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How Colonial Pattern Formation in Macroscopic Bacterial Growth Follow its Own Electric and Magnetic Fields

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Abstract:- This is an in-depth theoretical and experimental study explaining the formation of colonial patterns in the macroscopic growth of bacterial colonies under its own E&H electric and magnetic fields.

Recently there has been more and more work on the formation of bacterial colony patterns but they only consider the case where E and H are external to the compact bacterial colonies whereas in this article we consider the growth of hollow bacterial colonies in the form of two concentric circles under its own intrinsic fields E and H.

In addition, we offer an iron rich agar food dish which has been shown to be effective in producing a considerable part of bacterial cells rich in iron compounds and magnetic nano-needles called magnetotactics. This allows the study of the spatial formation and temporal evolution of growing colonial patterns in addition to the electrical and magnetic properties of the bacterial cells themselves.

Theoretical and experimental analysis elucidates that macroscopic growth can be classified into two main phases, the early onset phase and the subsequent intense second phase. In the first phase, colonial growth is a situation dominated by diffusion in a boundary value problem while in the dense phase the colony grows outward through radial branches following the intrinsic E field (which repel each other) and divides into circulars following the intrinsic H field.

The intrinsic E lines of the colony are radial rays while the H lines are closed concentric circles perpendicular to E. When the Agar is rich in iron compounds, the so-called magnetotactic bacteria form considerably during the second intense phase in two opposite orientations and follow the circles of the H field in the parallel or antiparallel direction.

At some point the magnetotactic bacteria separate or split from the radially negatively charged bacteria and follow the circular magnetic field in an interesting macroscopic phenomenon which is the subject of this article.

In other words, the theory predicts that in the second intense phase, the negatively charged electrosensitive bacterial cells should travel along the E field lines radially outward while the part of the magneto-tactical bacterial cells separate and follow the H field along concentric circles in a macroscopic phenomenon which should be observable experimentally. The present study is expected to effectively contribute to the theory and design of future bacterial batteries as a renewable energy source.

I. INTRODUCTION

The spatiotemporal formulation of macro-models in biological colonial systems such as bacteria is one of the most interesting and exciting, but in general quite complicated. Understanding it may be the key to our ultimate goal of studying the structure and behavior of the bacterial unit cell, or any other simple biological object, and its micro composition in addition to the physical and biochemical mode of action.

The current article is intended as a good starting point because, when the study of the mathematical physics of bioengineering is combined and compatible with the experimental results of the different phases of macroscopic growth of bacterial cells, it elucidates many additional electrical and magnetic properties.

Recently, there has been increasing theoretical and experimental research to study the macroscopic growth of colonial forms of compact bacteria [1-4]. In the compact colony, only external E&H are considered since the intrinsic E&H fields for bacterial cells in the colony add to zero in this form Figure. 1

On the other hand, when the Agar plate has a hollow configuration such that the shape of two concentric circles Fig. 2, the intrinsic fields E and H are dominant and the macroscopic growth of bacteria follows the intrinsic fields E and H prescribed by the boundary. conditions rather than following the concentration of food Agar himself.

Note that the intrinsic magnetic field H, never discussed before in the previous work, is normal to E and has no radial component as shown in Figure 2.

Electric and magnetic fields are normally calculated by the integral form of Gauss's theorem for electrostatics and Gauss's theorem for magnetism. Wakita et al, 1998 [1] carried out a detailed experimental study on the formation of bacterial colony patterns with particular attention to DBM phenomena of dense branched morphology type in colonies of bacterial species Bacillus subtilis.

They have achieved remarkable results. Wakita discovered that bacteria colonies grow outward and branch out radially. He also claimed that branches repel and sometimes split as they grow outward. He used a special microscope to observe that the average branch width and the average branch spacing constantly decrease as the nutrient concentration Cn increases, while their ratio remains unchanged with the approximate value of one. It was also found that the branch length distribution is very close to the exponential function, suggesting that branch tip division occurs randomly.

However, Wakita did not explain why the branches repel each other or the formation of the circular magnetic field H causing the magnetotactic bacterial cells to divide and circulate. Eden's growth model [2] describes the growth of specific types of diffusion-dominated clusters such as bacterial colonies and micromaterial deposits. These clusters develop by random accumulation of matter at their border. There is also an example of a surface fractal. The model was computer simulated for clusters of about 32,000 cells, but after the 1980s clusters of a billion cells were grown and slight anisotropy was investigated in the first phases.

M. Matsushita et al [3] examined in detail the density of bacterial colony developing at constant temperature as a function of the concentration of food agar in the geometric space. Zhayan Liu et al [4] examined the sterilization of cooling water systems by applying intensified external electromagnetic pulses to colonies of bacterial cells and looked at the experimental results from different angles.

He found that the bacterial inhibitory effect was 7.22% to 20.35% greater when the direction of water flow was parallel to the extrinsic magnetic field than in the anti-parallel, which we can see as a sign that the density of magnetotactic bacteria is almost equal to that of anti-magnetotactic bacteria.

The conclusion is that the previous work was devoted to the study of the formation of macroscopic growth patterns of compact cultures of bacteria under various conditions of food concentration, humidity, room temperature, oxygen content, value of pH, etc. but did not take into account the intrinsic magnetic field of bacterial cells in hollow colonies.

When charged bacterial cells are aligned and move macroscopically, as in the case of hollow concentric cylinders, they create an indispensable magnetic field. Perhaps this is the reason why previous work limited to compact colonies did not reveal much information about the structure of bacteria or their electrical and magnetic properties.

However, in a previous article [5] we showed that the macroscopic growth of Agar plaque bacteria in the form of two concentric Agar circles precisely follows the solution of the diffusion equation where in the early phase of growth bacterial cell density n and therefore its own E and H fields are not large enough to affect pattern formation.

In this article, we show that the growth of bacterial colony patterns in the next dense phase is a continuation of the first. In addition, the two phases inherently overlap.

Our basic assumption here is that almost all types of bacteria (aeropic or anaeropic, gram positive or gram negative, cucos, bacillus or helico) contain free electrons which they produce during metabolism and have the capacity to generate and conduct electricity through their nanowires. The electrical and magnetic properties of negatively charged bacterial cells that contain iron compounds (called magnetotactic bacteria) are that they can produce, sense, and trace E and H fields (extrinsic or intrinsic) [5,7].

In other words,Magnetic nanoneedles present in the body of bacterial cells are believed to be aligned parallel or antiparallel to the existing H field, whether intrinsic or extrinsic [7].

Magnetotactic bacteria have magnetosomes with which they can detect magnetic field lines. This allows magnetotactic bacteria to swim north or south to find the perfect location in the deep, dark waters of seas and oceans. (Wikipedia).

The idea of this article is to examine the notions mentioned above by inspecting and describing the macroscopic growth of bacterial hollow colony patterns and how to produce their own intrinsic E and H fields, and then riding them.

To our knowledge, none of the previous work has inspected or revealed the effect of the hollow shape of the agar boundary conditions on the resulting intrinsic electric and magnetic fields and therefore on the macroscopic growth of bacterial colonies that is the subject of of this article.

II. THEORY

In this article, we focus our attention on the geometry of the physical fields and the n / mL concentration of the bacterial cells and when the point of separation occurs i.e. the H field follower bacterium separates from the rays radials of the E- field and follows the H-field circles.

It should be mentioned that the splitting of the magneto-tactical bacteria into circular patterns from the negatively charged spikes that grow outward Figs. 2,4 is the starting point for the bacterial colony to generate electrical energy from nothing according to Poynting's vector theorem P = E x H [8].

This means that the theory includes a theoretical prediction supported by empirical verification of the basic conditions for formation of a radial field E which can produce adequate radial current and thus a significant circular field H.

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When the circular field H (which should be perpendicular to E) is produced, then
In return, the two fields, E and H, generate patterns of radial and circular bacterial colonies.

➢ *In conclusion*

- *The agar plate should not be compact but hollow with appropriate R1 and R2 ratios.*

(For the remainder of this particular theoretical and experimental case study, we consider the geometric shape of two concentric circles / cylinders with radii R1 and R2.)

- *The Agar food itself is rich in iron compounds and / or magnetite iron oxide (Fe3O4).*

Indeed, the hollow cylindrical geometry has surprising E and H fields and a striking but predictable power flow. as shown in figures, 2,3 and 4 [5,6,7]

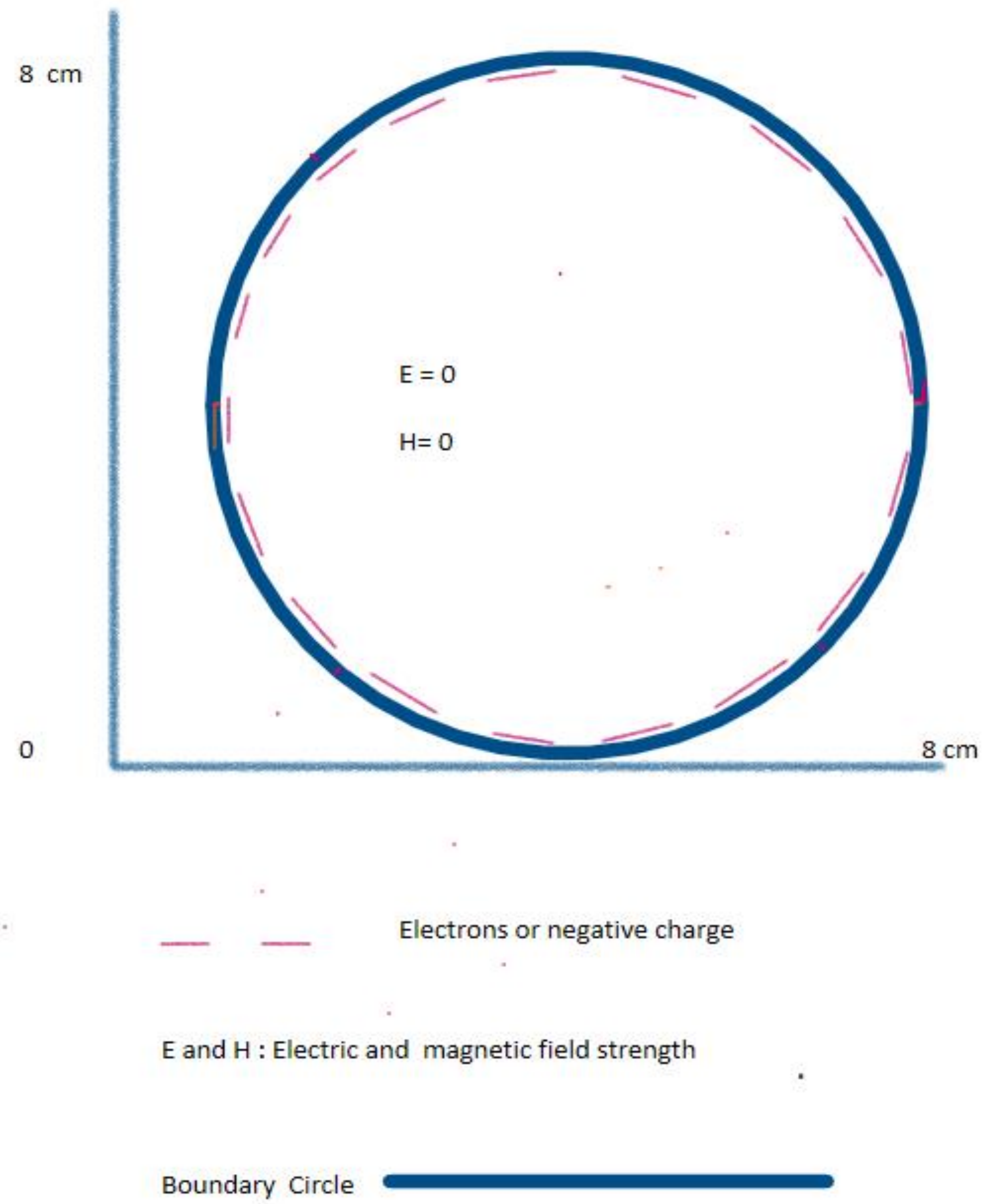

Fig. 1 Compact circular bacterial colony R1 = 0.

In Fig. 1, the COMPACT Agar bacteria colony does not have intrinsic E and H fields. Here, the growth of bacterial colonies is a process dominated by diffusion.

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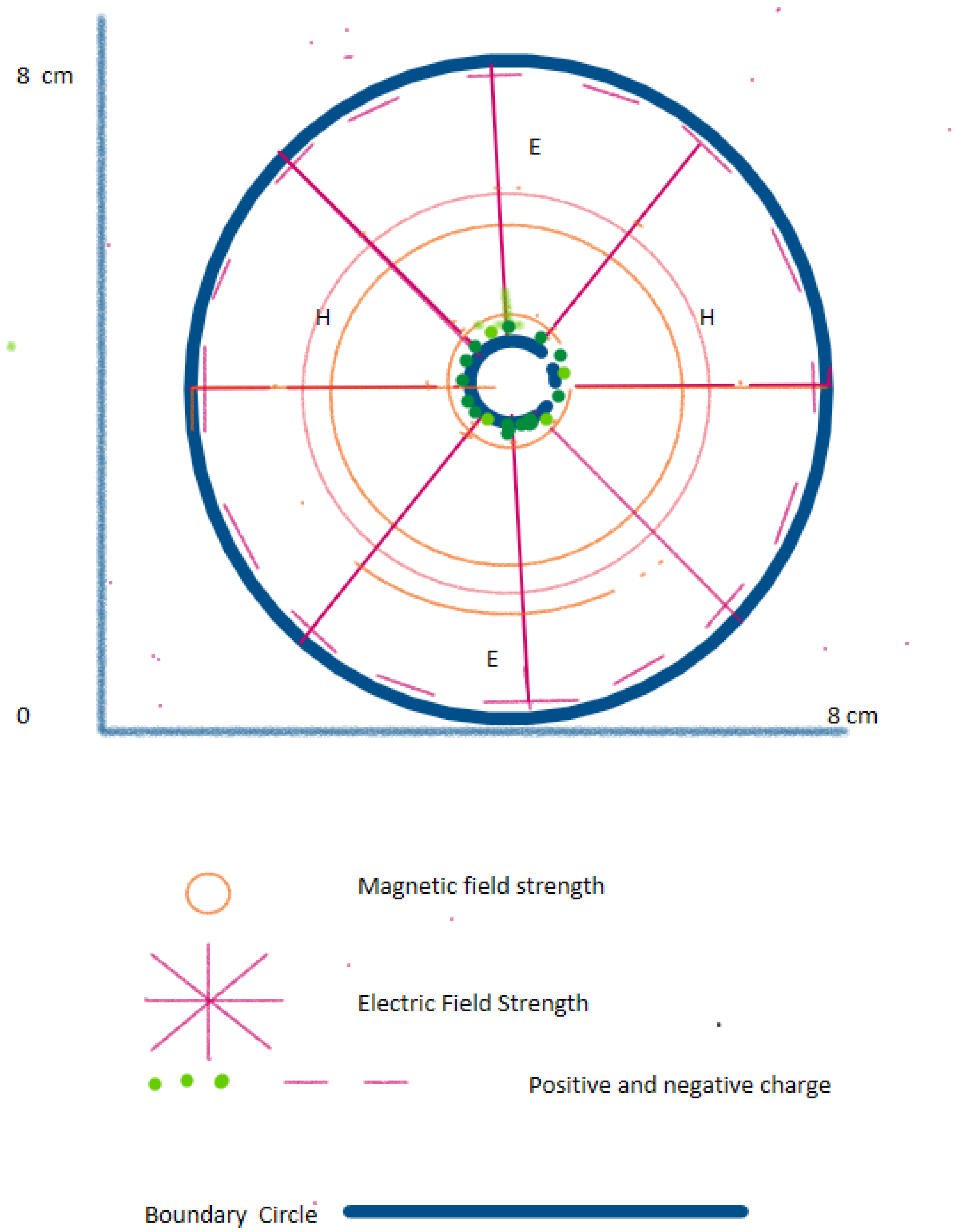

Fig. 2 Hollow concentric circular bacterial colony.

In Fig.2.The colony of HOLLOW Agar bacteria has its own intrinsic E and H fields.

- Here, the growth of bacterial colonies is a process dominated by its own intrinsic E and H fields.

Notice that:
H is perpendicular to E, i.e. H has no radial component.

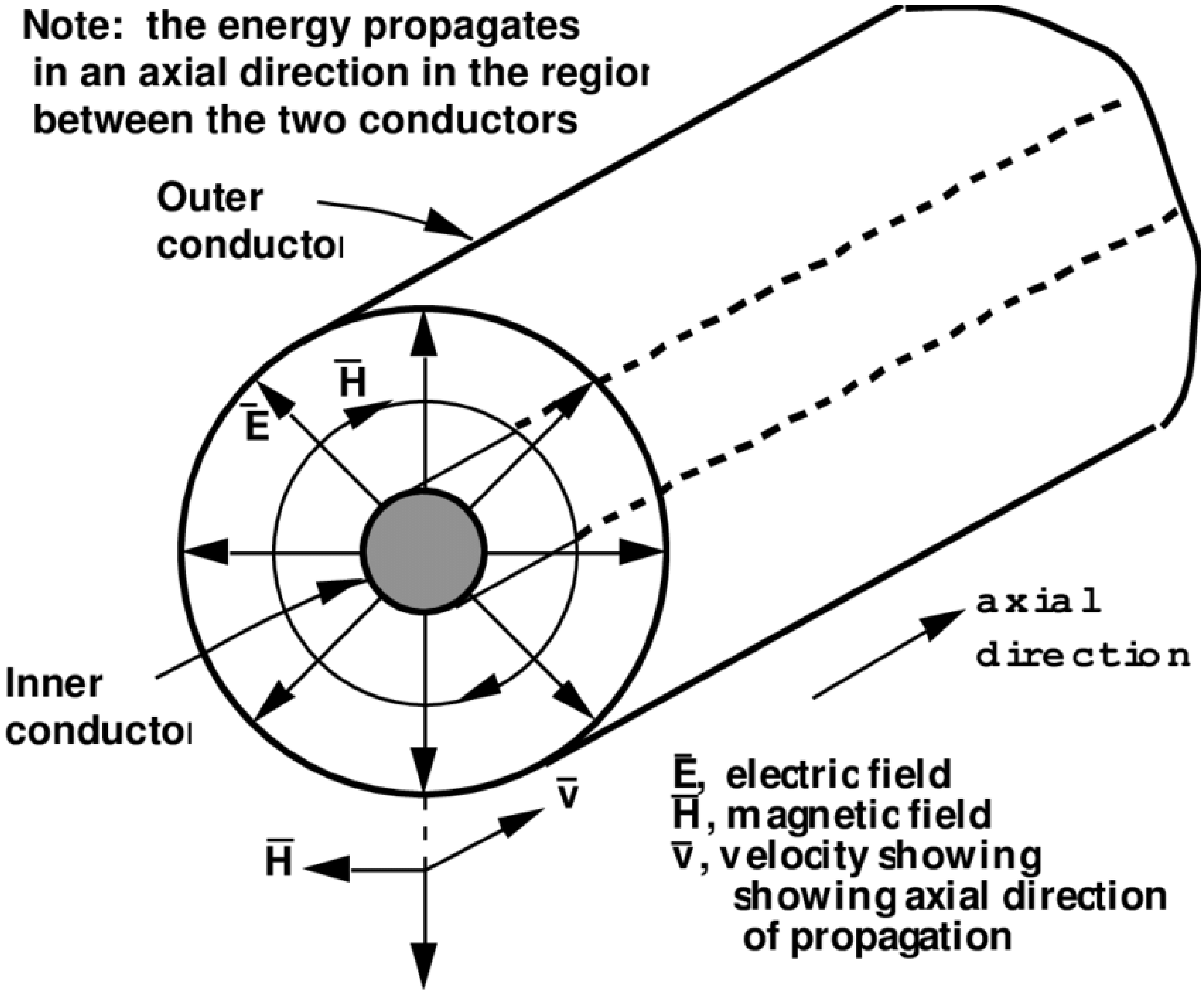

Fig.3 E and H fields and electric power flow in coaxial cylinders [6].

It is clear that a geometric configuration of bacterial colony similar to that in Fig. 3, will be able to produce an E field sufficient to force the motility of the electrostatic bacteria in the radial direction of the E field. In addition, it will also produce a sufficient H field, separate the magnetostatic bacteria and place or align their magnetic nano-needles along the H field lines thus moving them along the circular lines.

- Rule - Macroscopic separation of electrostatic and magnetotactic bacterial cells is possible and can be observed experimentally which is the target of our theoretical and experimental part.

Unlike the case of a compact bacterial colony where its intrinsic macroscopic fields E and H are reduced to zero as shown in Fig. 1, we have shown the inverse of a bacterial colony of hollow geometric shape Fig. 2 which can produce its own charge (electrons) will also generate its own electric field and macroscopic current and therefore its own perpendicular macroscopic magnetic field H.

The E and H macroscopic field lines are generated and directed based on the shape of the boundaries rather than the type and concentration of food agar.

The charged bacterial cells during its movement create an electric current along the radial lines of the E field which essentially produces circular magnetic field lines perpendicular to E.

Taking into account the Poynting theorem P = E x H, [8], it follows that the hollow agar colony could function as a bacterial battery producing electrical energy.

In both Figs. 1 and 2, The intensity of the E and H fields can be found by applying Gauss's theorem in electrostatics and Gauss's theorem in magnetism [9].

The importance of a detailed study of the macroscopic growth of hollow colonial models of bacteria under its own E and H fields can be summarized as follows:

- This can be of great help in the theory, design and development of the bacterial battery used to generate electricity as a promising source of new renewable energy.
- It can show whether the creation of bacteria from large biochemical molecules under intense heating / cooling and EMW inside hollow geometry is possible or not.

Note that the portion of bacterial cells that have become magnetosensitive increases in number when E is large enough and / or when the bacterial cells contain more iron compounds taken from its agar plate and therefore more tiny aligned nano-magnetic needles. The magnetic moment of these nano needles is either oriented parallel or antiparallel to its own magnetic field H (called magnetotactic bacteria) [7,10]. The two types, parallel and antiparallel are statistically in almost equal proportions.

It should be mentioned that the above description is observed experimentally in this work. On the other hand, turning to the study of the mechanism of temporal evolution of a bacterial colony, in the case of concentric circles on an agar plate, it is observed that the mechanism of development of the colonies over time begins with the accumulation and proliferation of the number of bacterial cells n at the internal and external circular borders.

This accumulation results in an E-radial field and a radial current. The numerical value of n bacterial cells can vary widely from 10 ^ 5 to 10 ^ 9 / ml but at some critical points when the density n becomes high and therefore its current becomes large enough, it produces an intense circular field H.

On the other hand, turning to the study of the mechanism of temporal evolution of a bacterial colony, in the case of concentric circles on an Agar plate, the theory predicts that the mechanism of colony development over time begins with the accumulation and proliferation of the number of bacterial cells n at the inner and outer circular boundaries.

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Consider, for example, Figures 2 and 3 which show a proposed bacterial battery geometry in the form of two concentric cylinders. The electromagnetic energy propagates perpendicular to the EH plane, that is to say parallel to the axis of cylindrical geometry with its inner cylinder as positive electrode and the outer cylinder as cathode.

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The particular geometric morphology of the radial and circular patterns of E and H should be valid for all geometries of concentric Agar circles.

Regardless of the type and concentration of food agar, the concentric radii are R1 and R2 or ambient temperature, etc.

We can show that:

- Rule -the power of the bacterial battery is proportional to the amount or volume of Food Agar itself expressed by 2 Pi (R2 ** 2 - R1 ** 2) L where L is the length of the Agar cylinder.

III. EXPERIMENTAL RESULTS

The experimental results are consistent with the predictions of the theory. The temporal evolution of the colony of concentric hollow bacteria takes place in two main phases which have different characteristics and different mechanisms, namely the early phase and the dense developed second phase [10]. The experimental spatio-temporal evolution of the bacterial colony is in perfect agreement with the hypotheses and the theory explained in I and II as follows:

A. Early Phases

Figure 4a shows a representative schematic diagram simulating experimental results for early phase growth models. Figure 4b shows the first phase of a real experimental growth of the bacterial colony patterns on high quality Egyptian bread after 3 days at 22 degrees Celsius in normal NPT humidity and pH 7.

R1 = 1.5 cm, R2 = 4.5 cm and Food agar rich in iron content 0.3 mg / 1 g.

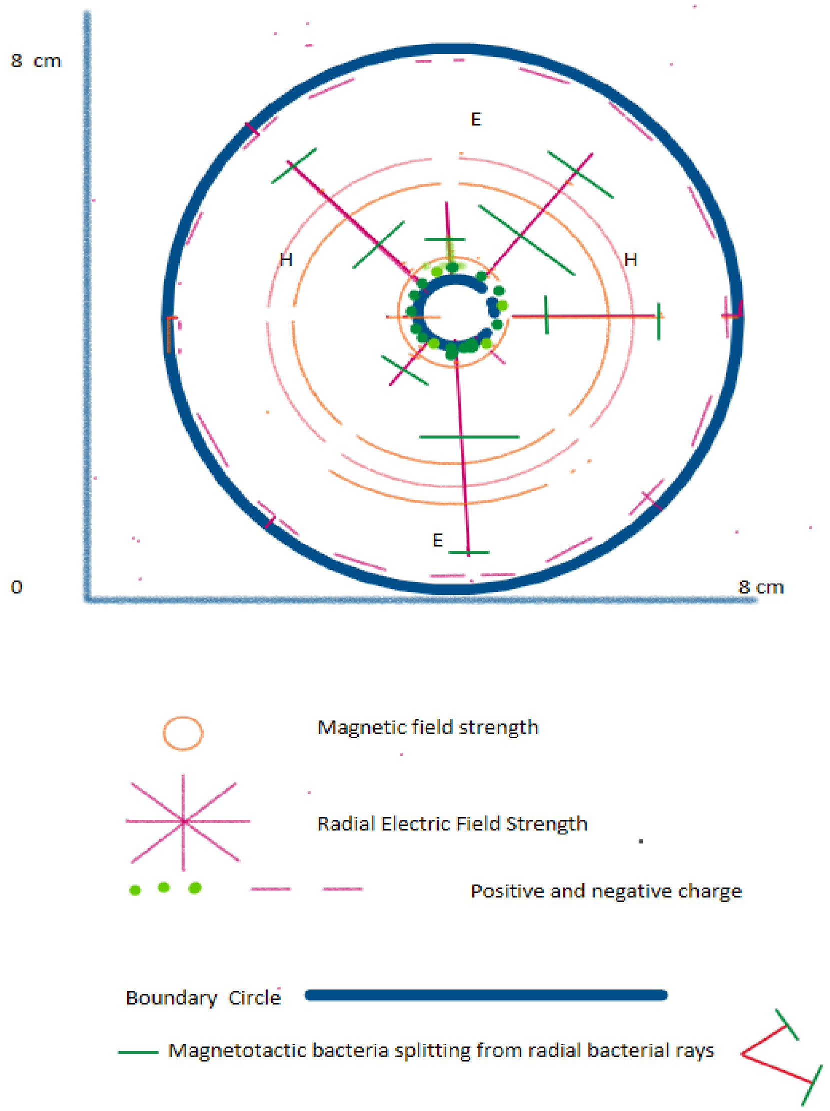

Fig.4a

Fig.4b
Figs.4a and 4b Early phase of bacterial colony patterns.

Note that the starting radial rays of the field E are not yet complete and that the tiny elements of the circular field H are in their first phase of formation perpendicular to E.

In the case of the initial phase where the densities n and E are low, no complete radial or circular pattern is observed. The same thing happens when R1 is small enough.

B. Developed Dense Phase

Fig.5

Fig. 5: 7 days Growth of bacteria on a flat food surface (high quality Egyptian bread) maintained at 4 degrees Celsius with a pH of 7, normal air and humidity

Figure 5 shows the late developed dense phase of bacterial colony experiments. Details are explained in Ref. 5.

It shows the well-developed complete radial and circular patterns of the hollow bacterial colony.

➢ *Interpretation of experimental results*

The interpretation of the experimental results validates the predictions of the theory and the assumptions of Sections I and II as follows:

- An experimental investigation shows that for circular bacterial patterns to appear, R1 must have adequate proportions with R2.and that food agar and bacteria should be rich in iron compounds. This is shown in the experimental results of Fig. 4b and Fig.5.
- Figs. 4a and 4b are an experimental validation that the early phase of bacterial colony growth is first dominated by diffusion when the bacterial density n is small and, therefore, its E and H fields are not yet sufficiently developed. The radial patterns of electrosensitive bacteria along the E field are short and the concentric circular patterns along the H field do not yet exist.
- Fig. 5, from Ref. 5 is experimental evidence that in the next dense phase, the radial bacterial patterns are evenly spaced, follow the E field and are negatively charged and therefore repel each other, as claimed by Wakita Ref. 1 And the circular radial patterns are formed when Agar food is rich in iron, about 3 mg per ml.
- The circular bacterial patterns following H field are also spaced at a constant distance dr from each other, showing that the splitting of the radial rays of E only occurs when n, therefore E and H are large enough. Environ n is a statistical function of (dr).
- In the dense developed phase Fig. 5, The incomplete circular branches emanating from the radial rays to the left and to the right are almost of equal length, showing that the statistical distribution of maginitotactic bacteria and anti-magnetotactic bacterial cells is almost equal.

IV. CONCLUSION

This theoretical and experimental study explains the formation of colonial patterns in the macroscopic growth of colonies of bacteria under the effect of its own electric and magnetic fields E&H in a hollow cylindrical geometry.

Previous work has focused on the formation of compact colony patterns by considering only the case where E and H are external to the compact bacterial colonies while in this article we consider the growth of hollow bacterial colonies in the form of two concentric circles under the effect of its own intrinsic fields E and H.

This allows the study of the spatial formation and temporal evolution of growing colonial patterns in addition to the electrical and magnetic properties of bacterial cells.

The predictions of the theoretical analysis, proven by the experimental results presented, show that the macroscopic growth can be classified into two main phases, the early onset phase and the intense second phase which follows. In the first phase, colonial growth is a situation dominated by diffusion in a limit value problem while in the dense phase, the colony grows radially outward along the E field. These outer branches are negatively charged in moving along the E field and repel each other, then divide into circular patterns along the intrinsic H field lines.

The negatively charged bacterial cells line up and move along their intrinsic E field lines in a radial outward direction while magnetotactic bacteria line up and follow the H field lines in closed concentric circles perpendicular to the lines field E.

The so-called magnetotactic bacteria are formed during the second intense phase in two opposite orientations and follow the concentric circles of the H field in the parallel or antiparallel direction.

In other words, during the intense second phase, the electrosensitive bacterial cells follow the E radial field lines and the magneto-tactical bacterial cells follow the H concentric circular field lines.

This study is expected to help a lot in the theory and design of future bacterial batteries, for example of concentric cylindrical shape, as a renewable energy source.

REFERENCES

[1]. Wakita et al, J. Phys. Soc. Japan. 67, pp. 3630-3636 (1998) [7 pages].
[2]. Eden M 1961 Proc. 4th Berkeley SYIIIP. on Mstlwmtics. Experimental investigation of the formation of dense branching morphology-type colonies in bacteria statistics and probabilities vol 4, p 223.
[3]. Matsushita et al, Physica (1999), Formation of colony patterns by a population of bacterial cells, A 274190–199 www.elsevier.com/locate/physica.
[4]. Zhayan Liu et al, 13th World Congress on Manufacturing and Management, GCMM 2016 The sterilizing effect of the direction of the solenoid magnetic field on heterotrophic bacteria in circulating cooling water.
[5]. I. Abbas et al, Macroscopic growth of bacteria precisely follows the solution of the diffusion equation, IJISRT Vol. 6, Oct. 2021
[6]. The Essex Echo 1995: The propagation of the electrical signal and the theory of cables Page 3
[7]. LeiY , Shuang et al, Magnetotactic bacteria, magnetosomes and their application, Microbiological research Revue, Volume 167, Number 9, October 12, 2012, Pages 507-519.
[8]. I. Abbas, Why Poynting's theorem P = E x H is quite valid for direct current circuits, Researchgate, 2020 October 2020
[9]. I. Abbas, A Numerical Statistical Solution to Laplace and Poisson Partial Differential Equations, Volume 5, November 2020.
[10]. I. Abbas, ResearchGate, Formation of colonial patterns in the macroscopic growth of bacteria under its own electric and magnetic fields., Dec. 2021.