IMAGE FORMATION ON THE HOLY SHROUD OF TURIN BY ATTENUATION OF RADIATION IN AIR

by ***Bernard A. Power***

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Introduction:

Probably the best available theory to explain the image formation on the Holy Shroud of Turin is that it was produced by some form of radiation passing across the air gap between the dead Body and the enveloping linen Shroud. The attenuation or fall-off in radiation intensity in the air gap could have caused the observed variation in image intensity from point to point on the Shroud so that points closest to the Body have the greatest intensity and those points furthest away are the faintest (6).

The intensity of this hypothetical radiation must be high enough to form the observed image by chemical discoloration of the linen fibrils through an acid-oxidation of the cellulose (1). The chemical process thus sets an energy requirement that must be met, and this same energy amount in turn will correlate to a radiation frequency and wavelength.

In previous research into a radiation mechanism the basic energy requirement for image formation has been investigated (2,3,4,5). The approach was to calculate the required energy by assuming it to be roughly equivalent to that needed to cause a slight scorching of the linen, since the observed slight discoloration on the Shroud is optically very similar - though not chemically identical- to the discoloration which can be produced in linen by slight thermal scorching (1,10). The calculated thermal scorch energy can then be used to investigate the radiation involved. The present paper will extend the analysis to relate the observed attenuation of radiation occurring in the Body-to-cloth air gap to the resulting energy and wavelength of the radiation.

The Observed Image Intensity Data

The correlation between image intensity on the Shroud and the air gap distance between it and an enveloped Body was first noted by Vignon. Then in 1976 at the New Mexico Conference, Jackson et al of STURP (6,7) presented measurements of the image intensity at 24 points on the Shroud photographs and correlated these with air gap distances corresponding to these image points as measured on human subjects draped in a linen cloth as in Figure 1. In 1982 STURP published additional data for 13 points on the Head and Face area of the Shroud, (8) making a total of 37 data points in all (Table 1). However, neither of these papers presented a mathematical analysis of the attenuation or fall -off of the image intensity with distance in the air gap.

Table 1

A. Shroud Image Intensity Data (1977)

Image Intensity	Cloth-to-body Distance (centimeters)	Body Area
0.55	0	Head
0.41	1.2	Head
0.41	1.2	Hand
0.38	1.3	Upper leg
0.31	0	Knee
0.28	0.8	Upper leg
0.27	0.8	Lower leg
0.25	0	Torso
0.24	1.5	Lower leg
0.20	0.5	Head
0.18	2.1	Torso
0.15	1.9	Lower leg
0.14	6.9	Lower leg
0.13	3.4	Torso
0.12	2.4	Upper leg
0.12	6.1	Torso
0.11	2.8	Upper leg
0.09	4.9	Torso
0.09	10.6	Lower leg
0.08	3.5	Upper leg
0.08	8.1	Lower leg
0.07	6.3	Torso
0.07	10.2	Lower leg
0.07	10.7	Lower leg

B. Shroud Image Intensity Data (1978(1982)

Image Intensity	Cloth to body Distance (centimeters x 2.303)	Body Area
0.325	0	Head
0.295	1.1	Head
0.285	0.75	Head
0.280	0.40	Head
0.275	1.30	Head
0.260	0.75	Head
0.250	1.55	Head
0.220	1.90	Head
0.195	1.00	Head
0.195	0.80	Head
0.190	1.00	Head
0.185	2.60	Head
0.160	2.33	Head

The significance of the image intensity measurements in Table 1 lies in the nature of the image itself on the Shroud. Its faint negative imprint is similar to a photographic half tone print, where the tonal variations which give depth and shape to the print arise only from the number of tiny individual dots or elementary image elements which are all of the same shade or tone. More image elements per unit area give a darker tone, fewer per unit area a lighter tone.

One can then visualize a process in which the intensity of an image forming radiation results in a different spacing of the individual image elements on the cloth. This happens if the intensity of the radiation depends on the distance that it travels through air so that it is thereby attenuated or reduced in intensity. Greater distance means lower intensity and wider spaced image elements formed on the cloth and vice versa. In this way the attenuation of a radiation beam with varying distances from a source through intervening air can match and explain the observed three-dimensional information contained in the Shroud image. Thus it is important to study the attenuation of the radiation in the Body-to-cloth air gap since it is this attenuation of the radiation which results in the tonal variations on the Shroud which make up the image.

The Radiation Attenuation Analysis

In order to analyze the image intensity data the measurements of Table 1 must first be reduced to a standard comparable form. This has been done in the following manner: First, the image intensity measurements were reduced or normalized to a standard intensity base by calculating the ratio of the image intensity I at any point on the Shroud to the maximum observed image intensity I_o (which would occur at a point of actual contact of the Shroud with an enveloped Body, for example at the forehead, tip of the nose or the hands).

$$\text{Standardized Intensity} = I/I_o \qquad (1)$$

At points of actual contact with the body, this standardized intensity ratio becomes equal to unity ($I_o/I_o = 1$) which is the maximum value of observed image intensity. At other image points, where this radiation has traveled across the air gap or the Body-to-cloth separation, it is reduced in intensity, i.e. it is attenuated, because of absorption of some of the radiation by the air and water vapor molecules in the air gap ($I/I_o < 1$). Thus, the intensity ratio I/I_o becomes progressively reduced, from the maximum value of unity at distance equal to zero, to lower and lower values with increasing distance across this gap.

The 1977 and the 1978 sets of data in Table 1 were both standardized in this same way by calculating the value of the intensity ratio I/I_o. When this is done the two sets of data are essentially compatible, since at the common point of maximum intensity at the points of contact of the Body with the Shroud, such as at the tip of the nose or at the forehead, the intensity ratio I/I_o becomes equal to unity in both sets and all the other points are then standardized relative to unity. The resulting data are listed in Table 2.

Table 2

Standardized Image Intensity Data of 1977 and 1978 (82) Combined

Intensity Ratio (I/I_o)	Distance from Body (cm)
1977)	
1.00	0
0.745	1.2
0.745	1.2
0.69	1.3
0.56	0
0.51	0.8
0.49	0.8
0.45	0
0.44	1.5
0.36	0.5
0.29	1.8
0.27	2.2
0.25	6.9
0.24	3.4
0.22	2.4
0.22	6.1
0.20	2.8
0.16	4.9
0.16	10.6
0.15	3.5
0.15	8.1
0.13	6.3
0.13	10.3
0.13	10.7
(1978)1982	
1.00	0
0.91	0.47
0.88	0.33
0.86	0.17
0.85	0.56
0.80	0.33
0.77	0.67
0.68	0.83
0.60	0.43
0.60	0.35
0.58	0.43
0.57	1.13
0.49	1.01

The data of Table 2 are shown graphically in Figure 2, using coordinates of relative intensity I/I_o versus Body-to-cloth distance x in centimeters. The 1978(82) data are plotted as square points and those for 1977 as dot points. It is clear that the 1977 data are generally consistent with the 1982 points when both are standardized to the same intensity in the manner described.

The next problem is to try to determine an equation which will give the best fit to this basic data of Table 2, and so permit a preliminary characterization of the radiation which could have formed the image.

The attenuation of any electromagnetic radiation in air follows the Lambert/Bouguer Law

$$I/I_0 = e^{-k\,x} \qquad (2)$$

where I_0 is the intensity of the radiation entering the absorbing air gap and I is the intensity value at any distance x into the air. The ratio I/I_0 is then the relative intensity (either a decimal fraction or a percentage value) of the intensity of the radiation at any distance x from the emitting point on the body. The constant k is called the absorption coefficient; its numerical value in air depends on the wavelength of the radiation. The value of k is small for small attenuation (i.e. transparent intervening air) and is large for large attenuation of the radiation (strongly absorbing air).

Electromagnetic radiation, other than soft X-rays or the edge of the ultraviolet, is strongly absorbed by air only in a narrow section of the microwave band from about 0.1 to 0.35 millimeters wavelength. At other wavelengths air is almost transparent to electromagnetic radiation so that there is no significant attenuation. Radiation without attenuation - that is with constant intensity- might indeed discolor the Shroud uniformly, but there would be no variations in shading from place to place and therefore no image produced. We have listed some values for k and corresponding attenuation ratios (I/I_o) at an air gap distance of 1 centimeter in Table 3.

Table 3

Attenuation Values of Electromagnetic Radiation in Moist Air (3 mm to 028 mm)

Wavelength (λ)	**Absorption Coefficient** (k)	**I/I_0 at x =1 cm.**	**Transmission** (%)
3 mm	2.3×10^{-5} per cm	0.9999	99.99%
1	2.3×10^{-4}	0.9998	99.98
0.5	2.3×10^{-3}	0.9977	99.77
0.4	0.046	0.955	95.50
0.3	0.23	0.795	79.50
0.29	0.69	0.50	50.00
0.28	6.9	0.001	00.1 (opaque)

The results in columns 3 and 4 indicate that moist air is almost transparent to electromagnetic radiation at wavelengths greater than 0.4 mm with almost no absorption occurring. But a very abrupt change takes place around 0.3 mm where very large absorption or attenuation sets in and the air gap becomes almost opaque to the radiation.

For example, the plotted data in Figure 2 shows that there has been almost 50% reduction in transmitted radiation intensity at 1 centimeter into the air gap ($I/I_o = 0.5$), and we see from Table 3 that this would mean a k value of about 0.69. At larger air gap separations ($x > 5$ cm) the k value would have to be very much greater, since the transmitted radiation then becomes almost constant at around 13% ($I/Io = 0.13$). For illustration, a curve with k equal to 0.69 is plotted in Fig. 2 as Curve A. This curve fits the observed data at 1 centimeter distance ($I/I_o = 0.5$), but then falls off so rapidly that it misses all the lower intensity data points at x larger than about 5 centimeters entirely. This means in all probability that no single attenuation curve will fit the Shroud image intensity data at both small and at large air gap distances.

A possible solution to this problem would be to assume that the radiation of Figure 2 actually consists of two components, or two kinds of radiation.

The first (Curve B) could be electromagnetic radiation of wavelength about 1 mm (microwave band) having an attenuation coefficient k of around 0.00023. Such radiation would have sufficient energy to act chemically on the linen of the Shroud to discolor it and cause the observed faint yellowish tint, but, because electromagnetic radiation of this wavelength has such a very low attenuation in air (k of 0.00023,Table 4) it would pass through the air gap with no change in intensity from its initial value of $I/I_o = 0.13$ and so would discolor the Shroud uniformly but show no variation of intensity with varying Body -to-cloth distances Thus no image would be transferred from the Body to the cloth. This kind of electromagnetic radiation would just put a general uniform light background coloring to the cloth at all points.

The second component of radiation, on this hypothesis, Curve C, would then be electromagnetic radiation (microwave band) which attenuates strongly with distance x from the body. The k value for this kind of radiation would be around 0.855 to fit the Shroud data image intensity at short distances of up to say 2 or 3 centimeters air gap. As seen in Table 4, radiation about 0.35 mm (microwave) would give the proper values of k and the proper absorption and transmission ratios for this radiation.

Then the combination of the two kinds of radiation (Curve D = B +C) would fit the observed data over the whole range of Body-to-cloth distances and would thus account for the observed image. This combined attenuation equation would be

$$I/I_o = 0.13e^{-0.00023\,x} + 0.87\,e^{-0.855\,x} \qquad (3)$$

Curve D in Figure 2 is thus the sum of the two other curves B and C. The curve C radiation drops off rapidly with distance in the air gap from $x = 0$ and is nearly zero at distances of x greater than about 5 centimeters. Curve B decays so slowly with distance x that it appears to hardly have decayed at all from its initial value of $I/I_{o.}$ which is 0.13 at distance x equal to zero, and then it just continues at this same value even out to distances of 10 centimeters from the Body across the air gap to the Shroud. The first component of radiation is plotted as Curve B in Figure 2, the second as Curve C, and the combined Equation 4 as Curve D. This new curve then gives an attenuation of 50% ($I/I_o = 0.5$) at 1 centimeter air gap. At distances of 4 cm and more the attenuation becomes a constant 13% ($I/I_o = 0.13$).

Each point on Curve D in Figure 2 is therefore just the sum of two other curves: First, of Curve B (which decays so slowly with distance that it is almost constant and runs across horizontally on Figure 2), and then, second, of Curve C which decays very rapidly with distance and would be nearly zero at a distance from the Body of 5 centimeters. So, at each air gap distance x we have in Curve D the sum of two intensities of the B and C curves so that D = B + C. The summation Curve D then fits all the observed image data points quite well.

Naturally some preliminary questions now arise. Is this radiation physically reasonable? Does it agree with any known physical process? Will it describe the chemical processes going on in the reaction of cellulose degradation or discoloring? How does the radiation interact with or couple to the cellulose fibrils?

Image Energy and Radiation Wavelength

A fundamental requirement of any consistent theory of image formation will have to be a consistent energy balance. The minimum energy required to form an image on the Shroud can be calculated or estimated (2,3,4,5). First, it is known that spectroscopically the image is quite similar to that which can be produced on linen by a slight thermal scorch (10). And so the chemical energy for any process which produces a similar image should be roughly equal to the scorch energy, which is readily calculable. Eventually, of course, the precise (non-scorch) process of image formation needs to the established, but one can at least establish a preliminary general level of energy needed by making the scorch assumption.

The energy for scorching linen can be calculated from the heat equation

$$E = m\, \Delta T\, c_p \qquad (4)$$

Here m is the mass of linen scorched, ΔT is the temperature rise required to reach scorch temperature of linen (200 - 15 =185° C). c_p for the linen is taken as being the specific heat of cellulose (0.34 calories per gram per degree temperature rise, expressed in Joules) This specific heat is then 0.34 x 4.186 = 1.423 Joules of heat energy per gram per degree temperature rise (9).

We have estimated the mass of linen fibrils of the Shroud which have been darkened by the image process ("slight scorch" or thermal degradation) as probably being in the range of 1 to 50 grams. Based on this estimate of linen scorched we can calculate from Equation 4 the following estimated range of the heat energy needed to chemically discolor the linen of the Shroud and form the observed image (Table 4).

Table 4

Estimated Mass of Image Fibrils Scorched	Heat Energy (E) for Scorching
1 gram	286 Joules
10 grams	2.86×10^3 "
20 "	5.72×10^3 "
40 "	1.14×10^4 "
50 "	1.43×10^4 "

At this point we must reiterate what was said at the very start of this investigation (2), namely, that these calculated energies for image formation represent only the *minimum* energy needed to form the image by bringing the temperature of the linen up to the scorch temperature of about 200 deg, C.(2). That is to say, the energy emitted by the Body in some manner - say by a transformation of matter process - might well be higher than these calculated values because only a portion of the emitted energy might actually be absorbed by the linen. We would say in that case that the *coupling* of the radiation energy to the cloth would be less than unity, where unity would represent a complete absorption of all of the emitted energy.

So with this in mind we interpret the energy estimates in Table 4 as the minimum energy needed, not the actual energy emitted by the Body, which may have been greater, depending on what we eventually find to be physically reasonable from an analysis of the radiation.

From here, with an estimated minimum energy in mind, we can go on to examine methodically the next level of relevant questions. First, the nature of the radiation involved, its energy and wavelength, and, second, the nature of the chemical process which gives rise to the coloring of the fibrils of linen, and then the chemical energy required.

The new attenuation equation (Eqn.3) points to a possible involvement of electromagnetic radiation in the microwave band, where the intrinsic energy per photon is low, so low that it could not directly initiate the rearrangement of the chemical bonds to produce the structures (e.g. C=O) which are needed to constitute the observed color. Thus, for microwave radiation we need to invoke a thermal process which raises the temperature of the linen sufficiently to bring about the necessary chemical reaction, not by direct chemical bond breaking, but indirectly through some sort of thermal action on the linen.

A first look at the energies involved in the formation of a double bond C=O chromophore from a single bond C-O indicates that it is around 90 kilojoules per mol, which is about the same as the energy needed to scorch 1 gram of linen (286 Joules,

Table 4). Of course, as stated, the matter of how the weak microwave energy couples to the linen so as to bring about this thermal reaction needs to be resolved.

The energy of radiation per photon absorbed by the linen fibrils can be calculated for microwave radiation. A corresponding energy can be calculated from the scorch energies (286 Joules per gram). On a preliminary analysis it appears that the energies of microwave radiation and of a linen scorch are roughly the same. Thus the attenuation analysis points to microwave radiation being involved in the image formation, and this radiation in turn may match the energy requirements calculated in Table 4. This agreement is encouraging for the further work that needs to be done to more fully explore the mystery of the image formation on the Holy Shroud.

Discussion

The attenuation of the image-forming radiation for the Holy Shroud has been mathematically analyzed and the value of the attenuation coefficient necessary to form the image ($k = 0.855$) has been determined. This k value requires that the radiation, if it is electromagnetic in nature, should be either soft X-ray, short ultraviolet or microwave radiation.

However, the X-ray-and ultraviolet options have in the past been ruled out because the energy involved would be so high that the effects on the linen fibrils would be to cause pyrolitic damage which is not observed (10).

The choice of microwave radiation attenuates the radiation properly across the Body-to-cloth air gap to form the image elements on the Shroud, and also roughly fits the calculated energy range needed to raise the linen temperature to the scorch temperature, namely about 286 Joules per gram of linen fibrils discolored.

Of course, an energy correspondence value does not prove that the Shroud image actually was formed by some sort of microwave beam. In addition to providing the correct energy the candidate radiation must also fit the chemical kinetics associated with the alteration of the cellulose fibrils, that is, for example, to break the single bond C-O in the cellulose molecule and form the necessary double-bond molecular chromophore (C=O) which could be the cause of the yellow color (1). This problem has not yet been analyzed carefully and assessed. The problem of how the radiant energy couples to or interacts with the cellulose fibrils is also to be studied. Finally, the pronounced verticality of the Shroud image is unresolved. A step by step study of these and other problems remains to be done.

References and Notes

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Bernard A. Power
255 Touzin Avenue
Dorval, Quebec, Canada
H9S 2N1
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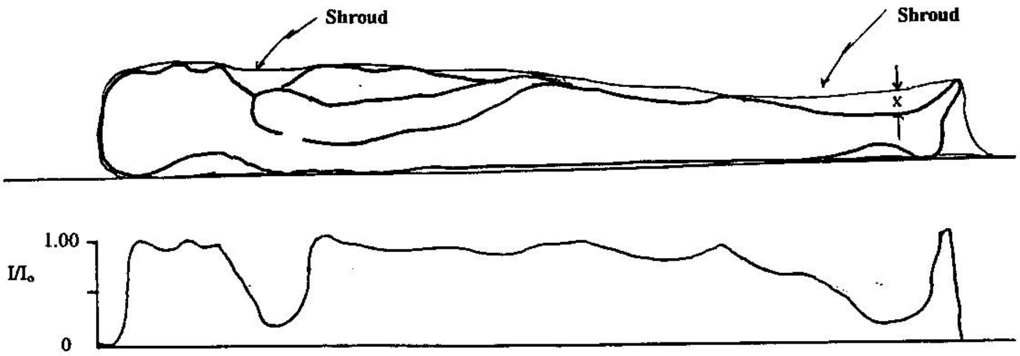

Fig. 1 Shroud image intensity profile versus cloth-to-body distance x

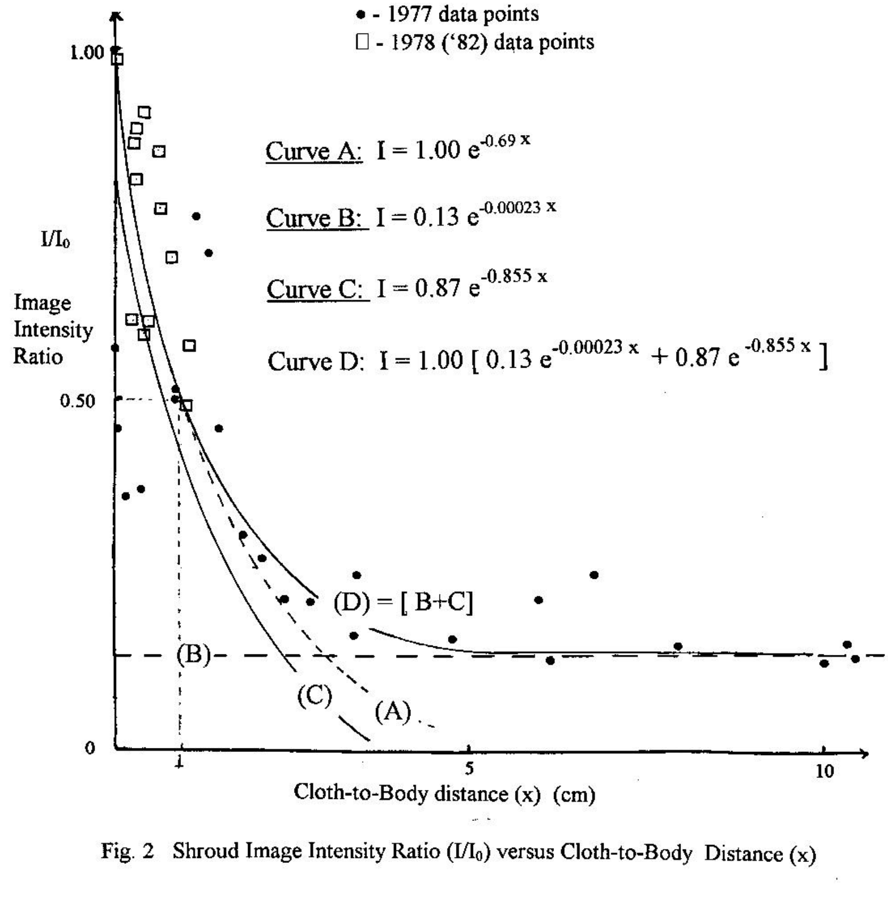

Fig. 2 Shroud Image Intensity Ratio (I/I_0) versus Cloth-to-Body Distance (x)