RESEARCH ARTICLE

# Evidence for charge of the photon: 694 nm red laser photons perturb a static magnetic field and movement in organic paper material exposed to sunlight

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## ABSTRACT

Photons, described by particle and wave theories, are accepted not to possess mass, charge nor deflected by a magnetic field. During electron-spin-resonance experiments, hair containing melanin was 694 nm laser- irradiated. An 'off-resonance' at laser-firing was observed in a time-scan at constant magnetic field, whilst monitoring laser-induced radical formation. It was hypothesized coherent photons interacted with the magnetic field. The radical g-value was invariant in successive field-scans, although the hair melted.

Melanin, in the solid state in hair, does not exhibit temperature-dependent paramagnetic. 4.3–9.8 x $10^{18}$ photons in 1.2 J–2.7 J per pulse impact a 1.8 x $10^{-5}$ $m^2$ hair surface area, and a mean 72% 'off resonance' signal-drop is determined from the time-scan, which translates to a field-shift of 4 G or 4 x $10^{-4}$ T. This is the same order of magnitude of hyperfine couplings, or field-shifts for absorption, due to proton nuclei (spin½) in the vicinity of the unpaired electron of the melanin radical. If the pulse is point charge ($N_{photons}.q_{photon}$) impacting the solid hair surface area at the speed of light c, $q_{photon}$ is 9.2 x $10^{-31}$ coulombs and q/e 5.8 x $10^{-12}$. The ESR observation is proposed to be spin-coupling of photons with charge and magnetism, with melanin radical unpaired electrons during the laser pulse. That photons carry charge is corroborated by repulsive movements observed between square paper pieces, comprising starch-based organic polymers, placed edges together within a plastic wallet and exposed to 4h+ sunlight. Movement is not detected in comparable experiments with heat alone.


**Key Words:** *Photon; Charge; Laser-irradiation; Electron-spin-resonance Spectroscopy; Melanin*

## INTRODUCTION

It is accepted that photons possess momentum but zero rest mass. In a review published in 2005 the authors conclude that photon mass is mathematically feasible, but conclusive experimental evidence was lacking [1]. These authors also stated that the failure to measure a rest mass of the photon does not prove its non-existence, and there are situations where the rest mass could be finite, for example when photons are moving slowly in solid media. The photon is described by wave and particle theories. The particle nature is suggested by the discrete energies of photons and quantized interaction with matter according to the relation $E = h\nu$ (where h is Planck's constant and $\nu$ is the radiation frequency). Wave theory has better described the phenomena of reflection, refraction, diffraction, and interference. The accepted view of a photon is that, in addition to not possessing mass, it carries no charge, nor is it deflected by a magnetic field [1]. The question of photon charge and mass is important, since the energy of the sun is significant, and should photons carry charge then the sun might further be exploited as an energy source. The controversy appears to centre on Einstein's theories that the mass of a photon moving at the speed of light would be mathematically infinite. The theory also predicts zero rest mass. The latter is more straightforward to address, in that it could be that photons do not come to rest but are always in a state of motion or absorption by matter. Photon mass challenges Einstein's theory. It is not the purpose of this article to address this in detail, but the point can be made that a paradigm can be challenged. That light bends in a gravitational field could be accounted for by a charge and mass theory of the photon. The nature of gravitation itself could also be addressed differently, if the force of attraction between masses is an extension of the collective attraction of all the protons in two massive bodies for all the electrons in their collective orbits. This is analogous to the weak Van der Waals forces which hold together molecules in a solid. The inverse square law of gravitational attraction is not unlike the inverse square law of electrostatic attraction between positive and

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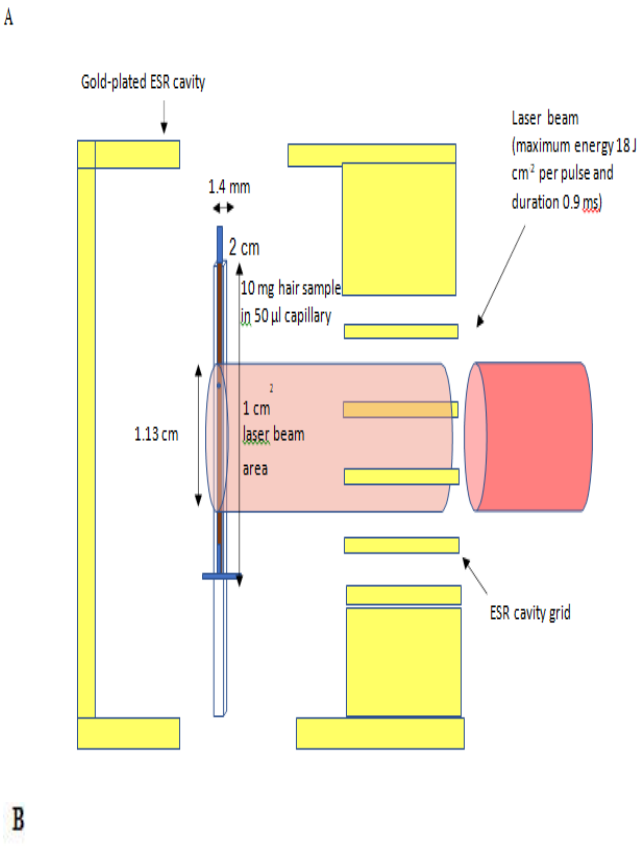
negative charge. The purpose here is to address the physical meaning of an experimental observation, which could suggest photons carry charge [2].

During a series of Electron-Spin-Resonance (ESR) experiments, a 694 nm ruby laser was used to irradiate a human hair sample contained in the cavity of the ESR spectrometer. A momentary 'off-resonance' was observed. This occurred in a time scan at a constant magnetic field monitoring the formation of a laser-induced radical. To the author, it appeared possible that the 'off resonance' was a result of a magnetic interaction of the laser photons with the applied static magnetic field. The field had been set to that required for peak microwave absorption (resonance) of the radical, and during the continuous scan with time, the hair sample was subject to groups of laser pulses of energy densities 17 J $cm^{-2}$ and pulse duration 0.9 ms. The time-scan spectrum was included in the paper published in 2004 'Differences in Production of Melanin radicals by 694 nm Ruby Laser and UVA radiation, but then represented again in 2019 in the RSC-ESR Group Conference in Glasgow, this time drawing attention to the 'off resonance' perturbations. This effect had not been observed in the author's laboratory using non-coherent light sources. It seemed not unreasonable that if light photons possessed angular momentum, or spin, as suggested by the wave theory, which describes photons as waves of oscillating electric and magnetic vectors in space, then this might not be detectable in a beam of non-coherent and out of phase photons emitted by a regular light source. It may, however, be theoretically detectable if the photons were in-phase as in the coherent radiation emitted by a laser. In this situation, a very small spin angular momentum may be additive. This is analogous to ferromagnetism as induced in iron when the paramagnetic unpaired electrons of the iron atoms are aligned by an external magnetic field and therefore induced to be in phase. In the absence of this alignment, the electron spin becomes random and non-aligned with the iron being non-magnetic. This observation suggested that if the red photons emitted by the laser were collectively associated with a measurable charge and associated magnetic field at the point of impact with the sample, which affected the external magnetic field, then they could individually possess a charge or spin. The ESR data were analyzed with this question in mind. In addition, to investigate the possibility that photons moving slowly through organic material carry a charge, experiments were designed to test the hypothesis using readily available natural and modern man-made materials and natural sunlight. Materials were desirably a large, even, surface area, and of the long-chain polymer composition. Paper meets these criteria being an organic cellulose material comprising starch polymers. The paper was cut into 2.5 cm x 2.5 cm and 5 cm x 5 cm squares to provide large surface area, placed edges together, and exposed to natural sunlight during the summer in England, UK. Evidence is presented for the repulsion between the paper pieces, which was not observed using heat alone, consistent with the accumulation of electrostatic charge [3-5].

## METHODS AND RESULTS

**ESR Observation of an 'off-resonance' suggesting photons are charged**

The experiments to laser-irradiate human hair in the cavity of the ESR spectrometer are described in reference 2, and the experimental setup used is shown in Figure 1. 10 mg of dark-brown hair, cut into approximately 2 cm lengths, was inserted into a 50 $\mu l$ silica capillary tube, of internal width 1.4 mm (Merck technical services) which was stoppered with wax at each end. The capillary tube was placed into a silica holder such that the hair strands were held vertically at the center of the gold-plated ESR cavity. The laser probe was held horizontally at a distance of approximately 0.5 m and the 1 $cm^2$ laser beam was directed onto the center of the ESR cavity grid. It was established by eye that the center of the beam was incident upon the hair sample in the cavity. It was first necessary to monitor in situ irradiation by recording ESR field scans (variation of the magnetic field at the constant frequency with time) immediately following the laser firing. The field-scan spectrum of the melanin in the hair had already been obtained, so instrument parameters were set to record the melanin spectrum; a broad singlet without any hyperfine splitting, and g value of 2.0022 typical of organic radicals and close to that of the free electron. (The equation for resonance is $g = h\nu(\beta B_o)^{-1}$ where $\nu$ is the microwave frequency, $B_o$ the magnetic field for peak microwave absorption, h Planck's constant (6.626 x $10^{-34}$), and $\beta$ is the Bohr magneton (9.274 x $10^{-24}$ $J.T^{-1}$)). Figure 2 shows examples of this data, and also after irradiation with 36 laser pulses. There were no perturbations that could be seen in the field-scan spectra immediately following the irradiation, but the melanin radical signal increased in intensity approximately threefold, consistent with radiation absorption by the sample. It was known the melanin semiquinone radical signal (microwave absorption) increases approximately two-fold with UV irradiation, reversing to ground state levels in the absence of UV. The laser radiation, by contrast, did not reverse to the ground state, as was established as the hair was further irradiated and field- scans were recorded immediately after and then 24 h later. The laser-induced radical was suggested to be a carbon radical, by contrast with the UV-generated semiquinone oxygen radical. UV photons are absorbed by the oxidised melanin quinone groups in the melanin polymer, with the excitation of an electron to an excited singlet state, which converts to a paramagnetic triplet state which has been detected with ESR. The oxidizing triplet state then reacts with reduced hydroquinone groups, also in the melanin polymer, increasing the population of semiquinone radicals which is disproportionate to quinones and hydroquinones after irradiation. The previous work suggested, however, that the UV and red chromophores were different, since, as red light absorption was lost on oxidation, the red chromophore was suggested to be the reduced hydroquinones. Figure 2 shows a simple Jablonski diagram for the absorption of red photons, exciting an electron in the ground state molecule to an excited singlet state, the likely conversion to a paramagnetic triplet state which then converts to the detected radical intermediate [6,7].



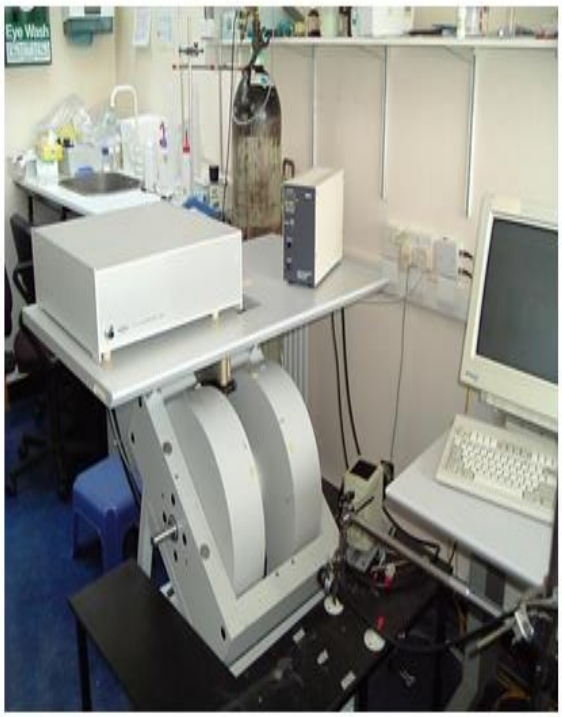



**Figure 1**.(***A***) *Diagrammatic 2-D representation of the gold-plated ESR cavity and grid onto which the1 cm² laser beam was directed.* (***B***) *It was established by eye that the beam was incident upon the dark-brown hair strands (10 mg) contained vertically in a 50 µl silica capillary tube (width 1.4 mm) within the ESR cavity of the Bruker EMX Spectrometer*

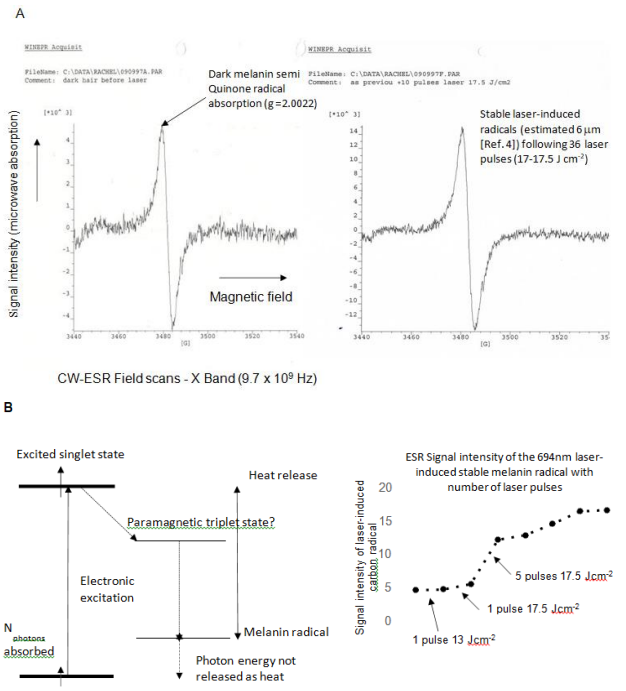



**Figure 2** *(A,B) W-ESR Field scans (9-10 September 1997) of the hair sample at X-Band microwave frequency (9.7 x 10⁹ Hz). C) Simple Jablonski diagram to show light absorption by melanin and electronic excitation to an excited singlet state and likely conversion to paramagnetic triplet state and detected stable radical intermediate.*

Figure 3 shows data from the ESR experiment to monitor the formation of the laser-induced radical with time. The magnetic field was set to the peak of the melanin radical absorption, 3489.54 G, which was obtained from the preceding field scan. The absorption was then monitored at a constant field with time and the laser fired at the sample during the time-scan, as shown in Figure 3. A perturbation of the absorption or 'off resonance' is observed every time the laser is fired at the hair sample. There is a brief loss of resonance, which is then restored following the laser pulse. The 'off-resonance' spikes observed in the spectrum of the dark-haired hair sample were not observed as clearly in that of an auburn hair sample which contained less melanin pigment, nor in any melanin in solution. It was, however, weakly detectable in solid melanin suspended in solid agar. The percentage loss in resonance was determined from the expanded and re-plotted time scan (Figure 3). The length of the signal drop from the peak point before the signal drop, to the lowest point relative to the signal peak, for each laser pulse, was taken where the loss was clearly above the baseline. The baseline was taken to be either a maximum or minimum reference point where the stable radical signal (in the absence of irradiation) was monitored with time, before firing the laser. The minimum (baseline 2) was a line drawn through the centre of the initial absorption and the maximum (baseline 1) was a line extrapolated through the absorption just before the first laser pulse. The signal drop was expressed as a mean of 11 laser pulses out of 15 laser pulses. The first pulse was discarded since the energy was lower (13.5 J cm$^{-2}$) and also three out of six of the initial pulses at 17 J cm$^{-2}$, where the signal increase due to the laser-induced radical was relatively small and not distinct from the baseline. The drop in signal was taken as

the distance from the peak signal just before laser firing to the lowest point of the signal after laser firing. This was then expressed as a percentage relative to the distance to the baseline at each point. The mean drop in signal over the 11 laser pulses was calculated to be 68.6% (baseline 2 Standard Deviation 10.5%) to 76.3% (baseline 1 Standard Deviation 12.5%) for these two baseline limits, giving a mean of 72.5%.

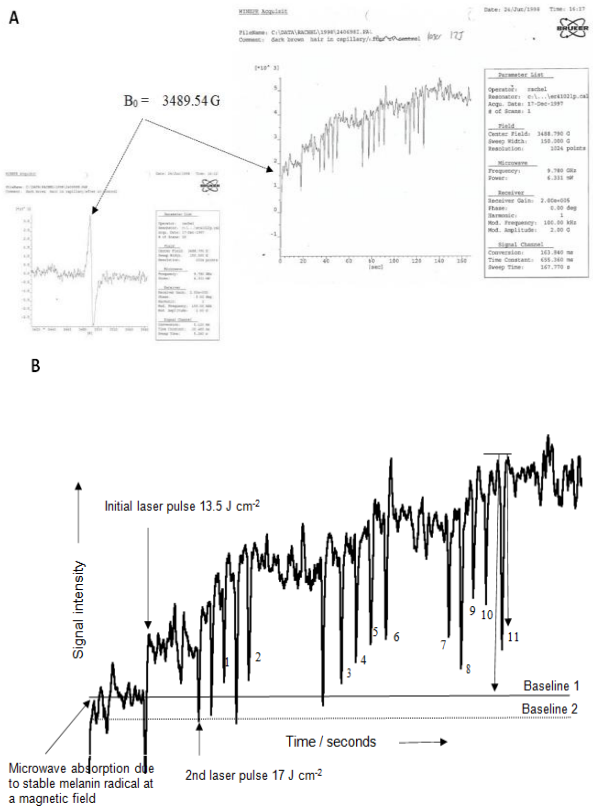



**Figure 3)** *(**A**)- Scanned original time scan data first obtained in 1998. (**B**)- Data replotted after importing into Excel as an ASCII file from the raw data obtained in 1998. The % signal drop was calculated from the peak of the signal before the 'off resonance' in the expanded data to the lowest point of the 'off resonance' relative to a baseline 1 (indicated solid line) and baseline 2 (indicated dotted line) for each point of laser firing for 11 laser pulses out of 15 laser pulses (indicated) of 17 J cm$^{-2}$. A mean drop of 72.5% was calculated from the means obtained of 76.3% (SD=12.5%) and 68.6% (SD=10.5%). The raw data was obtained on 24 June 1998 and is also included in the Supplementary Information file.*

Published data suggest that melanin only exhibits temperature-dependent Para magnetism when hydrated, and not when it is in the solid state as is the situation with melanin in hair [7]. Consistent with this there was no perturbation detectable in the field scans obtained immediately following laser-irradiation, where it might be expected that a temperature-induced change in the g value of the spectrum of the laser-induced radicals would become evident. Figure 4 shows the signal centre magnetic-field measurements and experimental microwave frequency for two independent experiments. There is no change in either the field for peak microwave absorption ($B_o$) or the microwave frequency ($\nu$) during irradiation. This is consistent with the g value being invariant (from the equation for resonance $g = h\nu(\beta B_o)^{-1}$ where $\beta$ is the Bohr magneton (9.274 x 10$^{-24}$ J.T$^{-1}$)). It was observed that the hair after laser irradiation had melted but not combusted, as it would have done in the air or in the hair follicle when targeted by the laser to cause combustion. The hair in the sealed capillary would be relatively hypoxic, restricting combustion. Hair containing moisture melts at 155°C and combusts at 233°C. Since a 1 cm$^2$ collimated laser beam was directed onto the hair held vertically in a capillary tube of 1.4 mm internal width, only part of the beam was incident on the hair. The spot size was 1 cm$^2$ therefore the length of hair upon which the laser beam was incident was the diameter, and 1.13 cm. For hair strands inside a capillary of internal width 1.4 mm, the irradiation area is 0.14 cm x 1.13 cm or 0.158 cm$^2$. Thus, the maximum beam energy which can impact the hair, even operating at the highest energy, is 0.158 J x 18 J or 2.85 J per pulse, assuming no scattering losses. It was established prior to firing the laser that the center of the beam was incident on the hair in the capillary, and the beam was directed upon the aperture to the cavity, with minimal overlap with the bars on the cavity grid. Thus, it is assumed that energy losses are not likely to be greater than 50% in this experiment, and therefore minimum energy that impacts the hair sample is taken to be 1.4 J per pulse and maximum energy 2.69 J for the 17 J used in the time scan experiment [8-12].

Alternatively, the specific heat capacity of hair is $0.6\ cal\ g^{-1o}C^{-1}$ The energy absorbed by the melanin in the hair is indicated by the heat released, which was sufficient to cause hair melting but not combustion. Hair containing moisture melts at 155°C and combusts at 233°C thus the hair temperature increases to between these two values. Figure 4 shows a plot of the expected temperature of the hair for absorption of different laser energies up to 18 J. The melting of the hair suggests between 6 J–10 J laser energy was absorbed. It was not certain, other than at the end of the experiment, that the hair had melted at the point of laser impact. From the field scans, the most significant increase in the stable laser-induced radicals is during the first five laser pulses at 17 J cm$^{-2}$ (Figure 2). It was likely that melting is reasonably certain after five laser pulses, therefore the heat release calculated using the hair specific heat capacity could also be taken as that occurring over five laser pulses. If melting occurs over 5 pulses, then this would be consistent with 1.2 J–2 J per pulse which is absorbed by the hair melanin on each laser firing. All the laser energy is assumed to be converted to heat after absorption. The quantum yield for laser-induced radical formation is not known, but studies to measure superoxide radical quantum yields from irradiated melanin are<0.0006 in the visible region above 400 nm. The number of absorbed photons not converted to heat will be determined by the quantum yield, which is estimated from the spin-concentration of the laser-induced radicals which are in the micromolar region, and from the incident number of photons, to be 0.00001. This is negligible compared with the number of photons converted to heat. Thus, from the two analyses, it is reasonable that 1.2 J–2.7 J laser energy defines the possible laser energies which impact the hair per laser pulse [13-17].

**Table 1**
**The raw data was obtained on 9 September 1997 and 15 September 1997 and are available in the Supplementary Information file**

| Experiment date | 090997 | 150997 | 090997 | 150997 |
|---|---|---|---|---|
| | Signal centre (G) | Signal centre (G) | Microwave frequency x $10^9$Hz | Microwave frequency x $10^9$Hz |
| Dark semiquinone | 3481.3 | 3483 | 9.761 | 9.766 |
| 1 laser pulse 13 J | 3480 | | 9.756 | |
| 1 laser pulse 17.5 J | 3480 | 3483 | 9.751 | 9.766 |
| + 5 laser pulses 17.5 J | 3480 | 3483 | 9.756 | |
| + 5 laser pulses 17.5 J | 3480 | | 9.751 | 9.766 |
| + 10 laser pulses 17.5 J | 3480 | 3483 | 9.751 | 9.771 |
| + 15 laser pulses 17.5 J | 3480 | 3483 | 9.756 | 9.771 |
| 30 mins after laser off | 3480 | | 9.751 | |

**TABLE 2**
**Plot of the estimated temperature achieved by 10 mg hair assuming a baseline temperature of room temperature of 18°C*, in the ESR cavity for different incident laser irradiation energies (J)**

| Laser energy absorbed by hair / J | Calories | Temperature rise*in 10 mg hair /°C |
|---|---|---|
| 4 | 0.96 | 95 |
| 6 | 1.43 | 143 |
| 8 | 1.91 | 191 |
| 10 | 2.40 | 240 |
| 15 | 3.58 | 358 |

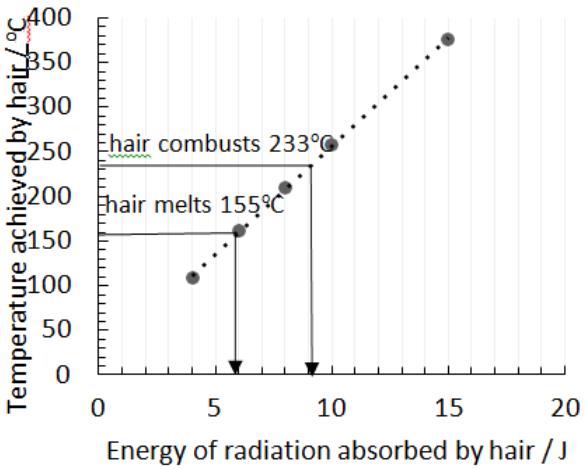



**Figure 4)** *Signal centre magnetic-field values (Gauss) and experimental microwave frequencies (Hz) from the raw data of two separate experiments undertaken in 1997, to irradiate dark-brown human hair (10 mg) in situ in an ESR Spectrometer with 694 nm ruby-laser-irradiation (maximum energy 18 J cm$^{-2}$ and pulse duration 0.9 ms).*

A loss of microwave absorption in the ESR experiment could be a result of a reduction in radical concentration through a chemical reaction, a heat-induced g-shift, or a change in the externally perceived frequency or magnetic field by the unpaired electron within the radical, such that the conditions for microwave absorption (resonance) are no longer met. In this experiment, the gradual increase of a laser-irradiation-induced stable melanin radical was monitored over time and there is no indication of any loss in the radical signal through a chemical reaction in the field scans. It is known that heat can induce changes in the spectrum of radicals, for example, in graphite [8- 11]. Heat is released during the experiment in the hair sample which melts, thus, in an experiment where the hair is lasered 36 times, the temperature of the hair in the capillary tube increases. Despite this, there is no shift in the peak resonance magnetic field of the laser-induced radical absorption or variation in experimental microwave frequency, thus the g value is concluded to be invariant. This is consistent with published data to show that melanin spin concentrations are invariant with temperature in the solid and frozen state, although they do vary in hydrated solution. In the ESR experiment, microwaves were generated by a Klystron microwave generator which is separate from the ESR cavity and not subject to heating or relative motion. The frequency of the waves entering the ESR cavity, therefore, remains unchanged. The cavity space is tuned by making small adjustments in the cavity volume using the iris until the microwaves form a standing wave in the cavity for the chosen microwave power. It is possible that cavity heating affects the cavity volume, and therefore tuning of the standing wave. In the field-scan experiments the cavity was tuned with the hair sample inside, and the scan of the intrinsic melanin radical was obtained. The hair was lasered and a spectrum was recorded immediately over 5 sec to 40 sec. Very small adjustments with the iris were made, after the irradiation, to again maximise the tuning or the standing wave in the cavity before irradiating the sample further. The radiation impacting the hair is taken to be 1.2 J–2.7 J per pulse, after the beam had first passed through the cavity grid, then through the silica sample holder walls and the capillary walls. The outer keratin layer of the hair, being a protein and non-pigmented, will absorb minimally at this wavelength. The energy in the laser beam not incident upon the hair would hit the back wall of the gold-plated cavity, being either absorbed or reflected. The gold lining of the cavity would probably scatter, rather than absorb radiation and generate heat. Because the sample was lasered successively, any cavity heating effects on the tuning of the microwaves due to cavity expansion throughout the experiment might be expected to increase linearly with time, not only through scattered radiation but also due to the hair sample temperature increasing. A sudden change in the microwave standing wave due to heat, however, ought to result in a complete loss of absorption during the time scan, rather than the reversible and incomplete signal drop observed after each laser pulse.

In the absence of any radical-radical recombination reaction, temperature-induced g-shift, or change in tuning of the standing wave in the cavity, it remains to consider the possibility that the magnetic-field changes in the spectrometer to a new magnetic-field $B_{new}$ during the period of 'off resonance'. The 'off resonance' is not a complete abolition of the absorption, and a residual absorption suggests that a proportion of the paramagnetic electron spins in the radical still undergo a spin-transition or resonance, the transition of unpaired electron spin from lower to upper spin states, which implies a new

resonant field. This effect of a local magnetic field affecting the field at which absorption, or resonance, occurs is understood in ESR spectroscopy, where the magnetic nature of neighbouring nuclear spins affects the position of resonance or microwave absorption. For example, for an unpaired electron in a radical which is distant by one covalent bond length from a hydrogen nucleus (spin ½), then the absorption is 'split' into two different absorption lines either side of the absorption for the isolated electron (phenomenon known as spin-spin coupling). Here the magnetic moment of the unpaired electron experiences either a 'spin-up' or 'spin-down configuration of the nuclear spin of an adjacent atom. This coupling is strongest when the neighbouring atom is directly bonded to the radical center, and decreases with bond distance. An electron has the spin number ½ and the melanin radical absorption has no detectable hyperfine splitting, consistent with an unpaired electron isolated from atoms such as hydrogen or nitrogen with nuclear spin. As an example, the spin-trap 5,5- Dimethyl-1-Pyrolline-N-Oxide (DMPO) is a nitroxide molecule used to identify radicals by trapping and formation of nitroxide radicals and is characterised by the unpaired electron located on an oxygen atom bonded to nitrogen (Diagram below). Adjacent to the radical is a C-H bond and the interaction of the β-hydrogen is used diagnostically to identify trapped radicals from the magnitude of the β-H hyperfine splitting (Figure 5). This varies depending on the radical centre, but can range between 6 G and 24 G [14]. The nuclear hyperfine coupling for a proton nucleus (spin ½) adjacent to a radical where the unpaired electron is delocalised, can be lower, for example in the ascorbate radical the β-H splitting is 1.8 Gauss [15]. For a nitrogen nucleus (spin 1) adjacent to the radical centre on an oxygen atom, the β-H splitting is of the order 15 Gauss [12,13].

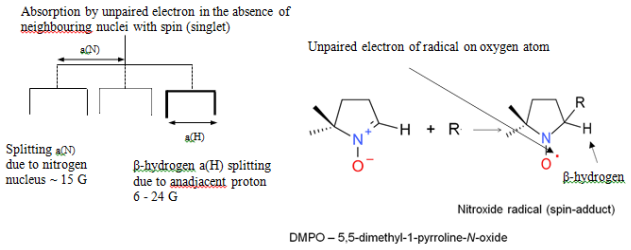



**Figure 5)** *Modelling perturbation of the magnetic field by charged photons*

**From a magnetic resonance perspective**

If the absorption at the resonant field Bo drops by 72%, and there is still some microwave absorption, this suggests the field has changed to that indicated by the arrow ($B_{new}$) in the simulation of the laser-induced radical shown in Figure 6. The laser-induced radical was simulated using the magnetic-field set for the time scan of 3488 mT (although this corresponded to the centre field of the field scan and not the precise value for Bo for the radical), the experimental microwave frequency of 9780 MHz; sweep width of +/-2.5 mT and a line-width of 0.81 mT was used which was determined from the field scans of the radical. The magnetic-field shift was calculated from the distance x/2 (cm) measured from the raw data, multiplied by the magnetic field scale in G $cm^{-1}$ to be 4 G or 0.0004 T. The distance x/2 was chosen since it was not known whether the 'off resonance' was to low or high field. Also shown (Figure 6) is the original field scan data and similar analysis of data from two independent experiments, which gives calculated field shifts of a similar value of 3.7 G and 4.4 G, with a mean of 4.05 G (n=2). This field-shift is of a similar order of magnitude to a proton hyperfine coupling, or transient interaction of the unpaired electron in the melanin radical with a magnetic moment broadly equivalent to spin ½ during the impact of the laser pulse with the hair surface, and thus charged entities moving between the melanin molecules within the hair. The laser pulse is directed on a precise area on the hair surface, thus if the pulse contains charged entities with spin, and therefore a magnetic moment, then repeated targeting of the same area is likely to locate the charged entities in the immediate vicinity of the laser-induced melanin radicals, immediately prior to absorption of the radiation. It is therefore proposed that the radical 'experiences' charge with a magnetic moment or spin, which perturbs the local field experienced by the radical, such that the resonant field shifts by 4 G during the laser pulse.

The condition for resonance is when the energy gap between the upper and lower spin states of the unpaired electron in the radical is equal to the microwave energy. During the 'off resonance,' the condition for resonance at the set-field Bo has not met $(h\nu \neq g\beta B_o)$. The two electromagnets in an ESR spectrometer are constructed to create a homogenous magnetic field across the sample, which is at the centre of the cavity between the two electromagnets. If g is invariant and the microwave frequency is constant, then it is proposed the magnetic field changes due to the impact of laser photons on the hair. The number of photons impacting the hair was calculated by dividing each estimated absorbed laser energy by the red photon energy, calculated using,

$E = h\nu = 2.7605 \, x \, 10{-}19 \; J \; photon^{-1}$ (where h=Planck's constant 6.626 x $10^{-34}$ Js and $\nu$ = 4.17 x $10^{14}$ Hz being the red-light frequency at 694 nm). For energies in the laser pulse of 1.2 J–2.7 J which impact melanin in the hair, this is 4.3–9.8 x $10^{18}$ photons per laser pulse (mean 7.1 x $10^{18}$ photons).

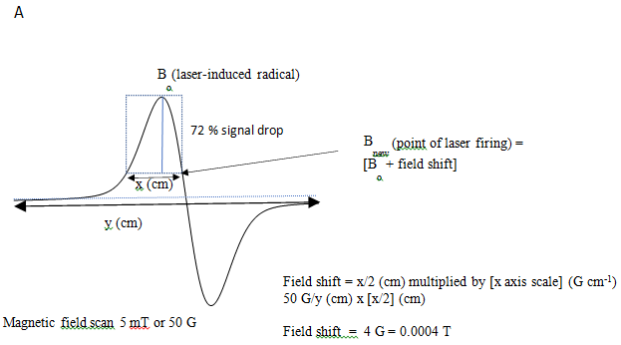
[The mean field change per photon impacting the hair is 0.0004 T (4 G) divided by 7.1 x $10^{18}$ which is 5.6 T x $10^{-23}$ T photon-1 (5.6 x $10^{-19}$ Gauss $photon^{-1}$)].

**From a physical perspective**

It might be questioned what rate of flow of electric charge might cause a momentary change in a magnetic field in the spectrometer. The magnetic field of a moving point charge is described by the Biot-Savart Law and is proportional to the charge and velocity. If the pulse is treated as a point charge of $N_{photon}$ x $q_{photon}$ (where $N_{photon}$ is the number of photons in the laser pulse and $q_{photon}$ the hypothetical photon charge) then the equation for the field-shift can be simplified (see Figure 6). The photons moving at the speed of light c impact a rectangle on the hair surface of dimensions 0.0014 m x 0.013 m or 1.8 $m^2$ x $10^{-5}$ $m^2$. The laser beam is collimated, thus the photon density at the surface of the hair is taken to be constant across the impact area.

Although the magnetic field due to the impacting photons is probably that due to the sum of the number of photons and the local

field due to each photon, here the rectangular impact area is considered to be 12 circles of radius 0.0007 m, or half the capillary width, each having an area of 1.5 $m^2$ x $10^{-6}$ $m^2$ which is $1/12^{th}$ the rectangle area. A local magnetic field induced by laser photons impacting each circle is taken to be over an impact radius of 0.0007 m, if the charge of the photons which impact the circle is taken to be a point charge at the centre of the circle. The number of photons impacting each circle is thus the total mean of 7.1 x $10^{18}$ /12 which is 6 x $10^{17}$. The field-shift per circle is the total field-shift per laser pulse impacting the rectangular area of the hair or 0.0004 T/12=0.000033 T. This is summarised in Figure 7 and the photon charge, calculated for photons impacting the hair at the speed of light, in Table 1. For photons entering the solid melanin in the hair, the velocity decreases together with the wavelength, the extent to which is not known. As the velocity decreases the calculated charge per photon, and q/e according to the equation above, would increase as shown in Figure 7 and Table 2-4 for photons moving at $10^{-3}$ c, as an example since the speed of light moving through the solid melanin is not known [14-18].



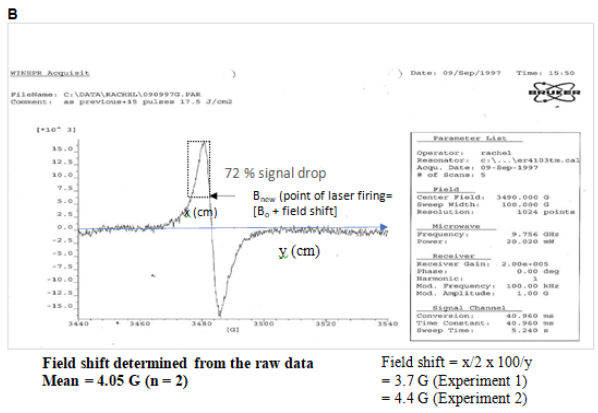




**Figure 6)** ***(A)****. Simulated spectrum using JEOL software of the laser-induced radical using centre field 348.8 mT; microwave frequency 9780 MHz; sweep width +/- 2.5 mT; line width 0.81 mT; Lorentz/Gauss ratio 50/50 and determination of the field shift at 72% drop in the resonant signal Bo. (B) Determination of the field-shift using the raw data from 1997-8 (from two different experiments).*

$$\vec{B} = \frac{\mu_0}{4\Pi}\frac{q\vec{v}\times\hat{r}}{r^2}$$ BIOT-SAVART LAW

Magnetic field b at distance r due to a moving point charge = $\mu o(4\pi r^2)^1$. q. v

($\mu o$=magnetic permeability of free space 4 $\pi$ x $10^{-7}$ T m A, q = particle charge and v = velocity of light)

The field shift B (shown in Figure 6 to be 4G or 0.0004T) might be expressed by the Biot-Savart Law shift by substituting for $\mu o$ and q:

$$B_{shift} = 4\pi x10^{-7}(4\pi)^{-1}.r^{-2}.[Nphotons.q(photon)]xvelocity$$

$$B_{shift} = 4\pi x10^{-7}(4\pi)^{-1}.r^{-2}.[Nphotons.q(photon)]$$

$$0.0004 = 10^{-7}.r^{-2}.[Nphotonsxq(photon)]x\ v$$

Where $N_{photons}$ = laser energy (J) divided by red photon energy E = 2.7605 J x $10^{-19}$ J/ photon

$E = h\nu$ (where h = Planck's constant 6.62 x $10^{-34}$ and $\nu$ = red light frequency at 694 nm 4.17 x $10^{14}$ Hz)

$Q_{photon}$ =0.0004 divided by ($N_{photons}$ x velocity x $10^{-7}$). $r^{-2}$

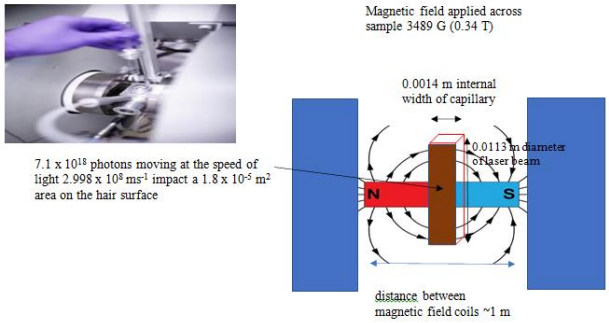



**Figure 7)***Derivation of a simplified equation from the Biot-Savart Law which describes the magnetic field due to a moving charge for the laser pulse impacting hair at the centre of the ESR cavity. Inset photo shows how a sample is inserted between magnetic field coils in an ESR spectrometer (here Jeol spectrometer)*

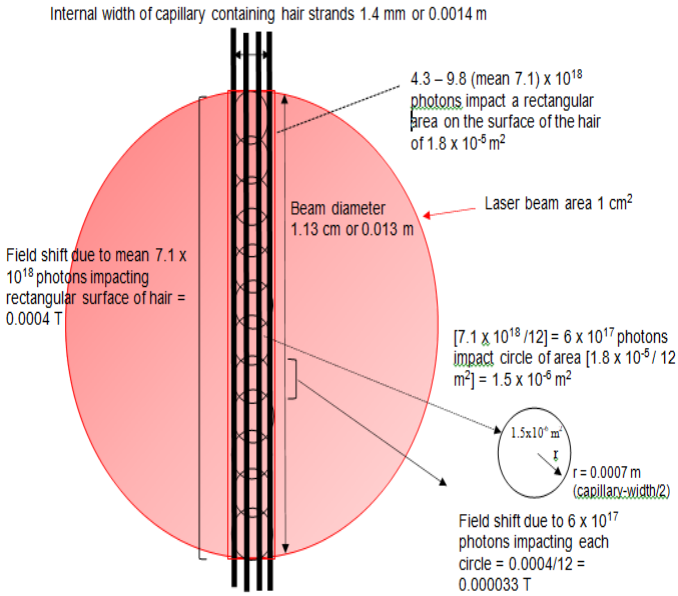



**Figure 8)***Calculated values of q photon and q/e (where e = 1.6 x $10^{-19}$ coulombs) for 6 x $10^{17}$ photons impacting a circle of radius of half the capillary width 0.0007 m at the speed of light (c=2.998 x $10^8$ $ms^{-1}$), and (B) 0.001 c.*

**TABLE 3**
**Calculated values of $q_{photon}$ at the speed of light (c=2.998 x $10^8$ $ms^{-1}$)**

| Radius r of circle including sample (m) | r = 0.0007 m |
|---|---|
| $N_{photons}$ impacting circle of radius 0.0007 m | 6 x $10^{17}$ |
| ($N_{photons}$ x 29.98/$r^2$) (velocity = speed of light c) | 3.6 x $10^{25}$ |
| $Q_{photon}$ = 0.000033 / ($N_{photons}$ x 29.98 /$r^2$) coulombs | 9.2 x $10^{-31}$ |
| Q/e | 5.8 x $10^{-12}$ |

**TABLE 4**
**Calculated values of qphoton at the speed of light 0.001 c**

| Radius r of circle including sample (m) | r = 0.0007 m |
|---|---|
| $N_{photons}$ impacting circle of radius 0.0007 m | 6 x $10^{17}$ |
| ($N_{photons}$ x 0.02998/$r^2$) (velocity = 0.001 c) | 3.7 x $10^{22}$ |
| $Q_{photon}$ = 0.000033 / ($N_{photons}$ x 0.02998 /$r^2$) coulombs | 8.9 x $10^{-28}$ |
| Q/e | 5.6 x $10^{-9}$ |

**Experiments to expose organic paper material to natural sunlight**

The organic paper material initially chosen was printed wrapping (flyer) paper, since it was light and impregnated evenly with black ink. The paper pieces edges together within commercially available plastic wallets (to prevent any effects due to air movements) were placed on the ground, weighted with small stones, in natural sunlight in July 2021 in the UK. Photographs were taken at hourly intervals alongside the author's watch to record the time. At 4 h+ sun exposure movement was observed between one of the paper pieces and the remaining three pieces, using 5 cm x 5 cm pieces (n=2) (Figure 8) and 2.2 cm x 2.5 cm pieces (n=1) (Figure 8). Figure 8c shows the results of an experiment in July 2022, where two types of black paper (80 gsm printed black and a two-sided black paper) were placed edges together within a plastic wallet and exposed to continuous sunlight 4h (Figure 8C(i)) and 6h+ (Figure 8C(ii)) (Experiment 19th July 2022 in Supplementary Information File-2). Also shown in Figure 8C (iii) is 80 gsm printed black paper placed edges together under a plastic container and a glass crucible at 6h+ (Experiment 19th July 2022). To investigate any involvement due to the plastic wallet, further experiments were undertaken in July 2022 to place the paper both within the wallet material and at the same time under the plastic wallet material but not directly in contact with the plastic, and instead contacting cardboard. Where the paper was in contact with plastic, a movement was more significant (shown in Supplementary Information File-2). The light transmissive and reflective properties of three different plastic wallets were measured for both visible-infra-red and $UV_A$+$UV_B$ using the radiometer. A plastic wallet intermediate in light Absorptivity (A) was the most effective at promoting movement (see Supplementary Information File-2). The incident energy of the sunlight, as the irradiance in $mW/cm^2$ of both UVA+UVB and visible-infra red, was recorded using a Pro-lite solar light radiometer with sensors to measure visible and infra-red radiation 400 nm–1100 nm and UVA and UVB (as shown in Figure 8D). The movements observed in three types of black paper in the sunlight were not observed when the paper was heated within a plastic wallet for 4 h at 60°C (Figure 8F) nor when heated to 130°C in a conventional oven for 4 h (Figure 8G). Thus, it is proposed that the movements observed in sunlight cannot be attributed to heat alone. These experiments are a summary of investigations undertaken in July in the years 2021-22 and a full summary and further details of the experiments is provided in the 'Supplementary Information File - 2'.

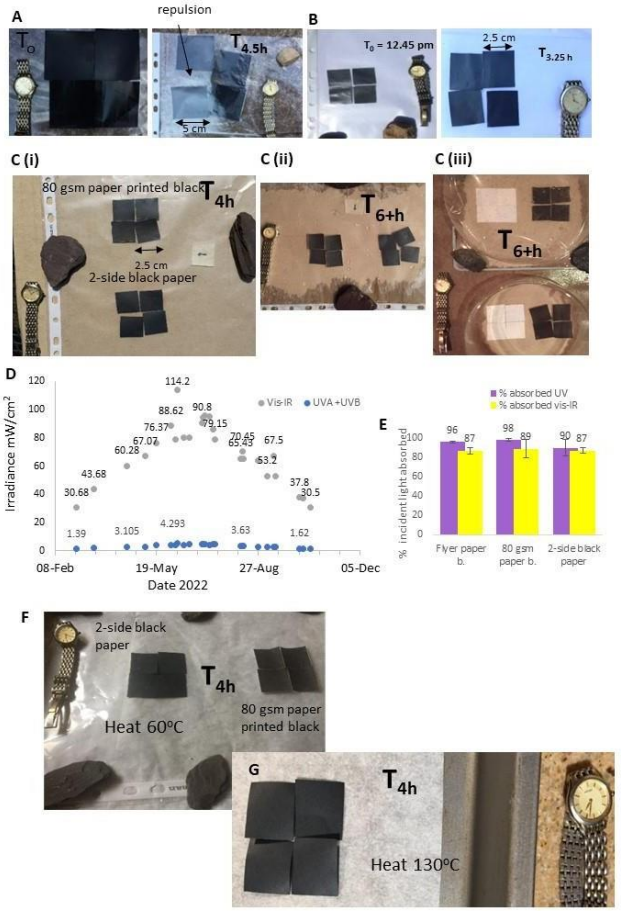



**Figure 9)** *(A) Black flyer paper edges together, in a plastic wallet (5 x 5 cm - and (2.5 x 2.5 cm (B) before and after 3 h-5 h UK sunlight in July 2021(C) - 80 gsm paper printed black and two-sided black paper in a plastic wallet exposed to C(i) 4 h sunlight; C(ii) 6+h sunlight and C(iii) 80 gsm printed black paper only under plastic and glass at 6+h sunlight exposure in July 2022. (D) incident total UVA+UVB and visible-Infra Red irradiance*

*measured using a Pro- lite solar light radiometer 12 pm–2 pm in direct sunlight 2022. (E)% incident UV and vis-IR radiation absorbed by the different black papers, determined by measuring the reflected compared to incident irradiance using a Pro-lite solar radiometer. (F) 2-sided black and 80 gsm printed black paper within a plastic wallet and heated 4 h at 60°C in a conventional oven; and (G) -2-side black paper heated 4 h at 130°C.*

## DISCUSSION

It is accepted that the velocity of light decreases in a dense medium compared with its speed in vacuo and also that a photon has particle and wave properties. Photon frequency is a fixed property of waves, which cannot be measured but only calculated and does not change when a wave passes from a vacuum into a more-dense medium [12]. Photon velocity and wavelength are variable, and according to the classical wave equation (wave velocity=f λ) wavelength λ must decrease as a wave passes into a more-dense medium proportionately as the velocity of light decreases. Laser photons in this experiment enter the keratin protein molecules of the solid hair matrix, within which the melanin-containing melanosomes are embedded, and then encounter the covalently bonded melanin polymeric macromolecules. Melanin is a brown/black light-absorbing pigment, which absorbs widely across the UV/visible and infra-red radiation spectrum. Melanin absorbs radiation at 694 nm but keratin protein has minimal absorption at this wavelength. A decrease in the velocity of a light wave moving through the solid hair sample arguably results in an increase of the electromagnetism, wavelengths per metre, compared with the radiation moving at the speed of light in a vacuum. This effect was not observed for melanin in solution where the reduction in velocity is likely to be less pronounced but was observed when dopa melanin was embedded in a solid agar matrix.

Light photons interact with matter, if absorbed, in a quantised way, initiating electronic transitions, if allowed, with the promotion of an electron from ground to the excited state. The electronic transition has a discrete energy equivalent to the photon energy. The excited state does not persist and excess energy is lost in a variety of ways, with the electron falling back eventually to the ground state. Excited triplet states are paramagnetic and arguably the conversion of a ground state non-paramagnetic molecule to a paramagnetic triplet state suggests the incorporation of material with magnetism into the molecule. Following absorption and photochemical reaction, light quanta behave similarly to molecules participating in chemical reactions [4], in accord with Avogadro's Hypothesis. There have been a number of studies to attempt to measure the charge of the photon, with disparate orders of magnitude as summarised in the paper by Hankins et al published in 2013 [16]. All previous studies measured the charge of the photon when it was travelling in free space or air. The difference between this experiment and previous studies, is that photons are impacting a solid material containing the absorbing molecule melanin, then travelling slowly in a solid medium, before absorption. In this experiment the wavelength of laser irradiation is 694 nm or 694 x $10^{-9}$ m. According to wave theory, this distance measured for the wave moving in space implies there will be in a 1 m distance in space, 1/694 x $10^{-9}$ m or 1.4 x $10^{6}$ wavelengths. The frequency of a wave is invariant as set by the electronic oscillation at source (for red light the frequency is 4.2 x $10^{14}$ Hz or 4.2 x $10^{14}$ emissions per second) [12]. As explained above, if the frequency remains constant, the velocity and wavelength both decrease when the wave moves from air into a more-dense medium. 4.3–9.8 (mean 7.1) x $10^{18}$ photons in the laser pulse are calculated to be concentrated at the impact area on the hair melanin. The photons emitted by the laser are in phase, and perhaps uniquely in this experiment, the wavefronts will be aligned and additive. This will also be applicable to the charge, and magnetism at the point of molecular impact of the wavefront with the absorbing molecule melanin, hence the possibility of an interaction with the external magnetic field collectively by the additive charge of 7.1 x $10^{18}$ photons. The range of previous q/e measurements for photons moving in air or space range widely from $10^{-14}$ to $10^{-46}$ in studies cited by Hankins et al. [16]. Application of the Biot-Savart equation to photons moving at the speed of light does enable a photon charge of 9.2 x $10^{-31}$ coulombs and q/e $10^{-12}$ to be calculated from this data, if the impact area is considered to be 12 circles of radius half the capillary diameter of 0.0007 m. Hankins et al measured a q/e of $10^{-14}$ consistent with a charge $10^{-33}$ coulombs per photon using a laser source for photons moving in air at the speed of light.

In this experiment, photons are colliding with an opaque, non-reflective solid medium and then moving at speeds slower than the speed of light within the solid. Here they encounter the covalent molecular structures of melanin and lipid and keratin protein molecules of the hair. From a physical perspective, photons interacting with solid materials can undergo reflection, refraction, diffraction or interference. Reflection occurs at highly polished metallic surfaces, and here photons behave as particles undergoing an elastic collision. A change of direction of photons moving through glass is refraction. Glass, amorphous silicon dioxide, is covalent in molecular structure with discrete localization of electrons in tetrahedral arrangement of paired electrons in bonds in a relatively open structure. Photon collision with the molecules in glass must differ from collision with polished metals due to the open structure, where radiation can pass through areas where there is not a concentrated electric field. In metals where electrons move freely in extensive conduction bands covering many atoms, the possibility of an encounter with a negative electrical field is higher than in glass where electrons are not delocalized. Refraction could reflect some electrostatic repulsion between photons with charge (presumed negative) and the discretely localized electrons of the silica molecules. The phenomena of diffraction and interference are not readily explained by a particle property of light. A monochromatic light source is directed on to slits such that two wave trains are generated with a constant phase difference. Diffraction is most pronounced when the width of the slit is similar to the wavelength. It also occurs with electrons, protons and neutrons as well as electromagnetic radiation. If the wave-train is viewed as a stream of particles with negative charge, diffraction might be due to slight deflection of the particles due to repulsive forces between photon charge and the negative electric field of the molecules forming the sides of the slit. For wave-trains with a regular phase difference this deflection will be constant for the different wave trains and augmentation will occur in regions of energy overlap (light areas) and areas of no photons resulting in dark bands. In addition, the ability of photons to integrate with electrons in atoms, and cause electronic excitation, could suggest that photons carry a negative charge.

$Q_{photon}$ here is calculated to be 9.2 x $10^{-31}$ coulombs for photons moving at the speed of light prior to entering the solid hair. When the wave enters the solid the velocity decreases, but the amount by which is not known but the number of waves per meter will increase

as the velocity decreases. In an opaque, highly absorbing molecule such as melanin, the photons move through a 'mesh' of covalent bonds linking atoms in the melanin polymer. Typical covalent bond lengths are 0.1 nm but the major and minor grooves in a coiled polymer such as DNA are 2.2 nm and 1.2 nm wide respectively . The wavelength of the ruby laser light is 694 nm and too large to penetrate intramolecular bonds; however, the order of magnitude of Van der Waals interactions in polymers such as proteins, the distance between molecules, is $10^3$ nm (for example, for the protein lysozyme Van der waals radii would be 18 x $10^3$ nm-22 x $10^3$ nm from the reported Angstrom values . Thus, the red light might reasonably be expected to penetrate between polymeric melanin molecules.

Presumably, photons move slowly until they are absorbed, in the case of melanin, by hydroquinone groups in the polymer and carbon radicals are then formed by homolytic bond scission. The photons could be said never to be in a state of rest, or to have zero velocity, since they are either in slow motion or absorption, where they are no longer photons. If the velocity decreases, then the charge of the photon would be expected to increase by a factor of the increase in waves per meter or velocity reduction. In the case of this experiment, the absorption of 694 nm photons by melanin creates radicals, which are stable and long-lived, in addition to the intrinsic stable semiquinone radicals in the polymer. Photons in the laser pulse will collide with, and then move between melanin molecules in the proximity of intrinsic melanin radicals and laser- induced radicals. The field-shift of 4 G, which is consistent with interaction of the radical electron spin ½ with a delocalised spin ½ (consistent with moving charge), suggests the interaction of melanin unpaired electrons spin-coupling during the laser pulse with photons with charge and associated magnetic moment. This is summarised in Figure 9.

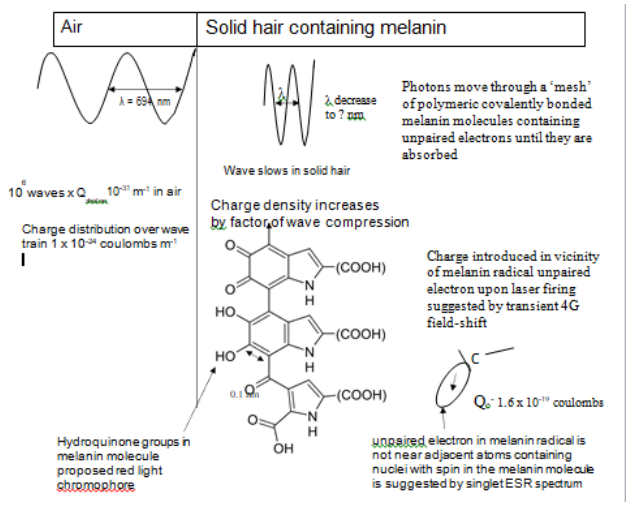



**Figure 9)** *Compression of wave and wavelength decrease on photons moving through melanin molecules in the hair. One wavelength is taken to be equivalent to one photon on the basis that one electronic excitation generates one wavelength or that light emission, like absorption, is quantised.*

The hypothesis that photons travelling at reduced velocity in the solid dark-brown/black hair between polymeric melanin molecules carry electric charge, was tested by experiments to expose paper, an organic material, to natural sunlight. The paper comprising long-chain starch polymers of cellulose and impregnated with black ink, a strongly light-absorbing chromophore, is taken to be a reasonable model for melanin in the hair exposed to light. The paper provides a large surface area, and when exposed to natural sunlight both in July 2021 and in 2022 four pieces placed edges together in a plastic wallet, thus on a plastic surface, exhibited movement. This is not observed over a similar time frame when the paper pieces in a similar arrangement within a plastic wallet were exposed to heat alone, although some paper curling from thermal expansion and drying could be observed. For paper on cardboard, movement was observed later from 6 h sunlight exposure. The effect of the plastic wallet, increasing the rate of movement, may result from reduced friction compared to cardboard, and also, consistent with a photon charge theory, from charge on the upper plastic surface adding to the total repulsive force on the paper. From experimental measurements in made in July 2022 using the solar radiometer, an average of 90.3 (+/- 6.2) mW/cm$^{-2}$ or 90.3 mJ s$^{-1}$ cm$^{-2}$ visible and infra-red solar energy was recorded between 12 pm–2 pm. The average total UVB + UVA in July was determined to be 4.6 (+/- 0.35) mJ s$^{-1}$ cm$^{-2}$ and therefore total incident solar energy measured using this system is 94.9 x $10^{-3}$ J s$^{-1}$ cm$^{-2}$. If these energies are incident on 5 cm x 5 cm pieces of area 25 cm2 and 89% incident visible-infra red (80.4 mJ cm$^{-2}$ s$^{-1}$) and 98% incident $UV_A$+$UV_B$ (4.5 mJ s$^{-1}$ cm$^{-2}$) are absorbed, that is enter the solid material and are not reflected, by the black printed 80 gsm paper (see Figure 8E), a total of 84.9 mJ s$^{-1}$ cm$^{-2}$ or 2.1 J s$^{-1}$ radiation energy moves into each piece of paper. If the mean photon energy (in wavelengths measured by the radiometer of 290 nm–1100 nm) is arbitrarily taken to be that of red light, E =2.76 x $10^{-19}$ J/ photon (see earlier in the manuscript), the number of photons which enter each piece of paper is of the order 2.1 /2.76 x $10^{-19}$ or 7.6 x $10^{18}$ photons s-1. This will be an underestimate, since the radiometer does not measure wavelengths above 1100 nm. The photon charge estimated from this study is 9.2 x $10^{-31}$ coulombs per photon, thus the charge incident on each 25 cm$^2$ piece of paper (excluding any filtration by overlying plastic or glass) would be calculated to be 7.6 x $10^{18}$ x 9.2 x $10^{-31}$ or of the order 6.9 x $10^{-12}$ coulombs s$^{-1}$ for the measured incident solar irradiance.

The paper moves when the proposed repulsive electrostatic force is greater than the force due to friction between the paper and the surface with which it is in contact. A crude calculation is to calculate the electrostatic force between two paper edges 5 cm x 1 cm wide, which assumes the major charge interactions are in the first 1 cm of material in contact. There will be repulsive charge contributions from the more distant parts of the sheet, but these will fall away rapidly under the inverse square law , and the electrostatic force between the paper pieces will be strongly dominated by the first layers of paper closest to the contact zone. If the hypothetical photon charge is distributed equally over the paper square, then along each arbitrarily 1 cm leading edge or 5 cm$^2$ area, one-fifth the total paper area, the charge build-up along each leading edge per second is 1.38 x $10^{-12}$ coulombs s-1 and thus 4.97 x $10^{-9}$ coulombs per hour. This charge is divided into five squares along the 5 x 1 cm leading edge, and the

charge of 9.94 x $10^{-10}$ coulombs is treated as being placed at the centre of each square. Using Coulomb's inverse square law, the electrostatic force between two point charges 1 cm or 0.01 m apart in the row of squares at 1 h would be a minimum of $[K.(q_1q_2)]/r^2$ = (9.94 x $10^{-10}$)2. 8.987 x $10^9/(0.01)^2$ (where K is Coulomb's constant) or 8.87 x $10^{-5}$ N per hour between each pair of squares and 4.44 x $10^{-4}$ N per hour between five pairs of squares of the paper edges in contact. This calculation is shown diagrammatically in the 'Supplementary Information File - 2'). If the paper weighs 80 g m-2 then a 25 $cm^2$ square paper piece of area 0.0025 $m^2$ has a mass of 0.2 g or 2 x $10^{-4}$ Kg. The downward force due to gravity on each piece of paper (mg) is 2.0 x $10^{-4}$ N x 9.807 or 2 x $10^{-3}$ N. The horizontal restraining force due to friction will depend on the surface on which the paper is in contact. Cardboard against cardboard, for example, is 0.5 and the resistant force to paper movement will be a product of the paper weight and the friction coefficient of the two surfaces in contact. The electrostatic force would equal the weight of material, which is the maximum force not taking into account the friction coefficient, at approximately 4.5 h on the basis of this crude calculation, so theoretically could cause the observed paper movement. More detailed calculations to take into account the underestimation of the incident energy; the friction coefficient of paper on both cardboard and plastic; a mathematically more detailed analysis of the charge interactions between the paper surfaces and charge losses due to molecular absorption is necessary, and forms part of ongoing work.

## CONCLUSION

An 'off resonance' in a time scan to monitor the formation of a laser-induced melanin radical at constant magnetic field, could reflect an interaction between charged and magnetic coherent laser photons in phase and the applied magnetic field. A 72% drop in the radical signal equates to a field shift of 0.0004 T (4 G) during laser firing. The photons in the pulse induce a measured shift in the magnetic field of 4G, which is the same order of magnitude of the hyperfine couplings, or field-shifts for absorption caused by adjacent proton nuclei (spin ½) in a radical, which are covalently bonded to the radical centre. Further work is needed, for example to undertake experiments to vary the energy in the laser pulse which would be expected to vary the size of the magnetic field-shift in the ESR time scan. Smaller measurement timescales, within the pulse duration, might be predicted to reveal a hyperfine interaction due to impacting and charged photons with the radical unpaired electron in the field-scan. This study does support, however, the work of others, that photons are charged particles at the point of collision and interaction with matter and movements in organic paper materials due to proposed electrostatic charge accumulation, when exposed to natural sunlight, also corroborate this.

All data generated or analysed during this study are included in this published article and its Supplementary Information file.

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