

# Evaluation of Hypotheses for Image Formation on the Shroud of Turin

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## Abstract

Multiple hypotheses have been proposed to explain how the front and dorsal images of a crucified man were formed on the Shroud of Turin. This paper evaluates various hypotheses for image formation. The primary criterion is that for a hypothesis to be true, it must be consistent with all the scientific evidence related to the images. The hypotheses evaluated include a generic gas diffusion hypothesis, the Maillard reaction hypothesis, a generic direct contact hypothesis, the electric charge separation hypothesis, a generic scorch hypothesis, and the roasted flour and oil hypothesis. There are many other hypotheses for image formation that have not yet been evaluated by the procedure used in this paper.

## 1. Introduction

In general terms, a hypothesis is a proposed concept for explaining observations about a phenomenon. The Shroud of Turin is a linen cloth that contains front and dorsal images of a crucified man. This paper will evaluate the merits of various hypotheses for how these images were formed on the Shroud. The characteristics of the front and dorsal images that form the basis for this evaluation are those used in developing the VCRB (Vertically Collimated Radiation Burst) hypothesis in Ref. 1. The criteria used for these evaluations are discussed in Ref. 2. The various hypotheses are evaluated in the following sections:

- Section 4. Gas diffusion hypothesis
- Section 5. Maillard reaction hypothesis
- Section 6. Direct contact hypothesis
- Section 7. Electric charge separation hypothesis
- Section 8. Scorch hypothesis
- Section 9. Roasted flour and oil hypothesis

Hypotheses that have not yet been evaluated in this paper include the following. There may be other hypotheses as well.

- Cloth collapse hypothesis of John Jackson and Mark Antonacci
- Ultraviolet light hypothesis of Paolo Di Lazzaro
- Corona discharge / Divine photography hypothesis of Giulio Fanti
- VCRB (Vertically Collimated Radiation Burst) hypothesis of Robert A. Rucker

## 2. Scientific Evidence Related to the Images

For a hypothesis for image formation to be true, it must be consistent with the scientific evidence related to the images. This includes both the macroscopic (large scale, how it looks) evidence and the microscopic (very small scale) evidence. Previous lists of the scientific evidence related to the images on the Shroud are in Ref. 3, 4, and 5. The 27 evidences related to the images that were used to develop the Vertically Collimated Radiation Burst (VCRB) hypothesis (Ref. 1) for image formation are listed below. These 27 evidences will be applied below starting in Section 4 to test the merits of various image formation hypotheses.

1. According to experiments performed in 1978 over a five-day period (120 hours) by about 26 researchers associated with the Shroud of Turin Research Project (STURP), these images have no pigment, no binder to carry pigment, no clumping of fibers or threads, no stiffening of the cloth, no cracking along fold lines, no brush strokes, and no outline.
2. STURP concluded the images were also not caused by a scorch from a hot object, any liquid, or by a photographic process.
3. There is a smooth gradation of discoloration on the Shroud from points vertically closer to the body relative to points vertically further from the body.
4. STURP detected no body decay products on the cloth.
5. The images are formed by some of the flax fibers in the linen threads being discolored.
6. The Shroud contains full size front and dorsal (back) images of a man who was scourged and crucified exactly like Jesus was scourged and crucified according to the New Testament.
7. The image of the face is a normal width for a human face.
8. The front image is a vertical projection upward from the body. The back image is a vertical projection downward from the body.
9. The Shroud does not include images of the sides of the body or the top of the head.
10. The front and dorsal images have a good resolution, perhaps in the few mm range.
11. Based on the location of the blood on the Shroud, the front and dorsal images are on the side of the cloth that faced the body. There appears to be very dim indications of the face and the hands on the other side of the cloth, i.e., on the outside of the wrapped configuration, though this is disputed.
12. A typical linen thread contains a hundred or more flax fibers twisted together. The images on the Shroud are caused by fiber discoloration in only the top two or three layers of fibers in a thread, with those discolored fibers facing toward the body, on both the front as well as the dorsal image.
13. The threads in the images are discolored in a mottled pattern, yet this mottled pattern forms the front and dorsal images of a crucified man.
14. The density of ion tracks in the image fibers is about the same as the density of ion tracks in the non-image fibers.
15. The discoloration on all the discolored fibers has approximately the same color, usually called a straw-yellow or light sepia color.

16. A flax fiber has a diameter of about 15 microns or micrometers ( $\mu\text{m}$  = one millionth of a meter), which is about one-fifth the diameter of a human hair. The discoloration on an image fiber has a thickness of less than  $0.2 \mu\text{m}$ , with the discoloration around the outer circumference of the fiber, with the inside of the flax fiber not discolored. Thus, in this example of a flax fiber with a  $15 \mu\text{m}$  diameter, the inside  $14.6 \mu\text{m}$  of the fiber diameter would not be discolored.
17. Images can be seen on the Shroud that result from bones near the surface of the body. This includes the area of the teeth, hands, backbone, and possibly the skull.
18. The images are two-dimensional yet contain 3D or topographical information related to the vertical distance from the body to the cloth at each point.
19. The images are negative images, i.e. having light and dark areas reversed.
20. The front and dorsal images have about the same quality, as though they were both made by the same process.
21. The discoloration on the image fibers is due to some of the single electron bonds of the carbon atoms being changed to double electron bonds. This is evidently the result of an oxidation-dehydration process.
22. The Shroud of Turin Research Project (STURP) concluded that the discoloration on the fibers is not caused by any material being added to the fibers.
23. The top threads facing the body create a non-discolored region on otherwise discolored threads that are beneath them, like a “shadow” of the top thread on the under thread.
24. The mustache has multiple lights spots or dark spots, depending on whether the observer is looking at either a positive or negative image.
25. The images were not affected by heat in the 1532 fire or by subsequent water thrown onto the Shroud after the fire.
26. Images of various parts of flowers were probably encoded onto the side of the Shroud facing the body, as though flowers were placed between the section of the cloth that was below the body and the section of the cloth above the body.
27. During the STURP experiments in 1978, many oxidizing and reducing agents were applied to image fibers to determine which agents would eliminate the fiber discoloration. None of them eliminated the discoloration except for diimite which eliminated the discoloration immediately when it was applied.

### 3. Criteria for Judging an Image Formation Hypothesis

The criteria for judging hypotheses for image formation can be separated into three categories: 1) “it must”, 2) “it should”, and 3) “it is preferred”, as discussed in Ref. 2:

1. For a hypothesis to be true, it must be consistent with the evidence.
2. A hypothesis should make predictions that are testable, falsifiable, and possibly unique.
  - 3a. A hypothesis is preferred if it explains more than one mystery of the Shroud.
  - 3b. A hypothesis is preferred if it is simple rather than complex.
  - 3c. A hypothesis is preferred if it exhibits “beauty”.

- 3d. A hypothesis is preferred if it considers aspects of the Shroud that it does not explain.
- 3e. A hypothesis is preferred if it is corroborated by one or more diverse areas of study.
- 3f. A hypothesis is preferred if it explains how information was used to form the images on the Shroud.

#### 4. Comments on a Generic Gas Diffusion Hypothesis for Image Formation

The following subtopics are listed according to the criteria in Section 3.

##### 4.1 For a hypothesis to be true, it must be consistent with the evidence.

The 27 evidences in Section 2 were used to determine whether a generic gas diffusion hypothesis for image formation would be consistent with the evidence. A gas diffusion hypothesis proposes that: 1) the Shroud wrapped the body of a crucified man, 2) diffusion of gas from the body to the cloth caused a chemical reaction that discolored specific fibers on the cloth, and 3) this process can explain the front and dorsal images that are on the Shroud.

Diffusion of a gas refers to a process in which molecules of one gas, such as molecules released or evaporated from the body, moves through another gas such as air by a process of random collisions between the molecules. If a collision between the molecule (M1) from the body and an air molecule (M2) is considered in a spherical coordinate system, then it is equally probable for the M1 molecule to be scattered in any azimuthal angle but the polar angle of the scattered M1 molecule is usually forward peaked, i.e. the M1 molecule is more likely to be scattered in the forward direction than the backward direction relative to its previous path. In spite of this usual forward peaking of the polar angle when molecule M1 scatters off molecule M2, after many scattering events, the direction and speed of molecule M1 will be essentially independent of the initial direction and speed of molecule M1. After this point, molecule M1 will follow what is called a “random walk” path, with each scattering event being independent of its original direction and speed. In this situation where there are enough scattering events between point A and point B, it will not be possible to communicate the initial speed and direction of molecule M1 from point A to point B by diffusion of molecule M1 through the air.

The average distance between scattering events of molecules in air is called the mean free path. The mean free path in air at sea level is 64 to 68 nm (nm = nanometer =  $10^{-9}$  m = a billionth of a meter) according to [https://en.wikipedia.org/wiki/Mean\\_free\\_path](https://en.wikipedia.org/wiki/Mean_free_path). Based on this mean free path in air, about 66 nm, a low energy molecule evaporated off a dead body wrapped in the Shroud would have over 15,000 collisions in the air if it had to travel across an air gap of only one millimeter ( $10^{-3}$  meter) between the body and the cloth. Such a molecule will certainly be following a random walk path after so many collisions with air molecules. If the cloth is 1.0 cm above the body, then over 150,000 collisions in the air would probably be required for a molecule to go from the body to the cloth by diffusion through the air. With this consideration, we can proceed to consider whether a generic gas diffusion hypothesis for image formation is consistent with the evidence.

Contradictions and unanswered questions for a generic gas diffusion hypothesis for image formation are listed below.

1. There are about a hundred linen fibers in a linen thread. A linen fiber is about 15 micrometers ( $\mu\text{m}$ ) in diameter which is about one-fifth the diameter of a human hair. In a fiber that is discolored in one of the images, the discoloration on the fiber has a thickness of less than  $0.2 \mu\text{m}$  (micrometers) with the discoloration around the outer circumference of the fiber, so that the inside (with a diameter of about  $14.6 \mu\text{m}$ ) of the flax fiber is not discolored. If this discoloration on the image fibers were caused by a chemical reaction resulting from diffusion of a gas from the body to the cloth, then it seems most likely this discoloration layer would have been much thicker than  $0.2 \mu\text{m}$  and it would have been thicker on the side of the fibers nearest to the body. The thickness of this discolored layer should also have been greater on the top layer of fibers in a thread than on the second or third layer of fibers. These expectations are contradicted by the evidence on the Shroud.
2. The images on the Shroud contain 3D or topographical information related to the vertical distance from the body to the cloth at each point. It is not clear how such vertical distance information could be deposited on the cloth by gas diffusion from the body to the cloth because of the random walk path of each gas molecule released from the body. This is because the total vertical path length of such a molecule would not be indicated by any physical characteristic of the molecule such as its direction or speed.
3. The Shroud contains front and dorsal images of a crucified man. It does not contain images of the sides of the body or the top of the head. With gas diffusion, the molecules released from the body, due to their random walk path, would have had an equal probability of going in any direction, including up, down, horizontally, or any angle in between. Thus, if the cloth was wrapped around the body and if the images are due to diffusion of gas released from the body, then the molecules would have hit the cloth with equal probability to the side of the body as above or below the body. This is contrary to the evidence on the Shroud.
4. Due to the superficiality of the discoloration on the threads and fibers, the Shroud of Turin Research Project (STURP) concluded that the discoloration on the fibers is not caused by any material being added to the fibers. The hypothesis of molecules diffusing from the body to the cloth proposes that these molecules will be deposited on the cloth to cause the discoloration. This contradicts STURP's conclusion.
5. The image on the Shroud of the face is a normal width for a human face. If the Shroud were wrapped around the head and thus in contact with it, the image of the face on the Shroud when it is unwrapped and thus flat would be much wider than a normal face. This evidence of the width of the face on the Shroud indicates that the cloth was not wrapped around the head but rather was relatively flat and some distance above the face during the encoding of the facial image. This indicates that the facial image was formed by some process that extended across the air gap between the body and the cloth. If the cloth was flat above the body, and if the image on the face were due to diffusion of a gas from the body, then as the distance from the centerline of the body is increased, there would be a significant decrease in the resolution of the face due to the random path of the molecules. This is contrary to the evidence on the Shroud.

6. As discussed above, the evidence indicates the top cloth was relatively flat above the body when the front image was encoded. On the dorsal image, the lack of flattening on the shoulders and buttocks indicates that the body was above the cloth that was below the body at the time of encoding the dorsal image. Thus, the top cloth that now contains the front image was some distance above the body when the front image was encoded, and the bottom cloth that now contains the dorsal image was some distance below the body when the dorsal image was encoded. It is difficult to understand how the resolution of the front and dorsal images could be the same, in the range of a few mm, at all distances from the midline of the body if the top cloth was flat above the body, the body was above the bottom cloth, and the images were caused by diffusion of gas from the body.
7. A gas diffusion hypothesis for image formation does not explain how the top cloth could have been levitated above the body and how the body could have been levitated above the bottom cloth. This appears to be an electrostatic effect which is not explained by a generic gas diffusion hypothesis.
8. Images can be seen on the Shroud that include bones near the surface of the body. This includes the area of the teeth, hands, backbone, and possibly the skull. It is not clear how gas diffusion between the body and the cloth could cause the appearance of bones in the images.
9. The mustache has multiple light spots or dark spots, depending on whether the observer is looking at either a positive or negative image. How are these “hot” spots on the mustache explained by a gas diffusion hypothesis? They are easily explained by an electrostatic effect.
10. The discoloration on the image fibers is due to some of the single electron bonds of the carbon atoms being changed to double electron bonds. This is evidently the result of an oxidation-dehydration process. What chemical reaction could have caused this that could have resulted from diffusion of gas between the body and the cloth? STURP detected no body decay products on the cloth. If it was not body decay products that were on the body that caused the fibers on the cloth to become discolored by a change from single to double electron bonds, then what was it?
11. According to the gas diffusion hypothesis, diffusion of a gas from the body to the cloth caused a chemical reaction that caused the correct fibers to become discolored with the correct length of discoloration to form the front and dorsal images of a crucified man on the Shroud. But to cause the correct fibers to become discolored with the correct length of discoloration requires information to flow from the body, where this information is located, to the cloth. How is this flow of information from the body to the cloth explained by a gas diffusion hypothesis for image formation?
12. The threads in the images are discolored in a mottled pattern, yet this mottled pattern forms the front and dorsal images of a crucified man. How is this explained by diffusion of molecules from the body?
13. The color of the discoloration on the fibers is usually called a straw-yellow to light sepia. This is the color normally caused by a scorch. How does the gas diffusion hypothesis explain this color, and that this color is the same on all the fibers?
14. The images were not affected by heat in the 1532 fire or by subsequent water thrown onto the Shroud after the fire? How is this explained by a gas diffusion hypothesis for image formation?

15. Various parts of flowers were probably encoded onto the side of the Shroud facing the body, as though flowers were placed between the section of the cloth that was below the body and the section of the cloth above the body. How does the gas diffusion hypothesis explain these images of flowers?
16. During the STURP experiments in 1978, many oxidizing and reducing agents were applied to the image fibers to determine which agents would eliminate the fiber discoloration. None of them eliminated the discoloration except for diimite which eliminated the discoloration immediately when it was applied. How does the gas diffusion hypothesis explain these experimental results?

There may be gas diffusion hypotheses that do not contradict all the above evidence, but they are expected to contradict most of the evidence discussed above. If a hypothesis contradicts the evidence related to the images in any way, it cannot be true.

- 4.2 A hypothesis should make predictions that are testable, falsifiable, and possibly unique. It is not known that any gas diffusion hypothesis makes predictions.
- 4.3a It is preferred that a hypothesis explains more than one mystery of the Shroud. As far as known, every gas diffusion hypothesis attempts to explain only image formation but no other mystery of the Shroud.
- 4.3b It is preferred that a hypothesis is simple rather than complex. A gas diffusion hypothesis may be simple, but if it contradicts any of the evidence, it cannot be true.
- 4.3c It is preferred that a hypothesis exhibits “beauty”. As far as known, no gas diffusion hypotheses argues for it having beauty.
- 4.3d It is preferred that a hypothesis considers aspects of the Shroud that it does not explain. As far as known, no gas diffusion hypothesis includes this consideration.
- 4.3e It is preferred that a hypothesis is corroborated by one or more diverse areas of study. As far as known, no gas diffusion hypothesis includes this consideration.
- 4.3f It is preferred that a hypothesis clearly explain how information was used to form the images on the Shroud. As far as known, no gas diffusion hypothesis includes this consideration.

## 5. Comments on a Maillard Reaction Hypothesis for Image Formation

The Maillard reaction hypothesis for image formation by Ray Rogers (Ref. 6 and 7) is an example of a gas diffusion hypothesis. Background for his Maillard Reaction Hypothesis is discussed in Ref. 6 starting on page 30 in the section titled “Hypothesize: A complex, natural hypothesis for image formation”. The Maillard reaction hypothesis proposes that: 1) the Shroud wrapped the body of a crucified man, 2) diffusion of gas from the body to the cloth caused a chemical reaction that discolored specific fibers on the cloth, and 3) this process can explain the

front and dorsal images that are on the Shroud. A presupposition of naturalism is made so that only naturalistic processes operating according to our current understanding of physics and chemistry are allowed as explanations. This presupposition rules out any hypothesis that involves radiation from the body. It was also assumed that the mean carbon date of 1260 to 1390 for the corner of the Shroud indicates that the Shroud was made in this period. This means that only processes available in this date range could be used in development of the hypothesis for image formation. It is reasoned that because the center of the fibers is not discolored, the chemical reaction that discolored the fibers must have been at low temperature. To discolor the fibers sufficiently at low temperature, the chemical reaction was probably a Maillard reaction which can quickly form intensely colored reaction products with the color resulting from conjugated double bonds. Maillard reactions are very common in food chemistry. The Maillard reaction that discolored the fibers to form the images was probably caused by gases released by decay of the body. The discoloration of the surfaces of the fibers and threads was due to concentration of materials in Saponaria wash water onto surfaces due to evaporation.

The more detailed description of this hypothesis is in Ref. 7. This paper reports evidence that color can be produced by reactions between reducing sugars that were left on the cloth by the manufacturing procedure and amines deriving from the decomposition of the body. It is claimed that impurities in ancient linen could have been suspended by the surfactant property of a *Saponaria officinalis* washing solution and they would be concentrated at the cloth surface by evaporation. Reducing saccharides would react rapidly with the amine decomposition products of a dead body to form the color.

Details of the Maillard reaction hypothesis are updated by Kelly Kearsse in Ref. 8 and 9. In Ref. 8, Kearsse uses a discoloration thickness on the surface of the image fibers of 0.7  $\mu\text{m}$  (micrometers) and concludes that “Here, it is suggested that amine groups from proteins/peptides/amino acids originating from the outer layer of skin may also function as substrates in the Maillard reaction. It is proposed that a “composite” Maillard reaction could provide a mechanism for additional resolution and detail in the Shroud of Turin image in the model originally suggested by Rogers.” In Ref. 9, he investigates a natural mechanism for blood transfer from the body to the cloth that would be consistent with a natural Maillard reaction hypothesis for image formation. He concludes that “The current report has evaluated the possibility that environmental conditions (specifically high humidity) could result in rehydration of dried blood sufficient to result in transfer to linen, analogous to the bloodstains on the Turin Shroud. ... The findings in this report are not meant to suggest that all bloodstains on the Shroud were originally dried and imprinted on the cloth due to high humidity, but, rather, to demonstrate a potential transfer mechanism for certain bloodstains that may have existed in this condition.”

The following subtopics are listed according to the criteria in Section 3.

#### 5.1 A hypothesis must be consistent with the evidence.

Since the Maillard Reaction Hypothesis is based on diffusion of gas from the body, the contradictions and unanswered questions from the previous section for a generic gas diffusion hypothesis must be considered. Results of this consideration are below.



1. There are about a hundred linen fibers in a linen thread. A linen fiber is about 15 micrometers ( $\mu\text{m}$ ) in diameter which is about one-fifth the diameter of a human hair. In a fiber that is discolored in one of the images, the discoloration on the fiber has a thickness of less than  $0.2 \mu\text{m}$  (micrometers) [Kearse uses  $0.7 \mu\text{m}$  in Ref. 8] with the discoloration around the outer circumference of the fiber, so that the inside (with a diameter of about  $14.6 \mu\text{m}$ ) of the flax fiber is not discolored. If this discoloration on the image fibers were caused by a chemical reaction resulting from diffusion of a gas from the body to the cloth, then it seems most likely this discoloration layer would have been much thicker than  $0.2 \mu\text{m}$  and it would have been thicker on the side of the fibers nearest to the body. The thickness of this discolored layer should also have been greater on the top layer of fibers in a thread than on the second or third layers of fibers. Ref. 7 asserts that the superficiality of the discoloration was caused by evaporation of the wash solution causing concentration of impurities, but it is very doubtful that this process could result in a discoloration of less than  $0.2 \mu\text{m}$  around the entire circumference of the image fibers. Ref. 7 is aware of this problem: “The hypothesis of a gaseous diffusion into the cloth would have produced a colour gradient through its thickness (Schwalbe & Rogers, 1982)”.
2. The images on the Shroud contain 3D or topographical information related to the vertical distance from the body to the cloth at each point. It is not clear how such vertical distance information could be deposited on the cloth by gas diffusion from the body to the cloth because of the random walk path of each gas molecule released from the body. This is because the total vertical path length of such a molecule would not be indicated by any physical characteristic of the molecule such as its direction or speed.
3. The Shroud contains front and dorsal images of a crucified man. It does not contain images of the sides of the body or the top of the head. With gas diffusion, the molecules released from the body, due to their random walk path, would have had an equal probability of going in any direction, including up, down, horizontally, or any angle in between. Thus, if the cloth was wrapped around the body and if the images are due to diffusion of gas released from the body, then the molecules would have hit the cloth with equal probability on the side of the body as above or below the body. This is contrary to the evidence on the Shroud.
4. Due to the superficiality of the discoloration on the threads and fibers, the Shroud of Turin Research Project (STURP) concluded that the discoloration on the fibers is not caused by any material being added to the fibers. The hypothesis of molecules diffusing from the body to the cloth proposes that these molecules will be deposited on the cloth to cause the discoloration. This contradicts STURP’s conclusion. Ref. 7 is aware of this problem: “microscopy, microchemistry, pyrolysis-mass-spectrometry, and laser-microprobe Raman analyses failed to detect foreign materials”.
5. The image on the Shroud of the face is a normal width for a human face. If the Shroud were wrapped around the head and thus in contact with it, the image of the face on the Shroud when it is unwrapped and thus closer to a flat condition would be much wider than a normal face. This evidence of the width of the face on the Shroud indicates that the cloth was not wrapped around the head but rather was relatively flat and some distance above the face during the encoding of the facial image. This indicates that the facial image was formed by some process that extended across the air gap between the body and the cloth. If the cloth was flat above the body, and if the image on the face were due to

diffusion of a gas from the body, then as the distance from the centerline of the body is increased, there would be a significant decrease in the resolution of the face due to the random path of the molecules. This is contrary to the evidence on the Shroud.

6. As discussed above, the evidence indicates the top cloth was relatively flat above the body when the front image was encoded. On the dorsal image, the lack of flattening on the shoulders and buttocks indicates that the body was above the cloth that was below the body at the time of encoding the dorsal image. Thus, the top cloth that now contains the front image was some distance above the body when the front image was encoded, and the bottom cloth that now contains the dorsal image was some distance below the body, i.e. not in contact with the body, when the dorsal image was encoded. It is difficult to understand how the resolution of the front and dorsal images could be the same, in the range of a few mm, at all distances from the midline of the body if the top cloth was flat above the body, the body was above the bottom cloth, and the images were caused by diffusion of gas from the body.
7. A gas diffusion hypothesis for image formation does not explain how the top cloth could have been levitated above the body and how the body could have been levitated above the bottom cloth. This appears to be an electrostatic effect which is not explained by a generic gas diffusion hypothesis.
8. Images can be seen on the Shroud that appear to include bones near the surface of the body. This includes the area of the teeth, hands, backbone, and possibly the skull. An interference pattern should be considered as the cause of what appears to be teeth. It is not clear how gas diffusion between the body and the cloth could cause the appearance of bones in the images.
9. The mustache has multiple light spots or dark spots, depending on whether the observer is looking at either a positive or negative image. How are these “hot” spots on the mustache explained by a gas diffusion hypothesis? They are easily explained by an electrostatic effect.
10. The discoloration on the image fibers is due to some of the single electron bonds of the carbon atoms being changed to double electron bonds. This is evidently the result of an oxidation-dehydration process. What chemical reaction could have caused this that could have resulted from diffusion of gas between the body and the cloth? STURP detected no body decay products on the cloth. If it was not body decay products that were on the body that caused the fibers on the cloth to become discolored by a change from single to double electron bonds, then what chemical reaction was it?
11. According to the gas diffusion hypothesis, diffusion of a gas from the body to the cloth caused a chemical reaction that caused the correct fibers to become discolored with the correct length of discoloration to form the front and dorsal images of a crucified man on the Shroud. But to cause the correct fibers to become discolored with the correct length of discoloration requires information to flow from the body, where this information is located, and be deposited on the cloth. How is this flow of information from the body to the cloth explained by a gas diffusion hypothesis for image formation when this hypothesis involves molecules moving in a random walk path from the body to the cloth?
12. The threads in the images are discolored in a mottled pattern, yet this mottled pattern forms the front and dorsal images of a crucified man. How is this explained by diffusion of molecules from the body?

13. The color of the discoloration on the fibers is usually called a straw-yellow to light sepia. This is the color normally caused by a scorch. How does the gas diffusion hypothesis explain this color, and that this color is the same on all the fibers?
14. The images were not affected by heat in the 1532 fire or by subsequent water thrown onto the Shroud after the fire? How is this explained by a gas diffusion hypothesis for image formation?
15. Various parts of flowers were probably encoded onto the side of the Shroud facing the body, as though flowers were placed between the section of the cloth that was below the body and the section of the cloth above the body. How does the gas diffusion hypothesis explain these images of flowers?
16. During the STURP experiments in 1978, many oxidizing and reducing agents were applied to the image fibers to determine which agents would eliminate the fiber discoloration. None of them eliminated the discoloration except for diimite which eliminated the discoloration immediately when it was applied. How does the gas diffusion hypothesis explain these experimental results?

5.2 A hypothesis should make predictions that are testable, falsifiable, and possibly unique. The Maillard reaction hypothesis recommends experiments to test predictions made by this hypothesis. It appears these predictions are testable, falsifiable, and possibly unique. The important question is whether any of these experiments have been conducted and if so, what were the results?

5.3a It is preferred that a hypothesis explains more than one mystery of the Shroud. The Maillard reaction hypothesis only considers image formation.

5.3b It is preferred that a hypothesis is simple rather than complex. “The Maillard reaction is relatively complex, with multiple products generated in the interaction of a single type of carbohydrate with an individual amine bearing substrate, many of which remain to be fully characterized” (Ref. 8).

5.3c It is preferred that a hypothesis exhibits “beauty”. The Maillard reaction hypothesis does not suggest the presence of beauty.

5.3d It is preferred that a hypothesis considers aspects of the Shroud that it does not explain. The Maillard reaction hypothesis does not consider this.

5.3e It is preferred that a hypothesis is corroborated by one or more diverse areas of study. The Maillard reaction hypothesis does not consider this.

5.3f It is preferred that a hypothesis clearly explain how information was used to form the images on the Shroud. The Maillard reaction hypothesis does not consider this.

## 6. Comments on a Generic Direct Contact Hypothesis for Image Formation

The following subtopics are listed according to the criteria in Section 3.

6.1 For a hypothesis to be true, it must be consistent with the evidence.

The 27 evidences in Section 2 were used to determine whether a generic direct contact hypothesis for image formation would be consistent with the evidence. A direct contact hypothesis proposes that: 1) the Shroud wrapped the body of a crucified man, 2) contact between the body and the cloth causes a chemical reaction that discolors specific fibers on the cloth, and 3) this process can explain the front and dorsal images that are on the Shroud. This means that the fibers were discolored to a maximum extent where there was contact between the body and the cloth, and that the fibers were not discolored at all where there was no contact. Contradictions between a generic direct contact hypothesis and the evidence related to the evidence are listed below.

1. The tip of the nose would have been closest to or in contact with the cloth above the body. This explains why the fibers are discolored to a maximum extent at the tip of the nose. However, there is a smooth gradation of discoloration down the nostrils where the cloth would not have been in contact with the body. This smooth gradation of discoloration even where the cloth would not have been in contact with the body is a general feature of the Shroud. This is not consistent with the image being formed by contact between the body and the Shroud. This is because at each point on the cloth, there is either contact with the body or no contact with the body so that the process that caused the discoloration is either 100% on where there is contact or 100% off where there is no contact. This is inconsistent with the smooth gradation of discoloration that is on the Shroud.
2. There are about a hundred linen fibers in a linen thread. A linen fiber is about 15 micrometers ( $\mu\text{m}$ ) in diameter which is about one-fifth the diameter of a human hair. In a fiber that is discolored in one of the images, the discoloration on the fiber has a thickness of less than 0.2  $\mu\text{m}$  with the discoloration around the outer circumference of the fiber, so that the inside (with a diameter of about 14.6  $\mu\text{m}$ ) of the flax fiber is not discolored. If this discoloration on the image fibers were caused by a chemical reaction due to contact between the body and the cloth then the fibers should have been discolored through the fiber instead of just around the circumference of the fiber.
3. The images on the Shroud contain 3D or topographical information related to the vertical distance from the body to the cloth at each point. This is not consistent with the images being formed by contact between the cloth and the body.
4. The Shroud does not include images of the sides of the body or the top of the head, but these images should have been formed on the Shroud if the cloth was wrapped around the body and if the images are due to direct contact.
5. The image on the Shroud of the face is a normal width for a human face. If the Shroud were wrapped around the head and thus in contact with it, the image of the face on the Shroud when it is unwrapped and thus flat would be much wider than a normal face. This evidence of the width of the face on the Shroud indicates that the cloth was not wrapped around the head but rather was relatively flat and some distance above the face during the encoding of the facial image. This indicates that the facial image was formed by some process that extended across the air gap between the body and the cloth, which also disproves the direct contact hypothesis.

6. Images can be seen on the Shroud that include bones near the surface of the body. This includes the area of the teeth, hands, backbone, and possibly the skull. It is not clear how direct contact between the body and the cloth could cause the appearance of bones in the images.

A direct contact hypothesis for image formation should also explain the following:

1. The discoloration on the image fibers is due to some of the single electron bonds of the carbon atoms being changed to double electron bonds. This is evidently the result of an oxidation-dehydration process. What chemical reaction could have caused this that could have resulted from contact between the body and the cloth? STURP detected no body decay products on the cloth. If it was not body decay products that were on the body that caused the fibers on the cloth to become discolored by a change from single to double electron bonds, then what was it?
2. According to the direct contact hypothesis, contact between the body and the cloth caused a chemical reaction that caused the correct fibers to become discolored with the correct length of discoloration to form the front and dorsal images of a crucified man on the Shroud. But to cause the correct fibers to become discolored with the correct length of discoloration requires information to flow from the body, where this information is located, to the cloth. How is this flow of information from the body to the cloth explained by a direct contact hypothesis for image formation?
3. The color of the discoloration on the fibers is usually called a straw-yellow to light sepia. This is the color normally caused by a scorch. How does the direct contact hypothesis explain this color?
4. Why were the images not affected by heat in the 1532 fire or by subsequent water thrown onto the Shroud after the fire?
5. Various parts of flowers were probably encoded onto the side of the Shroud facing the body, as though flowers were placed between the section of the cloth that was below the body and the section of the cloth above the body. How does the direct contact hypothesis explain these images of flowers?
6. During the STURP experiments in 1978, many oxidizing and reducing agents were applied to the image fibers to determine which agents would eliminate the fiber discoloration. None of them eliminated the discoloration except for diimite which eliminated the discoloration immediately when it was applied. How does the direct contact hypothesis explain these experimental results?

There may be direct contact hypotheses that do not contradict all the above evidence, but they are expected to contradict most of the evidence discussed above. If a hypothesis contradicts the evidence related to the images in any way, it cannot be true.

- 6.2 A hypothesis should make predictions that are testable, falsifiable, and possibly unique. It is not known that any direct contact hypotheses makes predictions.

- 6.3a It is preferred that a hypothesis explains more than one mystery of the Shroud. As far as known, every direct contact hypothesis attempts to explain only image formation but no other mystery of the Shroud.
- 6.3b It is preferred that a hypothesis is simple rather than complex. A direct contact hypothesis may be simple, but if it contradicts any of the evidence, it cannot be true.
- 6.3c It is preferred that a hypothesis exhibits beauty. As far as known, no direct contact hypothesis argues for it having beauty.
- 6.3d It is preferred that a hypothesis considers aspects of the Shroud that it does not explain. As far as known, no direct contact hypothesis includes this consideration.
- 6.3e It is preferred that a hypothesis is corroborated by one or more diverse areas of study. As far as known, no direct contact hypothesis includes this consideration.
- 6.3f It is preferred that a hypothesis clearly explain how information was used to form the images on the Shroud. As far as known, no direct contact hypothesis includes this consideration.

## 7. Comments on an Electric Charge Separation Hypothesis for Image Formation

The electric charge separation hypothesis for image formation on the Shroud was proposed by D. S. Spicer, et al. in Ref. 10. The following subtopics are listed according to the criteria in Section 3.

### 7.1 A hypothesis must be consistent with the evidence.

This hypothesis proposes that certain chemicals, either from decay of the body and/or from materials placed on the body during the burial process, would have moved from the body to the cloth to form the images on the cloth by one or more chemical reactions. To produce the good resolution of the image of the crucified man that is on the Shroud, these chemicals moved from the body to the cloth along electric field lines due to the presence of an electric field in the tomb. This electric field caused polar molecules to orient themselves and move in a way that caused discoloration on the fibers and threads by an oxidation process, which caused the image on the cloth. This hypothesis assumes that the Shroud covered Jesus' crucified body and that his image on the cloth was formed by a natural mechanism. There are multiple issues or problems with this hypothesis.

1. If the Jesus' front and dorsal images were formed on the cloth by a natural process, then why are there not many pieces of cloth that contain images of the bodies they covered, either in life or death? If it is a natural process, then why are there not thousands or millions or billions of cloths that contain an image of the person they covered? Since the images on the Shroud are unique, it seems more likely they are the result of a unique process, even if the specifics of this process

have not yet been investigated by science, so that this process is outside or beyond our current understanding of physics.

2. The cause of the electric field is not known, but four possibilities are suggested: the normal electric field of the earth, thunderstorms, radon collecting in the tomb, and a piezo-electric field due to an earthquake (page 2 in Ref. 10). However, the mechanism that discolors the fibers, as it was discussed in the paper (Ref. 10), operates in one direction, with that direction depending on the direction of the electric field. Since a front image was produced above the body and a dorsal or back image was produced below the body, and the quality of both images are about the same, the electric field had to be pointing down about half the time and pointing up about half the time. But the suggested mechanisms for producing the required electric field are not consistent with this. The earth's electric field would always point in the same direction. The electric field, if any, produced by radon in the tomb would also always point in the same direction. And the electric fields produced by thunderstorms, lightning, and earthquakes would be of short duration. Thus, none of the suggested options would cause the electric field in the tomb to point up about half the time and down about half the time, so that no naturalistic process is suggested that could form the required electric field.

3. Based on statements in the New Testament, it is usually believed that Jesus could have died at the earliest about 3 PM on Friday and his resurrection could have been at the latest about 6 AM on Sunday. This means he would have been dead for up to 39 hours at the longest. Since putrefaction and decomposition would be the main sources of gases from a dead human body, and since these processes are usually said to take place between two and seven days after death, only a small amount of decay gas would be expected to come from his body while it was in the tomb, so it seems unlikely this small amount of decay gas could have formed the images.

4. It is not known how much of the available spices were used to anoint the body on Friday. John 19:39-40 says "Nicodemus, who had first come to Him by night, also came, bringing a mixture of myrrh and aloes, about a hundred pounds weight. So they took the body of Jesus and bound it in linen wrappings with the spices, as is the burial custom of the Jews." This apparently indicates that the spices (all 100 pounds?) were incorporated into the process of wrapping the body, yet the other Gospels do not mention this fact. Jesus' burial was done very hurriedly to complete the task before the Sabbath started at sundown so it is questionable whether there was enough time to fully anoint all of the body. This is probably also indicated by the women who came to the tomb early on Sunday morning to anoint the body. Mark 16:1 says "When the Sabbath was over, Mary Magdalene, and Mary the mother of James, and Salome, bought spices, so that they might come and anoint Him." And Luke 24:1 says "But on the first day of the week, at early dawn, they came to the tomb bringing the spices which they had prepared." Thus, it is not clear how much of the 100 pounds of the myrrh and aloes was applied to the body on Friday evening. It is also not clear how much of the myrrh and aloes would have to be applied to the body to cause the images on the cloth, and no chemical reaction is suggested for how myrrh and aloes could have formed the images.

5. The electrical conductivity of the body is assumed to be excellent so that the body can be modeled as a highly conductive metal such as copper in a cylindrical geometry. In the electric field, this assumption results in the electric field lines being perpendicular to the surface of the cylindrical metal conductor. However, a conductor made of metal is an excellent electrical conductor because the electrons in the outer orbit of each metal atom are held so loosely that

they can easily transfer from one atom to another, thus easily causing either a direct electrical current or an alternating electrical current. This is not true of a human body.

Further analysis of this image formation hypothesis will have to be added later.

7.2 A hypothesis should make predictions that are testable, falsifiable, and possibly unique. This hypothesis does not make predictions, though it should be possible to make predictions from this hypothesis.

7.3a It is preferred that a hypothesis explains more than one mystery of the Shroud. This hypothesis only attempts to explain image formation on the Shroud.

7.3b It is preferred that a hypothesis is simple rather than complex. This hypothesis is fairly complex.

7.3c It is preferred that a hypothesis exhibits “beauty”. This hypothesis makes no claim about it having beauty.

7.3d It is preferred that a hypothesis considers aspects of the Shroud that it does not explain. This hypothesis does not consider this issue.

7.3e It is preferred that a hypothesis is corroborated by one or more diverse areas of study. This hypothesis does not consider this issue.

7.3f It is preferred that a hypothesis clearly explain how information was used to form the images on the Shroud. This hypothesis does not consider this issue.

## 8. Comments on a Generic Scorch Hypothesis for Image Formation

The 27 evidences in Section 2 were used to determine whether a generic scorch hypothesis for image formation would be consistent with the evidence. This generic scorch hypothesis was assumed to involve placement of a linen cloth around a hot object such as a statue or a bas relief. Contradictions between this hypothesis and the evidence are listed below.

1. STURP concluded the images were not caused by a scorch from a hot object. This is because the images did not fluorescence under ultra-violet light. This conclusion directly contradicts the scorch hypothesis.
2. There is a smooth gradation of discoloration on the Shroud from points vertically closer to the body compared to points vertically further from the body. This is not consistent with contact between the Shroud and a hot object as in a scorch hypothesis. At each point, there is either contact or no contact. This is basically inconsistent with a smooth gradation of discoloration.
3. The image of the face is a normal width for a human face. If the Shroud were draped around the face on a hot statue, the face on the Shroud would be much wider than a normal face.



4. The Shroud does not include images of the sides of the body or the top of the head. A statue hot enough to scorch the front and dorsal images would probably also form side images.
5. A scorch would quickly go through the thickness of the cloth, so there would be an easily discernable image on both sides of the cloth. This is contrary to the Shroud.
6. The images on the Shroud are caused by fiber discoloration in only the top two or three layers of fibers in a thread. A scorch, as assumed here, would discolor all the fibers in a thread.
7. The threads in the images are discolored in a mottled pattern. This mottled pattern that is on the Shroud would not be produced by a scorch.
8. The discoloration on an image fiber has a thickness of less than 0.2  $\mu\text{m}$ , with the discoloration around the outer circumference of the fiber, with the inside of the flax fiber not discolored. This would not be true of a scorch.
9. Images can be seen on the Shroud that result from bones near the surface of the body. This includes the area of the teeth, hands, backbone, and possibly the skull. This is not true of a scorch.
10. The images on the Shroud contain 3D or topographical information related to the vertical distance from the body to the cloth at each point. This is not true for a scorch on a cloth laid around a hot object.
11. In the images on the Shroud, the top threads facing the body create a non-discolored region on otherwise discolored threads that are beneath them, like a “shadow” of the top thread on the under thread. This would not be true of a scorch because of how rapidly the heat would be transferred across the thickness of the cloth.
12. On the Shroud, there are multiple bright or dark spots on the mustache, depending on whether the observer is looking at a positive or negative image. This is not explained by a scorch.

Also, it is not known whether specific scorch hypotheses make predictions. There are different types of scorch hypotheses that may not contradict the evidence as above. However, they are also expected to contradict the evidence in multiple ways. If a hypothesis contradicts the evidence in any way, it cannot be true.

## 9. Comments on the Roasted Flour& Oil Hypothesis for Image Formation

As another example, the 27 evidences in Section 2 will be used to judge the merits of Colin Berry’s Roasted Flour and Oil (RFO) hypothesis for image formation (Ref. 11, posted June 20, 2020). He calls this his FILM-SET model, which is an acronym for Flour Imprint, Liquid-Migrating, Solid-Entrapping Threads. He previously called this his “Model 10” hypothesis. In a review of Berry’s postings in Ref. 11 over a 12-year period, it was difficult to determine the nature of his RFO hypothesis. His hypothesis appears to be that a mixture of flour and oil was placed on a human-size statue or bas relief of a crucified man. It was then roasted over a linen cloth to produce the images of a crucified man that is on the Shroud of Turin. He has tried to optimize his hypothesis in multiple ways, finally using a mixture of flour and oil on a small toy figurine of the super-hero called Iron Man. He then placed this flour and oil covered figurine on a piece of linen cloth and roasted it in a hot oven to produce an image of the figurine on the

cloth. The figurine has a height of about fifteen cm (5.9 inches) and appears to be plastic. My comments are below.

1. Berry evidently assumed that the Shroud was proven to be some type of a forgery or fake because of the 1988 carbon date to 1260 to 1390, but multiple analyses have proven that this date for the Shroud should be given no credibility (Ref. 12). According to this assumption, the RFO process to make the images on the Shroud probably took place between 1260 and 1390, but this ignores the many evidences that the Shroud is much older than 1260-1390. If the Shroud was made in 1260-1390, then the nail wounds would have been in the middle of the palms instead of the wrists, and the thumbs would have been prominently shown, consistent with paintings in the middle-ages but inconsistent with the Shroud of Turin.
2. The RFO process to make the images probably would have left material on the cloth that would have been detected during the five days of STURP experiments in 1978. It probably would have produced clumping of fibers or threads and possibly stiffening of the cloth.
3. The STURP experiments found no evidence of capillarity (soaking up of a liquid) because only the top two or three layers of fibers were discolored, yet the RFO process would have involved capillarity in the fibers and threads due to soaking up of the oil.
4. The RFO hypothesis does not explain the scourge marks or blood stains on the Shroud.
5. The Shroud includes front and dorsal images of a crucified man. The quality of both images was about the same, indicating that both images were probably formed by the same process. However, Berry's testing related to his RFO hypothesis only produced an image of the bottom side of the figurine that was lying on the cloth. We are not shown evidence of an image that was produced on cloth that was above the figurine.
6. The resolution of the front and dorsal images on the Shroud has been estimated to be about four to five mm. It appears that the resolution of the toy figurine produced on the cloth is not as good as the images on the Shroud. This would have been far more apparent if testing of the RFO hypothesis used a larger model of the crucified man that is imaged on the Shroud rather than a toy figurine.
7. The plastic figurine used for testing of the RFO hypothesis produced a blurry erratic image of itself on the side of the cloth that was in contact with the bottom of the figurine. We are not told or shown whether there is also an image on the other side of the cloth. If there is an easily discernable image on the other side of the cloth, this would contradict the Shroud of Turin. We are also not shown an image on a cloth that should have been placed above the figurine during the roasting process.
8. The images on the Shroud are caused by fiber discoloration in only the top two or three layers of fibers in a thread, with those discolored fibers facing toward the body, on both the front as well as the dorsal image. This is referred to as the superficiality of the images on the Shroud. It appears there is no claim that this is true for the RFO hypothesis, and it is doubtful that this would be true.
9. The threads in the images on the Shroud are discolored in a mottled pattern, yet this mottled pattern forms the front and dorsal images of the crucified man that can be seen on the Shroud. It is difficult to imagine how a scorch would produce the mottled pattern that is on the Shroud.

10. The discoloration on all the discolored fibers on the Shroud has approximately the same color, usually called a straw-yellow or light sepia color. The image of the figurine on the cloth is the wrong color. It might be called a gray to black color.
11. The discoloration on an image fiber on the Shroud has a thickness of less than 0.2 micrometers ( $\mu\text{m}$ ), with the discoloration around the outer circumference of the fiber, with the inside of the flax fiber not discolored. Apparently there is no claim that this is true for the RFO hypothesis, and it provides no mechanism that would cause this to be true.
12. Images can be seen on the Shroud that result from bones near the surface of the body. This includes the area of the teeth, hands, backbone, and possibly the skull. The RFO hypothesis provides no mechanism that would cause this to be true.
13. The images on the Shroud contain 3D or topographical information related to the vertical distance from the body to the cloth at each point. The RFO process may indicate some slight presence of 3D information on the cloth but it appears to be less significant than on the Shroud. There is also no clear mechanism in the RFO hypothesis that would produce 3D information on the cloth.
14. On the Shroud, the discoloration on the image fibers is due to some of the single electron bonds of the carbon atoms that were previously in the cellulose being changed to double electron bonds, apparently due to an oxidation dehydration process. This means that there were no materials added to the cloth to form the images. Instead, the atomic structure of the atoms in the cellulose was merely rearranged, with addition of oxygen and removal of water in the process. This is contrary to the RFO hypothesis which claims that a chemical reaction of flour and oil on the cloth in the roasting process caused the discoloration.
15. On the Shroud, the top threads facing the body create a non-discolored region on otherwise discolored threads that are beneath them, like a “shadow” of the top thread on the under thread. It appears there is no claim that this is true for the RFO hypothesis, and it is very unlikely to be true due to the capillarity of the oil on the cloth.
16. On the Shroud, there are multiple bright or dark spots on the mustache, depending on whether the observer is looking at a positive or negative image. It appears the RFO hypothesis does not explain these spots on the mustache on the Shroud.
17. The images on the Shroud were not affected by heat in the 1532 fire or by subsequent water thrown onto the Shroud after the fire. It appears the RFO hypothesis does not explain this.
18. Images of various parts of flowers appear to have been encoded on the side of the Shroud facing the body. It appears the RFO hypothesis does not explain this.
19. During the STURP experiments on the Shroud in 1978, many oxidizing and reducing agents were applied to image fibers to determine which agents would eliminate the fiber discoloration. None of them eliminated the discoloration except for diimite which eliminated the discoloration immediately when it was applied. It appears the RFO hypothesis does not explain this.

Also, it is not known whether the RFO hypothesis makes any predictions.

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