic and bulk) χ. Then, assuming a $e^{j\omega t}$ a time dependence, the propagation of acoustic wave phenomena are described by the following field equations[32]:

Newton Law

$$\rho_1 j\omega \boldsymbol{v_1}(\boldsymbol{r}) = -\nabla P_1(\boldsymbol{r}) + x\, \nabla\big(\nabla.\,\boldsymbol{v_1}(\boldsymbol{r})\big) + \boldsymbol{f} \qquad (2)$$

where v_1 is the velocity, P_1 the pressure field and f is the force density (N/m³) because of the electric charge distribution   inside the sphere.

Mass continuity equation

$$j\omega P_1(\boldsymbol{r}) = -c_1^2 \, \rho_1 \, \nabla. v_1(\boldsymbol{r}) \qquad (3)$$

The force density term f in eq. (2), taken into account the charge distribution given in eq.(1) and the incident electric field $\boldsymbol{E}(r) = E_o \, \hat{z}$ of the microwave radiation propagating along the x axis and polarized parallel to z axis (see Fig.1), considering the size of the particle to be extremely small compared to microwave radiation wavelength,   is obtained to be:

$$\boldsymbol{f} = \rho_1(\boldsymbol{r})E_o\hat{z} \qquad (4)$$

Operating on the eq.(2) the $\nabla.$ operator   from the left hand side, substituting eq.(3) , eq.(4) and rearranging the terms the following wave equation is obtained:

$$\nabla^2_. P_1 + k_1^2 P_1 = E_o \, u_o z \qquad (5)$$

where

$$k_1 = \frac{\omega/c_1}{\sqrt{1+j\varepsilon}} \; , \; \varepsilon = \frac{\omega\chi}{c_1^2 \, \rho_1} \; , \; u_o = -\frac{10Q}{3\sigma \, \alpha^2} \qquad (6)$$

The pressure field   outside of the particle assuming an ideal fluid, is described by two respective equations of eqs. (2) and (3):

$$j\omega\rho_o\boldsymbol{v}_o(\boldsymbol{r}) = -\nabla P_o(\boldsymbol{r}) \qquad (7)$$

$$j\omega P_o(\boldsymbol{r}) = - \, c_o^2\rho_o\nabla.\boldsymbol{v}_o(\boldsymbol{r}) \qquad (8)$$

where $P_o(\boldsymbol{r})$ is the pressure, $\boldsymbol{v}_o(\boldsymbol{r})$ the velocity, ρ_o the mass density and c_o the acoustic speed. Also combining eqs.(7) and (8):

$$\nabla^2 P_o(\boldsymbol{r}) + k_o^2 P_o(\boldsymbol{r}) = 0 \qquad (9)$$

where $k_o = \omega/c_o$ is the wave constant of the infinite space outside of the sphere.

3. Solution of the boundary value problem.

The field expression inside the sphere r<α

The acoustic pressure inside spherical particle being excited by the interaction of microwave electric field component acting to electric charges, being inside the spherical volume could be described in terms of the Primary ($P_{10}(\boldsymbol{r})$) and secondary ($P_{11}(\boldsymbol{r})$) pressure fields[33].

In the analysis to follow spherical coordinates are used *r, ϑ* and *φ* being radial distance from the origin, *ϑ* being the angle measured from z axis and *φ* the azimuth angle.

The primary field $P_{10}(\boldsymbol{r})$ should satisfy eq.(4) with the right hand side inhomogeneous term. Based on the Green's theory, assuming the outside medium being infinite, the primary pressure is determined by using the equation:

$$P_{10}(\boldsymbol{r}) = u_o \iiint_{Sphere} G_1(\boldsymbol{r},\boldsymbol{r}') \, z' d\boldsymbol{r}' \quad (10)$$

inserting *z'=r'cos(ϑ')* and the expansion[34]

$$G_1(\boldsymbol{r},\boldsymbol{r}') =$$
$$-jk_1 \sum_{n=0}^{\infty} j_n(k_1 r_<) h_n^{(2)}(k_1 r_>) \sum_{m=-n}^{n} Y_n^m(\theta,\varphi) Y_n^{*m}(\theta',\Phi') \qquad (11)$$

where $j_n(.)$ and $h_n^{(2)}(.)$ are the spherical Bessel and Hankel (second type) functions, $r_< = \min(r,r')$ and $r_> = \max(r,r')$, the angular spherical wave function

$$Y_n^m(\theta, \varphi) = j^n \sqrt{\frac{2n+1}{4\pi} \frac{(n-m)!}{(n+m)!}} e^{jm\varphi} P_n^m(\theta, \varphi) \quad (12)$$

and $P_n^m(\theta, \varphi)$ being the Legendre function.

Substituting eq.(11) into (10) and *z'=r'cos(ϑ')*, the fact the double summation in eq.(10) being limited on the terms m=0 and n=1 after the orthogonality of the angular wave functions and the Bessel functions integral[35]

$$\int_{r=0}^{\alpha} j_1(k_1 r_<) h_1^{(2)}(k_1 r_>) r'^3 dr' = a^4 j_1(k_1 r) w_o + jr/k_1^3$$

whith $w_o = (3h_1^{(2)}(k_1 a) - k_1 a h_0^{(2)}(k_1 a))/(a^2 k_1^2)$

leads to the result of the primary pressure field

$$P_{10}(\boldsymbol{r}) = jk_1 u_o E_o \cos(\theta) \left(a^4 j_1(k_1 r) w_o + \frac{jr}{k_1^3}\right) \quad (13)$$

Noticing that the primary field depending only to $P_1^o(\cos\theta) = \cos(\theta)$ angular function (n=1and m=0 terms), the secondary pressure field is written easily:

$$P_{11}(\boldsymbol{r}) = A j_1(k_1 r) \cos(\theta) \quad (14)$$

The field expression outside the sphere (r>α)

Considering the excitation only the wave with cos(ϑ) dependence and the necessity of radiation condition to be valid for $r \to +\infty$ we can write easily:

$$P_o(\text{r}) = B h_1^{(2)}(k_1 r) \cos(\theta) \quad (15)$$

In eqs.(14), (15) the unknown coefficients A and B, are determined by imposing the validity of the boundary conditions at the spherical surface $r=\alpha$:

Continuity of pressure fields $P_{10} + P_{11} = P_0$

Continuity of radial velocities $\hat{r}.\left(v_1(r) - v_0(r)\right) = 0$

Then the A and B coefficients are calculated easily after some algebraic operations.

The final solution for the secondary field inside the sphere and in particular for the total pressure is obtained to be:

$$P_1 = a^{-2}QE_o\cos{(\theta)}W \qquad (16)$$

$$W = -j2.569k_1a\left[(j_1(k_1r)w_o + \frac{jr}{a^4k_1^3}) + j_1(k_1r)S\right]$$

$$S = T/R$$

$$T = \left(ak_1j_1'(k_1a)w_o + \frac{j}{a^3k_1^3}\right)h_1^{(2)}(k_oa)a^{-1}k_o^{-1}$$

$$- (j_1(k_1a)w_o + ja^{-3}k_1^{-3})h_1'^{(2)}(k_oa)$$

$$R = j_1(k_1a)h_1'^{(2)}(k_oa) - (1+j\varepsilon)j_1'(k_1a)h_1^{(2)}(k_oa)\frac{\rho_ok_1}{\rho_1k_o}$$

4. Numerical Calculations

After computing the pressure field as given in eq.(16) it is shown that the "form factor" W is a function of the dimensionless quantities $k_1a, k_oa, (\rho_ok_1)/(\rho_1k_0), r/\alpha$ and the parameter related to viscosity of the virus particle $\varepsilon = \frac{\omega\chi}{c_1^2\rho_1} = \left(\frac{k_oac_o^2}{c_1^2}\right)\delta$ where $\delta =$

$\chi/(c_o \rho_1\, \alpha)$ is a quantity related to total viscosity of the spherical virus particle. Remembering that $\chi = \frac{4\eta}{3} + \kappa$ [36] where η, κ are the shear and bulk viscosity coefficients of a Newtonian fluid, we take the quantity δ as a "measure of the degree of viscosity" in our calculations. Furthermore, the interest being on the maximum pressure on the particle we take $\theta = 0$ or π on the two poles of the sphere were the rupture of the virus capsid is sought.

In Fig.2 numerical results of the W "form factor" are given in the range $0.1 < k_o a < 3.0$ for various parameters of the ratios $\frac{\rho_o}{\rho_1} =$ $1.05, 1.1, 1.2$ and 1.3, c_0=1560m/s (speed of sound in the outer space), c_1=1950 m/s (speed of sound inside the sphere) . Meanwhile the viscosity parameter is taken χ=0.01 and χ=0.001 which corresponds to total viscosity constant corresponding to δ=0.1 and δ=0.01 (N· s/m^2). The numerical results show interesting resonance behavior when viscosity is δ=0.01 . The phenomenon is stronger as δ decreases.

 It is well known that scattering of incident waves to a sphere (acoustic or electromagnetic waves) shows resonance phenomena when the refractive index of the spherical scatter has a large value. This phenomenon is well known in classical and quantum physics (Regge poles). As mentioned in the introduction section several researchers have foreseen this phenomenon. However, in present analysis the adopted model and analysis takes into account, although in a simplified form, all the involved mechanisms. The

resonance is occurring near the angular frequency $\omega=\pi c_o/(2a)$ which corresponds to "dipole mode" of the spherical particle.
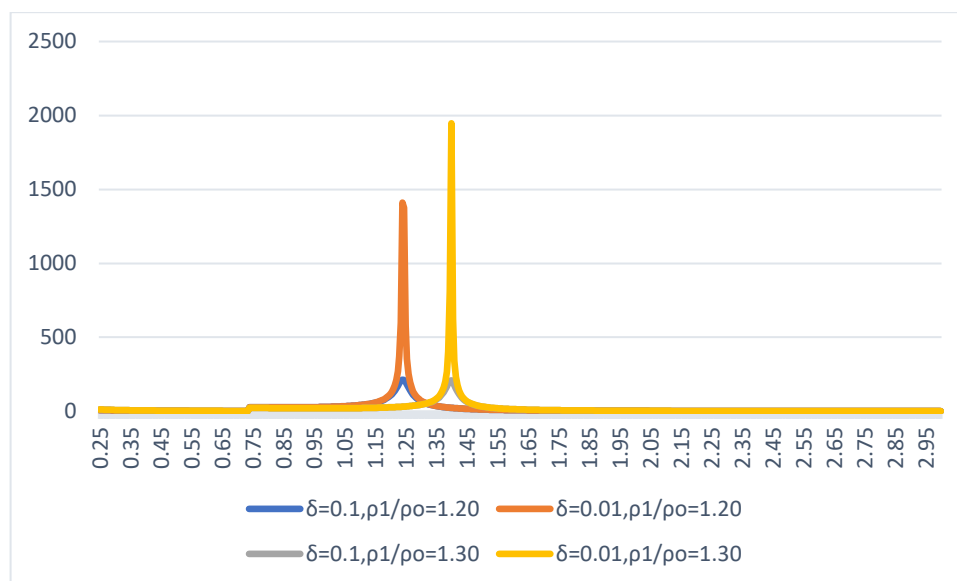

Fig.2. Dependence of W (eq.(16)) function to $k_o\alpha$.

In order to assess the feasibility of utilizing the phenomenon to compete the virus populations we need to calculate the pressure being developed at the spherical surface. Placing in eq.(16) $r=\alpha$, 2α =100 nm and $Q=Ne_o$, e_o=1.62x10^{-19} Cb (electron charge), N being the number of + or − charges we obtain after   eq.(16) the pressure P_1 =$4\cdot 10^{-5} \cdot N\cdot E_o\cdot W$, since $W\sim 2.000$ (see Fig.2) following the data given ref.9 , the surface electric charge being $\sigma \le 0.5 eo/nm^2$ the virus area being $A_s=4\pi\alpha^2$ we obtain $N\sim 3\cdot 10^4$ and $P_1 \sim 2.400\ E_o$ (Pa). Then if the imposed electric field at microwave frequency is E$_o$=1.000 (V/m) (this corresponds a power density 130 mW/cm^2 much less used in hyperthermia treatments many time being 15.000 mW/cm^2 as a continuous wave signal), we arrive to the estimation that the pressure oscillation amplitude exerted on the two poles of the virus will be $P_1\sim 2.4$ MPa. The mentioned microwave field generated pressure wave on the capsid surface seems to be comparable

with the bulk Young's module being equal to 5 MPa (see end of the section 'Methods' of ref.8).

In Fig.3. computations in case of zero viscosity are presented for various ratios ρ_1/ρ_o. The strong resonance phenomenon the ratio ρ_1/ρ_o is 1.3 while the lowering of the resonance frequency as this ratio decrease while the peak value of *W* has some variation.

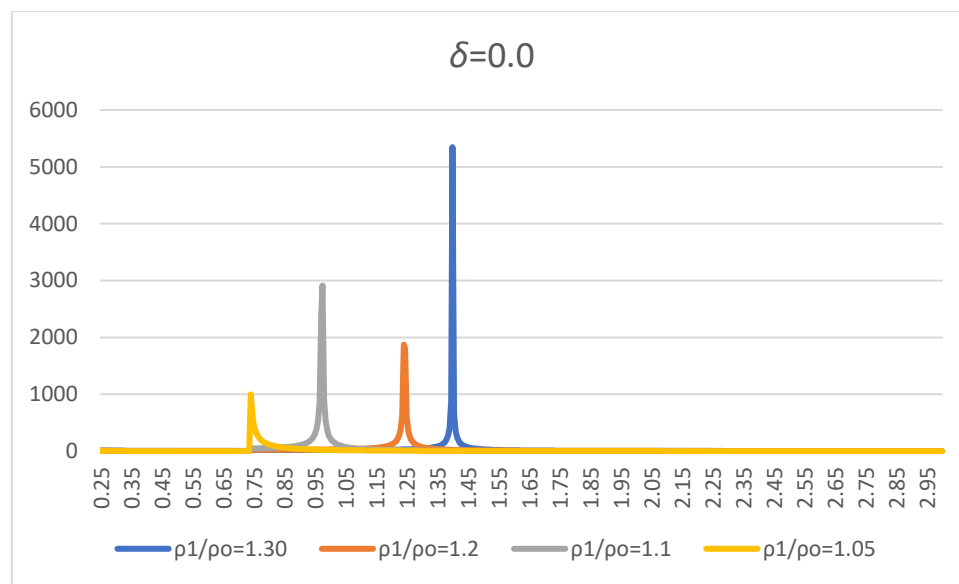Fig.3.   Dependence of W (eq.(16)) function to koα in case of absence of viscosity.

The above initial results show that the argument expressed by the National Taiwan University in their seminal paper of ref. 18. is verified theoretically with the present model.

The microwave resonance frequency is compute easily known the value of $k* = k_o a$ the peak value is attained, that is $f_{resonance}$ *(Hz)=k*$^*c_o$ */(2π)*.

5. Conclusions

A rather simple model of a virus particle allowed to analyze the coupling phenomena between microwave (electromagnetic) radiation and acoustic waves generated inside the particle. Based on recent publications on virus physical and electronic properties of viruses, similar to Covid-19, computations show that the possibility of strong interactions to generate rupture or capsid of the viruses. This action is based on the Coulomb force exerted by the oscillating field on the inhomogeneous electric charges within the spherical particle. The microwave resonance frequency – which is identical with the acoustic wave- is in the region 6-10 GHz.

The prospect of using the presented principle to sterilize public spaces, hospitals, clinics etc. is an attractive proposition. The present microwave technology is available for the development of this type portable devices. Moreover the existing more than 40 years experience on clinical hyperthermia which is based on the use of low microwave frequencies as an adjuvant therapy to treat in many cancer diseases, makes attractive to investigate the possibility of developing technologies to implement the mentioned idea in the future to depopulate virus populations inside the human body. Prior to this, extensive in vitro trials in virus and cell cultures need to be carried out to follow with animal trials as well.

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