Electric Charge Separation as the Mechanism for Image Formation on the Shroud of Turin: A Natural Mechanism

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Abstract

Among the most problematic features of the image on the Shroud of Turin is the fact that the unknown process of image formation is confined to the outermost fibers of the linen cloth, with no discernible alteration within the inner volume of the cloth, and that the image contains vertical displacement information, by which a three-dimensional reconstruction of the crucified body is possible. We recognize two important facts: 1) the Shroud linen is a dielectric material, i.e., the constitutive molecules in its fibers are polar molecules that tend to align themselves in an enveloping electric field leading to surface charges appearing on the outermost layers of the surface fibers, and 2) the human body, being composed of approximately 70% water by weight with electrolytes that support a myriad of electrical impulses in the living body, is an electrical conductor, i.e., when immersed in an electric field, charged ions within the body will distribute themselves at the outer surfaces of the body to ensure that no net electric field remains within the body. We advance the hypothesis that a constant, or slowly varying electric field was present in the tomb and that the two stated facts provide the underlying mechanism for formation of an image with vertical displacement information: the revealed surface charges on the Shroud serve as collection sites for polar gas molecules or ions emanating from the body or from the aloe and myrrh that had been applied before entombment, substances that could serve as oxidizers or other active species for inducing visual surface alterations, and the extension of the electric field in the vicinity of the surface of the body out to distances away from the body would provide mapping of surface features of the body onto the non-conforming (tented) portions of the Shroud. We demonstrate this electric and geometric process with simplified analyses. We suggest that relatively simple laboratory tests could explore the plausibility of this mechanism and propose that researchers suggest the chemical mechanisms whereby surface fiber alterations could be achieved with preferential surface deposition. Tests such as these could identify the strengths of electric field necessary to produce the image in a timely fashion consistent with the entombment time and determine their magnitudes in relation to the ambient earth electric field, which is known to exist with a magnitude between 100 and 300 volts per meter in the vertical, downward direction. Confirmation of electrically based image formation would enhance the plausibility of this hypothesis. If an anomalous electric field is required, investigations into the origins of such an electric field are warranted.

1 Introduction

In this paper we examine a novel image formation mechanism that comprises a uniform low frequency quasi-electrostatic field and polar molecules to produce the image of a crucified man on a linen cloth known as the Shroud of Turin. Given that to date the historical evidence tracks the origins of the cloth back to at least the 6th century AD, that forensic evidence strongly supports the conclusion that the man enclosed by the Shroud was in fact crucified, which totally undermines the assertion of forgery by revealing details in physics, chemistry and medical knowledge only available in the 20th century, and that there are additional physical tests, other than the one-off and often cited C_{14} test against the authenticity of the Shroud, that date the Shroud to the 1st century AD, we will assume that the crucified man was in fact Jesus of Nazareth and use the New Testament Gospels as a source of information for Jesus' crucifixion.

Among the many STURP (Shroud of Turin Research Project) findings regarding the images of a crucified man found on the Shroud of Turin (ST) there are six that point to a clear and natural explanation for both the dorsal and ventral images of the cloth [22, 16, 1, 2, 3, 8, 20]. These are:

1. Images on the cloth exist only of the dorsal and ventral surfaces of body and these images lie only on the fibers found at the extremities of the cloth

2. No image or discoloration exists between the two surfaces of cloth, i.e., within the cloth

3. There is no image of the top of the head or sides of the body enclosed by the cloth [14]

4. The image density on the cloth appears to embody information on the vertical distance between the cloth and the portion of the ventral body imaged, as if the cloth were held flat and horizontal slightly above the body or, in the case of the dorsal image, between the cloth on either the floor or shelf on which the body lied and the back of the body. In essence, the closer the cloth was to the body the darker the image, and the farther away the fainter the image [13]

5. A body image is visible in areas where there was no contact between the body and the cloth

6. The coloration does not appear under the threads where they cross in the weave of the cloth

7. Both the dorsal and ventral body images appear to have similar contrasts

Finding 3 and 4 clearly suggests that a vertical vector field [14] was an essential component of formation of the image, while findings 1,2,3,5, and 6 suggest that an electric field was involved. The quality and resolution of the image also tells us the electric field must have been slowly varying in time and space assuming the body contained within the Shroud was not moved during *rigor motis*. Possible causes of such electric fields are:

A. An ambient atmospheric electric field typically of order 100-300V/m and pointed downward [12]

B. Average ambient electric fields typically found during thunderstorms $\simeq$ 1-10kV/m pointed downward

C. Radon vented into the tomb (values as high as 1×10^5 Becquerels found around Jerusalem [19] during normal periods), possibly released during an earthquake, likely producing electric fields pointed upward

D. Piezo-electric fields due to an earthquake [23, 6] with no *a priori* direction

An examination of each of these naturally caused electric fields supports the conclusion that these sources' electric fields will likely vary in time from minutes to hours depending on the specific source. Sources A, B, and D suggest that the spatial variation of the electric field can be on the order of a kilometer and thus be essentially spatially uniform within the tomb where the wrapped body was placed. However, case C would require radon that leaked into the tomb, spread roughly uniformly on the floor of the tomb and be several centimeters in depth, a likely scenario, since radon is a gas heavier than air. Because radon decay products produce highly penetrating negatively charged beta particles (electrons) and weakly penetrating positively charged alpha particles (helium nuclei) a layer of radon gas on the floor of the tomb would drive charge separation by depositing electrons in the roof and upper walls of the tomb while leaving behind deposited alpha particles. This would have the effect of establishing a floor to ceiling electrical capacitor with a generally vertically directed quasi-static electric field throughout the tomb. In principle, all four sources are possible. Given these arguments we will assume that the electric field is quasi-uniform in our calculations. In addition, given the high resolution of the image, that is, there is no evidence of image smearing, we must also conclude that the image was formed in a very short time relative to a body going into and coming out of *rigor mortis*, which for a crucified man would be a period $\Delta t \lesssim 10$ hours. This latter result, plus the likely time variation of the electric field, places a strong physical constraint on the mechanism we are proposing.

2 Critical Components of Hypothesis: The Relevant Physics

We provide in this section a quick review of the critical components of our hypothesis, all of which are well understood physically. These are the physics of conductors, polar molecules, and dielectrics in the presence of a quasi-static electric field $\mathbf{E}_\infty$.

2.1 Conductors and Quasi-Static Electric Fields

It is well known that the human body is an excellent conductor when dealing with quasi-static electric fields. This means that the human body, like any conductor placed in a quasi-static uniform electric field $\mathbf{E}_\infty$ external to that conductor will react in such a way as to insure that no electric field can exist internal to the conductor [12]. This is accomplished by mobile ions in the conducting body fluids moving in response to the electric field in such a way as to reduce the effect of that electric field in the body. As charged ions can go no farther than the surface of the conductor, they accumulate there (the electric field will not cause charges to move perpendicular to it so that there will not be any charge buildup on a surface exactly parallel to $\mathbf{E}_\infty$). This new charge distribution on the surface of the conductor tends to cancel the external field until the net electric field in the conductor is zero, while at the same time modifying the external electric field just outside the body, a process occurring in a time measured in milliseconds or less and certainly less than other naturally occurring changes in the tomb. Because the body is electrically neutral, positively charged ions will be found on some portions of the surfaces of the body and negatively charged ions will be found on other portions of the surfaces. In addition, because the surface of a conductor is by necessity a constant potential surface, the resulting electric field $\mathbf{E} = -\nabla\phi$ at the conductor surface must be perpendicular to that surface, where ϕ is the potential. Since $\mathbf{E}$ is zero in the conductor and non-zero outside the conductor, it follows that the non-zero $\mathbf{E}$ at the conductor surface is due to the local surface charge density σ and by Gauss' law yields $E_n = 4\pi\sigma$, where E_n is the component of the electric field normal to the surface. As the surface of the conductor is an equi-potential surface, there is no transverse component of $\mathbf{E}$ at the surface (see Figure(1)).

To *illustrate* some of these concepts we computed the analytical solution for the potential that will result when a conducting cylinder of radius a is placed in a uniform electric field $\mathbf{E}_\infty$. We impose boundary conditions such that $\mathbf{E}(r \Rightarrow \infty) = \mathbf{E}_\infty$ and that the potential at the cylinder surface and throughout the cylinder interior, be a constant, here taken to be zero. We obtain the unique solution

$$\phi = -E_\infty r \cos\theta \left(1 - \frac{a^2}{r^2}\right) \ , \ r \geq a \tag{1}$$

so that the surface charge density on the cylinder surface is found to be

$$\sigma(\theta) = \frac{E_\infty}{2\pi a} a \cos\theta \tag{2}$$

in which we have multiplied and divided the parameter a to emphasize the presence of vertical height. From Figure(2) we can see that the magnitude of the charge density is largest at $y = \pm a$, where $\theta = 0, \ \pi$, while at $x = \pm a$ and $\theta = \pm\pi/2$ the surface charge density is zero (see Figure(1)). *This result demonstrates that the quantity* $a\cos(\theta)$ *is exactly the height above the horizontal axis (and, by inference, above or below any horizontal reference plane) of the point where the surface charge density is determined and proves that the surface charge density contains the essential vertical displacement information.* Note that our simple model demonstrates that image distortions will only occur after θ exceeds 60^o from the normal since $\cos(\theta) \approx 1 - \frac{\theta^2}{2}$ for small θ, which is *consistent* with STURP results but not rigorously so since the human body is not a cylinder.

Although detailed mathematical computations of the distorted electric field and charge distribution on the body are beyond the scope of this paper, we can draw inferences about more general solutions than this simple cylindrical model. Equation(1), for example, strictly applies to the conducting cylinder immersed in the uniform, vertically aligned electric field $\mathbf{E}_\infty$; this equation is an exact solution of Maxwell's equations for the boundary conditions of a conducting body and an electric field approaching $\mathbf{E}_\infty$ (where infinity just means a distance at which the effects of the presence of the conducting body are negligible). In fact, this equation comprises just two terms in an infinite series expansion for the general two-dimensional solution with these boundary conditions. In general, the two-dimensional expression for the electric potential is given by the expression

$$\phi(r,\theta) = -E_\infty \sum_{\ell=0}^{\infty} \left[A_\ell r^\ell + B_\ell r^{-(\ell+1)}\right] P_\ell(z) \ , z = cos(\theta), \ \ell = 0, 1, 2, \cdots \tag{3}$$

The P_ℓ are the Legendre polynomials; they are linearly independent of one another and form an infinite basis set for representing any functional form of θ. The first few Legendre polynomials are $P_0 = 1$, $P_1 = z$, $P_2 = \frac{1}{2}(3z^2 - 1)$. Of course, the specification of the coefficients A_ℓ and B_ℓ is carried out by imposing the boundary conditions. In the case of A_0 we see that it appears as a constant in the expression for the electric potential; we set this equal to zero, for convenience. Requiring that this potential vanish on the cylindrical surface of our conducting body led to the expression in Eq(1).

The definition of the surface of the cylindrical body was given by $r = a$. If the surface of the conducting body were more complicated, its representation could be given also in terms of Legendre polynomials:

$$r_s(\theta) = a \sum_{\ell=0}^{\infty} C_l P_\ell(z) \tag{4}$$

where, like the A_ℓ and the B_ℓ, the C_ℓ are also constants; a is no longer a radius but instead a scaling constant. The charge density on the cylindrical conducting surface was computed using the (normal) electric field strength on the surface at each point, which resulted in the expression

$$\sigma(\theta) = \frac{E_\infty}{2\pi} cos(\theta) \tag{5}$$

We now recognize that the right-hand side of this expression is the first term in a Legendre expansion, as well. For a more realistic conducting body this expression must be replaced by

$$\sigma(\theta) = \frac{E_\infty}{2\pi} \sum_{\ell=1}^{\infty} Q_l P_\ell(z) \tag{6}$$

We arrive at an important conclusion: we see that the charge density distribution is a function of the angle θ as measured from the vertical axis to the radius vector pointing to the region of interest on the surface, as depicted in Figure(2). We see that this remains true for the general solution expressed in terms of Legendre polynomials, since $z = cos(\theta)$. Therefore, the charge density at any point on the conducting body surface explicitly embodies vertical displacement information, since the vertical displacement must be given by $h_s = r_s(\theta)cos(\theta)$ and $r_s(\theta)$ is completely determined by $cos(\theta)$.

We see, then, that the inference is valid even for a complicated surface structure that the charge density on a conducting body in a vertical electric field embodies geometric vertical displacement information. This is strong confirmatory evidence for the origin of the image on the Shroud being electric in nature. The fact that Equation(6) is not linear means that the fine structure in the contour of the conducting body must introduce small corrections to the image intensity but, in any case, the lead term will always dominate, and this term is linear in the vertical displacement.

The insights developed here for a complex conducting body surface give us confidence in drawing inferences from the simple cylindrical model. A very important consequence of an electric field outside of a conductor having only a component normal to the conductor surface is that regions of a conductor surface which are convex with small radii of curvature will have much greater local densities of electric field and surface charges than regions that are flat or concave. Because the human body is an excellent conductor, the distribution of charge on the body surface will provide a one-to-one map of a human body's surface when transferred to a flat surface (the surface of a cloth) that then must also contain this 3D information. As we will see, these results will play an important role in the formation of the Shroud image.

2.2 Polar Molecules

Polar molecules are molecules that have permanent dipole moments even in the absence of an electric field because their volume charge distributions are intrinsically asymmetric and the time it takes such a molecule to interact with its immediate surroundings is shorter than the intrinsic kinetic motion time of the molecule, which is the time it would take to smoothly average out any net dipole moment. Polar molecules typically have dipole moments that are 3-4 orders of magnitude larger than non-polar molecules [12].

2.2.1 Polar Molecules and Dielectrics

The behavior of a dielectric made up of polar molecules is significantly different from that of a dielectric made up of non-polar molecules. In a dielectric comprising non-polar molecules an externally applied electric field will induce a small dipole moment in each molecule. On the other hand, if the dielectric is made up of polar molecules, major differences become apparent. Without an external electric field the polar molecules are randomly oriented so any bulk effect is essentially

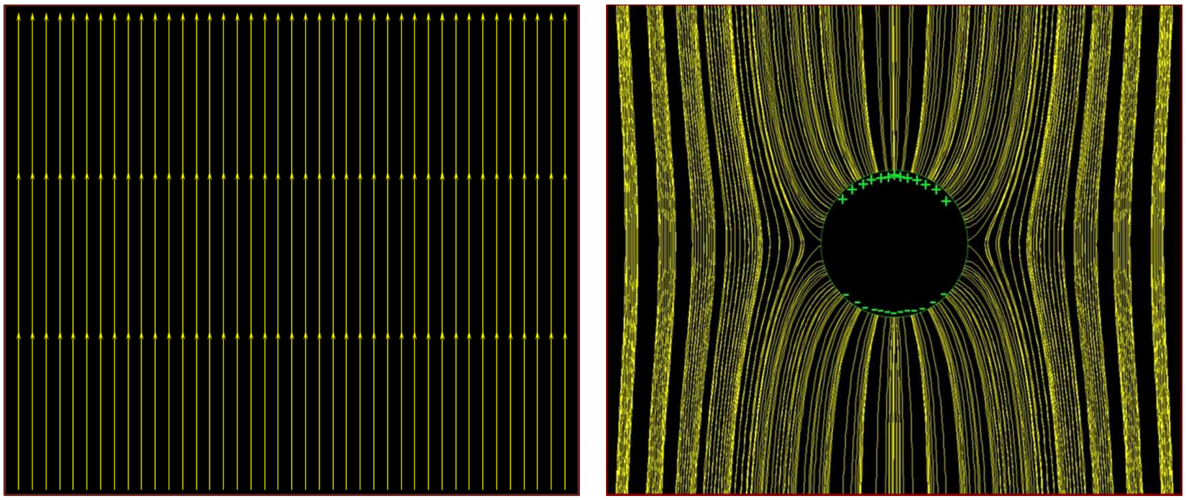

Figure 1: Left figure: uniform vertical electric field; right figure: electric fields surrounding a conducting cylinder. Notice that where the external electric field is almost normal to the surface of the cylinder the charge density is largest while where $\mathbf{E}_\infty \cdot \mathbf{n} \simeq 0$ there is little or zero surface charge density, where $\mathbf{n}$ is the unit normal to the surface of the cylinder. The green "+" and the "-", represent, respectively, positive and negative charge.

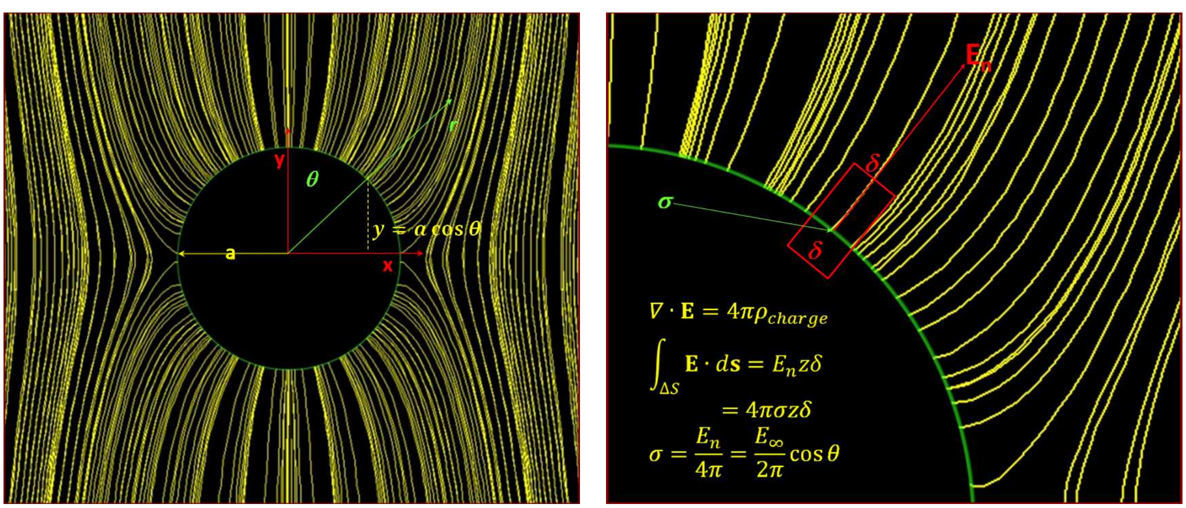

Figure 2: On the left, uniform electric field line changes are caused by the introduction of a cylindrical conductor; on the right is the determination of the surface charge density, which contains the essential vertical displacement information associated with the conductor's geometry

Molecule	Dipole Moment (C-m)
H_2O (water)	6.17×10^{-30}
NH_3 (ammonia)	4.82×10^{-30}
$(NH_2)_2CO$ (urea)	1.50×10^{-29}

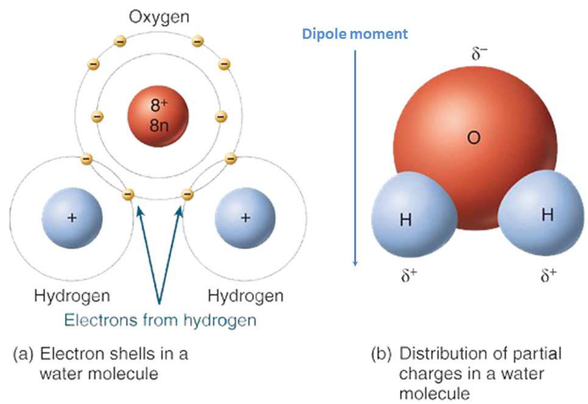

Figure 3: On the left are examples of polar molecules and their moments and on the right the example of the polar water molecule

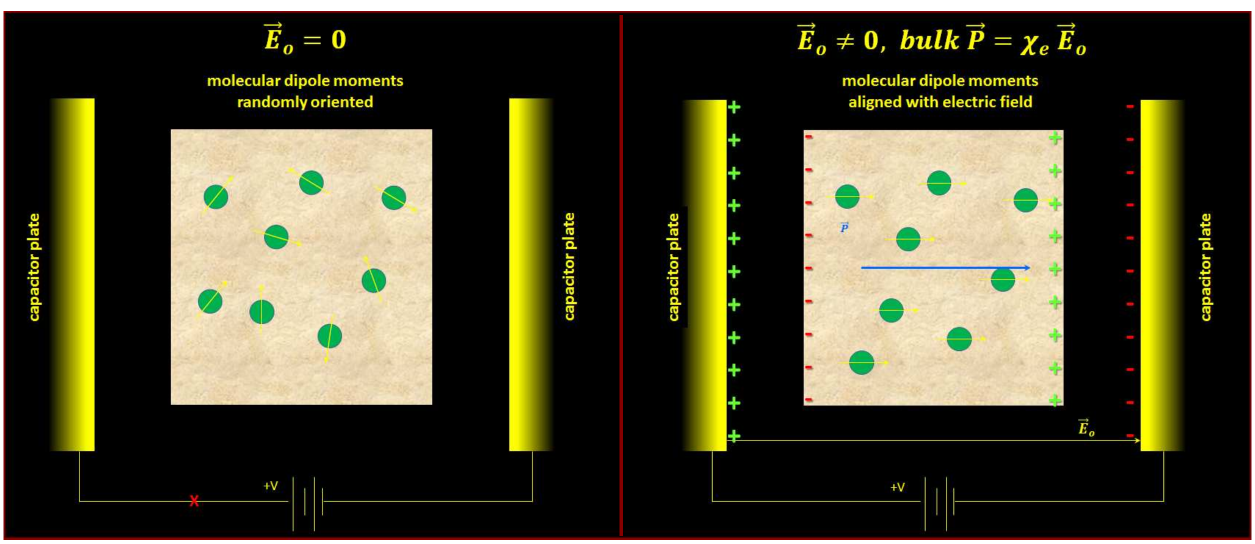

Figure 4: The left configuration shows two parallel plate conductors on either side of a dielectric made up of polar molecules before a voltage is applied. The right configuration illustrates how the polar molecules line up "head-to-toe" and with molecular charge exposed on both sides of the dielectric. A bulk polarization electric field $\mathbf{P}_o$ is produced proportional to the external electric field $\mathbf{E}_o$ such that $\mathbf{P}_o = \chi_e \mathbf{E}_o$

zero. However, when an external electric field is applied, the polar molecules align "head-to-toe" so that the net electric field within the dielectric volume is reduced but no change in the external electric field occurs. In addition, the "head-to-toe" behavior of the polar molecules causes molecular charge to be *exposed on the external surfaces* of the dielectric. The net result of this is a bulk polarization electric field $\mathbf{P} = \chi_e \mathbf{E}$ and $\sigma_{polarization} = \chi_e \mathbf{E}_n$, where χ_e is the electric susceptibility. This exposure of molecular charge at the very top-most threads of the dielectric surfaces acts like an image capturing device so that any surface charge density distribution on the conductor itself will appear as a one-to-one mapping on the outer dielectric surface in proximity to, but not necessarily in contact with, the conducting body.

2.2.2 Polar Molecules and Diffusion in the Presence of an Applied Electric Field

Historically numerous authors have suggested that a variety of molecules emanating from the body of the Man in the Shroud could diffuse from the body surface to the cloth. The subsequent oxidation of the cloth's outer fibers through a chemical reaction of the diffusing molecules with the cloth was proposed as the cause of the image seen on the Shroud. This hypothesis just as often was rejected because diffusion by its very nature would cause a poor image with low resolution, contrary to what is seen. However, in the presence of an external electric field, and therefore the existence of surface charge density, this objection is no longer valid, if the diffusing impurity causing the oxidation of the Shroud fibers is a polar molecule. This follows because the surface charge density on the cloth's outer surfaces will act as preferential attachment sites for the impurity polar molecules. This suggests that sweat, which will be very abundant on the body of a man being crucified, may be the cause of the yellow threads that make up the image seen on the Shroud of Turin. Sweat contains lactate, urea, water, minerals (Na, K, Ca, Mg, Zn, Cu, Fe, Cr, Ni and Pb in order of abundance in sweat), and bacteria. Urea, an acid, is known to cause cellulose to yellow and is capable of producing reducing diamide. Because the urea molecule has a large polar moment, when it diffuses from the body the end of the molecule with a complementary charge preferentially attaches to the molecular charge exposed on the outer surfaces of the dielectric cloth. *It is this critical component that is missing in other hypotheses that use electric fields and at the same time allows smaller electric fields to achieve image formation.*

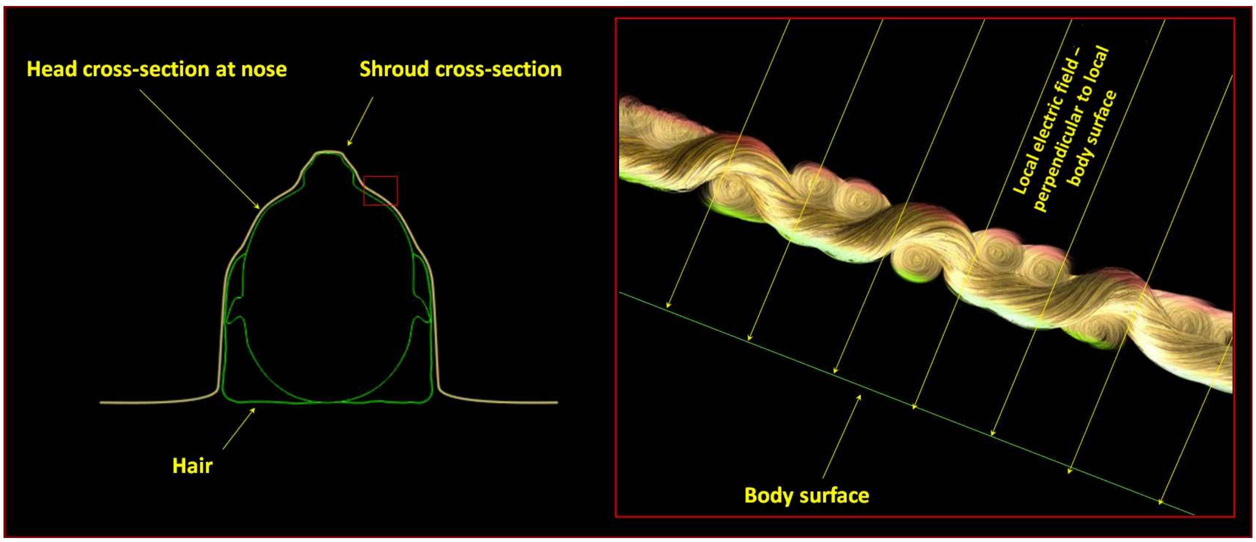

Figure 5: On the left is across-section of the head and cloth at the nose and on the right a close-up of a section of the head cross-section at a tented portion of the cloth between the nose and the cheek. The red and green colors at the two surfaces of the fiber represent negative and positive charge, respectively. The electric field shown is taken to point downwards, i.e., inwardly directed and normal to the nose-cheek surface.

3 Previous Electric Field Hypotheses

Surprisingly there have been many authors who have mentioned electric fields as an image formation mechanism. However, these suggestions were little more than speculations offered without substantiation. More recently Cordiglia[1] [15], Lattaruo [17], De Liso [5, 6], and Fanti [10, 7, 11] have made a variety of more detailed conjectures. Cordiglia's appears to demonstrate that an electric field can in fact make excellent images but it was difficult for us to determine the details of how this was accomplished from the paper. De Liso's work also showed interesting results using piezo-electric fields produced by earthquakes. Fanti and his colleagues research has been the most aggressive. This hypothesis is the most detailed of any of the other hypotheses. It is better know as the "corona discharge" model (CDM) [10]. In addition, Fanti, Lattarulo, and Pesavento [9] have begun performing experimental tests of the CDM. Because we lack details regarding the Cordiglia and De Liso hypotheses our comments here will be limited to the CDM. Our electric field model differs in two fundamental ways from the CDM. We emphasize weak electric fields, probably of order 1kV/m or less while the CDM requires electric fields that are near air breakdown magnitudes, that is, $\approx 3MV/m$. In addition, because our electric fields are so weak we need an additional means to oxidize the surfaces of the linen cloth. This we accomplish with reactive polar molecules diffusing from the body, which are then concentrated by the electric fields at locations on the body where the body geometry is mapped to the surface of the Shroud. Our reasoning is that while CDM can work in much the same way as our model, the large electric fields needed by CDM to oxidize the fibers maybe so large that they carbonize them. In addition, the occurrence of such large electric fields by natural means is difficult to explain.

4 Hypothesis

At this point we have reviewed three critical pieces of elementary physics needed to explain the Shroud image. Let us now perform a simple "gedanken" experiment: we wrap a conductor in the shape of a human body with a dielectric cloth made up of linen (historical note: linen was one of the first materials used to make a capacitor because of is excellent electric susceptibility) and place the wrapped body in a uniform electric field. We do the "gedanken" experiment in three steps. First we place a conductor (the body) in a uniform electric field. Next we wrap the conductor in a dielectric cloth made of linen. Finally, we allow the diffusion of polar molecules from the body to the cloth. At each step we examine what we should expect.

4.1 First Step: Place Body in an Electric Field

As noted in section 2.1 any conductor placed in an electric field will cause a surface charge density to form on the conductor, the distribution of which will depend greatly on the geometric properties of the conductor surface. If we assume that the surrounding electric field is vertical and pointed downwards and further assume that the conductor, *only* for sake of argument, floats freely in a plane perpendicular to the electric field, we find that the ventral side of the conducting body becomes negatively charged while the dorsal side of the body is positively charged. The surface charge density being greatest on the nose, brows, cheeks, lips, fingers, hair, eyelids, mustaches, edges of the arms, legs, and fingers. On the dorsal side the surface charge density will be less pronounced except around the hair, shoulder blades and perhaps the scourge wounds, if they are deep (blood would normally prevent the image forming precisely at the wound but there may be convex features

[1] There are numerous references to Cordiglia's work but the only one we could actually obtain and read was kindly provided to us by Professor Giulio Fanti

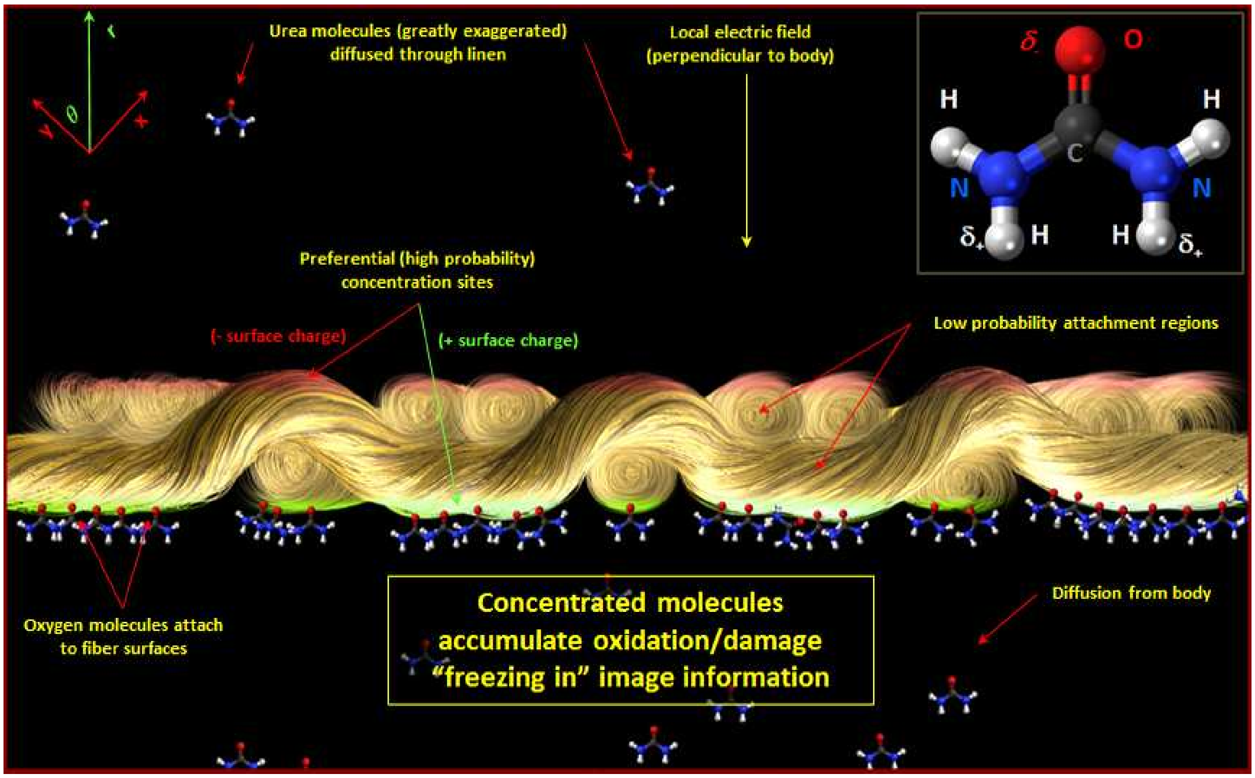

Figure 6: An enlargement of a cross-section of a region of Shroud cloth showing both surfaces. Here, as an example, we use urea molecules that diffuse from the surface of the body to and through the cloth. As polar molecules, they preferentially attach to the surface where the charge density is greatest and therefore produce high molecular concentrations at these points. In this depiction we show the local electric field actually perpendicular to the body, pointing downward in the image. This would induce a polarization charge density on the cloth surface fibers closest to the body that is positive. The consequence of this is the attraction and attachment of urea molecules, in which the oxygen atoms with negative charge become attached to the cloth fibers with positive charge. This is inherently an oxidation process. It is worth noting that the body need not be in contact with the cloth to produce an image. Insofar as the cloth is in the vicinity of the body surface, the electric field in which the cloth is locally immersed is approximately the same field as the electric field normal to, and at, the surface of the body. Therefore, the polarization charge distribution on the outermost fibers must approximate the charge distribution on the surface of the body.

nearby). Further, since the surrounding electric field is vertical, those portions of the body that have surfaces tangent to the electric field should not have any appreciable surface charge density. This implies that the sides of the body, the top of the head, and the bottom of the feet should have negligible image formation.

4.2 Second Step:Wrapped Body in an Electric Field

We next wrap the conducting body with a dielectric linen cloth and immerse this assembly in an uniform electric field, exactly as before. What should we expect? Let us define some terms. The wrapping cloth will have four surfaces perpendicular to the electric field direction, two on the ventral side of the body and two on the dorsal. The surfaces closest to the body surface we will refer to as inner ventral surface and inner dorsal surface, while the remaining two surfaces will be the outer ventral surface and the outer dorsal surface. All other surfaces will be tangent to the electric field direction and will not play any role in what follows (see Figure(5)). With this nomenclature we find the outer ventral surface to be negatively charged, the inner ventral surface to be positively charged, the outer dorsal surface to be positively charged, and the inner dorsal surface to be negatively charged. The charge distribution on the body surfaces will remain the same as discussed in section 4.1. Figure(6) shows this in more detail. At this point the electric field creates a surface charge distribution over the ventral and dorsal sides of the body. This same surface charge distribution has a one-to-one mapping onto the cloth. If the surface charge density itself could oxidize the cloth's surface threads, the detailed image mechanism we are seeking would be complete. In fact, if the electric field were large enough, it could cause oxidation of the surface threads by itself. However, we do not think that near-breakdown electric fields are necessary to create the image, nor are they very likely.

4.3 Third Step:Wrapped Body in an Electric Field and Molecular Diffusion

At this stage we have a surface charge distribution on both the ventral and dorsal sides of the body as well as matching surface charge distributions on both sides of the ventral and dorsal cloths, but of opposite signs. An examination of the Shroud literature suggests that there are two schools of thought regarding the washing of Jesus's body prior to His body being placed in the Shroud. One view argues that Jewish rites required that the body not be washed [18] while others argue, based on forensic evidence, that it must have been washed [24]. We agree with the second school [24] because both the crown of thorns head wounds and scourging would cause profuse bleeding. These wounds alone would have caused blood to cover most of Jesus'upper body but no evidence of caked blood is found anywhere on the Shroud except for areas limited to the wounds. In addition, if the body had not been washed (at least superficially), there would not have been an image, since blood blocks its formation, as STURP showed. However, both schools of thought might be valid, if the body was only superficially washed so as to collect most of the blood and dirt on the corpse. Of course, it was likely still slowly bleeding (see Figure(7) as forensic evidence demonstrates even after death [24] but leaving sufficient sweat to to support image formation. The likelihood is that Jesus sweated profusely during the crucifixion, making the existence of highly concentrated urea and other impurities on the body highly probable. (Figure(6) illustrates the diffusion of urea molecules toward the cloth from the body and concentrating there). Because the surface charge distributions on both sides of the cloth are identical, but with different signs it is possible for an image to form on both sides of the dorsal and ventral cloths. As the Man in the Shroud appears to have been placed on the floor or on a table/shelf, the outer dorsal image should be very weak or absent. An image could form on the outer ventral side of the Shroud, but would be weak, since the attachments would there

Figure 7: Blood flow in the wound of a decedent after washing. The sequence of bleeding over a few minutes following the washing of a dried wound of a deceased accident victim who had lived for a few hours and was autopsied a few hours later. The flow begins in the upper left image and proceeds from left to right on top, then left to right on bottom. Orientation: Side of face, ear at bottom, mustache upper right.

be hydrogen bonding.

5 Why Does the Image Not Fluoresce?

The STURP measurements showed that the Shroud fluoresced everywhere except in regions of the image. This suggests to us that the image formation mechanism somehow changed the allowed atomic transitions that permits the rest of the cloth outside of the image areas to fluoresce. This fact suggests that identifying what is allowing fluorescence can help to determine what chemically causes the image. A good start would be to see whether calcium fluoride or residual pectins (an Alan Adler suggestion[2]) are present on the cloth.

6 Is the Image Unique?

Since there is only one known image with the properties of the Shroud image, the question often arises: "why don't we see similar images of other people who were found wrapped in a shroud?". The answer for our mechanism is quite simple: 1) the exceptional burial; 2) the body preparation for burial; and, 3) the high quality of the Shroud cloth.

Except in times of war or revolts, the burial of an executed person was in conformity with Roman usage, as with Jewish Law, and the bodies of the executed were thrown into pits owned by the court. The Man of the Shroud received an honorable burial, in a truly exceptional manner [4], and was wrapped in a very high quality cloth. In addition, as noted in section 4.3, the body appears to have been washed, at least to some degree, since otherwise the Shroud of Turin would show only one continuous dried blood stain. If we define A as the set of people subject to Roman law who were not crucified and another set represented by B that were crucified (whose bodies were disposed of by a variety of ways that wouldn't have allowed their bodies to be wrapped in any cloth) we can immediately see that there can be no overlap of sets A and B, except in one unique case, that of Jesus. In addition, people from that time who died and were wrapped in a cloth were not covered in sweat from a crucifixion. Nor were they wrapped in a burial cloth of high quality (the high quality of the Shroud cloth matrix is extremely importance to image resolution), even if they were placed in a tomb. Hence the uniqueness of the image.

7 Hands

Observers of the ventral side of the Shroud often comment on the detail in the hands and how long the fingers appear to be. Our mechanism for image formation explains this in a very natural way. First of all, there had to be considerable trauma to the hands and arms as a result of the crucifixion. They were elevated considerably above the rest of the body throughout the crucifixion and the arms must have been severely traumatized by having to manage the full body weight. Circulation had to be compromised and it would certainly be the case that the hands and forearms would have been considerably dehydrated due to profuse sweating, which would lead to a desiccated state for both the hand and forearm tissues, which, as a result, would reveal the underlying bones. In addition, this would have been much more pronounced than anywhere else on the body, with the possible exception of the mouth and lips. As a result of the desiccation state of both the hand and forearm tissues, the bones making up the hands and forearms would form prominences so that the

[2] Brian Walsh private communication

surface charge density would naturally be greater on these body features, leading to sharper and high contrast images.

8 Predictions and Unresolved Issues

An observer examining both the dorsal and ventral images on the Shroud might conclude that they appear to have similar values of contrast with respect to the linen cloth. This observation imposes a constraint on any image-producing mechanism that depends on a vector field such as an electric field since it implies that the mechanism must function the same way in producing both the dorsal and ventral sides. This presents a dilemma for our proposed image mechanism: we have suggested that the electric field, in which the linen of the Shroud is embedded, produces a polarization surface charge density that acts as attraction sites for polar molecules; our suggestion that urea molecules might be the mechanism for linen oxidation leads to attachment on the linen fibers above the body that promote oxidation, while attachment to fibers on the linen below the body do not.

We believe that a vertical electric field is essential to the formation of the dorsal and ventral images that capture vertical displacement information, where the displacement is measured between any point of the physical body and a selected horizontal reference plane (the surface on which the body rests is a convenient and valid reference plane). Our suggestion of urea molecules as the mechanism of image capture on the linen is speculative and illustrative only. We can further speculate as to what mechanisms might be consistent with compatible contrast ventral and dorsal images but characterization of these and others is strongly dependent on the assumptions about the physical environment that might enable such image formation a circumstance that implies the need for much further research. Nonetheless, it is not unreasonable to identify at least a few possibilities worthy of consideration.

There are at least three possible mechanisms that come to mind. The first mechanism postulates the existence of multiple polar molecules of differing polarities, each producing an image on the respective sides of the linen cloth. That such a situation could occur is not in doubt physically but leaves unresolved what molecules might be involved and whether the needed molecules are indeed present. These molecules would need to have the necessary electrical properties (including dipole moment) but must also be capable of facilitating the capture of an image on the surface fibers of the linen cloth.

The second mechanism involves the existence of limestone dust in and around the freshly dug tomb. Limestone in the presence of water produces carbonic acid. The attachment of limestone particulates at the charge polarization sites may produce a latent image capture that is activated by varying environmental drift in relative humidity, for example. This is only one of the possible ways in which limestone might lead to the capture of an image. Limestone in dust form can be found with particulate sizes as small as 5 microns and larger. In addition, limestone dust is positively charged [21] which makes it susceptible to electric fields. Furthermore, given the prevalence of radon in the Jerusalem area it becomes highly likely that beta rays from radon seeping into and then decaying within the tomb could change the charge state of an ambient limestone particulate aerosol, thereby producing an electric charge distribution in the aerosol comprising positive and negative limestone particulates that can be attracted to the polarization surface charge density sites caused by the electric field (as well as neutral particulates that would not be attracted or attached). In order to have comparable contrasts on the dorsal and ventral sides of the Shroud the flux of radon entering the tomb and then decaying must be high enough to cause some positively charged limestone particulates to become neutral and others to become negative so that the number of particulates concentrated on the polarization surface charge density sites are comparable on both the dorsal and ventral sides of the Shroud.

The third mechanism involves the origins of the electric field itself. We have assumed for simplicity that the electric field is essentially static, or at least slowly varying with time and space. In reality however, the situation may be more complex. Any time an electric field develops, there is the possibility that it is a result of a an evolving electric current system associated with the tomb. While this is the certainly the case for earthquake or thunderstorm produced electric fields it is less clear for radon produced electric fields. Nevertheless, such a system would necessarily possess inductive, capacitive, and resistive properties that are determined by geometric properties and how the circuit might be completed. All electric current systems must obey Lenz's law: it takes a certain amount of time for the circuit to be established and any change in the current system will be resisted for a time comparable to the development time of the current system.

The importance of this is that an electric field always emerges in a time-varying electric current system. When the electric current in a system evolves from a condition of zero net current, an electric field results that tends to resist this change of current; when the electric current falls towards zero, the electric field opposes this change as well, appearing as a change in direction of the electric field to that appearing during the growth of the current. If such a current system is wholly contained within the tomb or is part of a larger current system, the electric field throughout the tomb could reverse direction, thus permitting a sequential image formation on both inner dorsal and ventral sides of the Shroud where only one polar molecule such as urea or lactic acids might be involved.

Our hypothesis predicts that lateral image distortion resulting from unwrapping the captured image ("arc length" horizontal length) occurs and concentration sites leads to continuous densities and partial oxidation of fibers - not binary states (fully modified versus not at all). And we need information about the dielectric properties of the Shroud material and the dominant chemistry of the oxidization process.

9 Future Work

We believe our hypothesis can readily be tested simply by using the same test facilities as have been used by others who have proposed electric fields as the cause of the image. Fanti, Lattarulo, and Pesavento [9] could easily test our hypothesis by covering the conductive manikin used in their experiments with a coating of urea and lowing the voltages used. We would suggest starting at 10kV/m, then 1KV/m and then finally 200V/m. Our only concern would be the material used for the Shroud in the tests, since the quality of the cloth and its electric susceptibility appear essential to the image formation process.

10 Discussion and Conclusions

As should be clear, our hypothesis depends on a completely natural mechanism. It does not conflate the image formation mechanism with the Resurrection, nor should it. The image is not the recording of the Resurrection but it is an image capture of the body of a crucified man consistent with the historical records of the crucifixion of Jesus Christ. That no hitherto satisfying mechanism for image formation has been discovered is not proof that a supernatural explanation must be the only other choice, nor does the discovery of a credible mechanism of image formation impugn the belief in the reality of the Resurrection. If it were possible to take a photo of the Ascension-where is the miracle? Is it the Ascension or the photo of it? We believe that the Shroud Image is indeed the image of Jesus Christ's lifeless body only and it strengthens the historical argument for His existence, death, and His Resurrection.

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