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Quodons for Reducing Collateral Damage in Cancer Therapy

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ABSTRACT
Evidence is shown for the first time that stable, mobile, lattice excitations called quodons can interact with biological materials. Quodons are highly-localised packets of kinetic energy in which a few atoms vibrate at frequencies outside of phonon bands. They propagate at near sonic speed and can transport charge in absence of an externally applied voltage over distances of several meters at room temperature. They arise because of nonlinear interactions of colliding particles in condensed matter. Experiments show that alpha particles of 5.5 MeV can each generate about 50,000 quodons with mean energies of 5 eV, sufficient to influence cellular processes. This was demonstrated by exposing seeds of Vigna radiata to quodons at ambient temperature. It is shown that relativistic protons used for prostate cancer therapy, will create great numbers of quodons as they propagate through flesh to the target organ. The large number of stable quodons are probably the dominant cause of cellular destruction. Experiments show that quodons can propagate for at least 4 cm in flesh. Techniques have been developed for separating quodons from the relativistic particles creating them. This opens the way for reducing or eliminating collateral damage caused by protons. How quodons interact within cells is not yet known but is probably as a result of a transient extreme heat pulse. The equivalent Sievert and Gray units for a known flux of quodons is unknown. We measure the flux in terms of the number of quodons moving in a given direction per second. Since each quodon can carry a unit of charge, the SI unit of a quodon-current is the ampere.

Keywords: Quodon; Nonlinear; Lattice; Biological; Tumour; Prostate

INTRODUCTION
A novel type of lattice excitation, called a quodon, is created in energetic two-particle collisions in condensed matter. They have been shown to interact beneficially with biological material in the form of Vigna radiata (mung) beans. They are predicted to play a significant role in proton beam irradiation of prostate cancer tumours. A quodon is a type of soliton, which has been extensively studied.[1] Here, the medium in which it exists is condensed matter consisting of atoms. A defining condition is how they are created during the degradation of swift particles by collisions. In the present case, it consists of about twenty atoms contained within a mobile envelope that moves at about 2 km/s. Within the envelope the atoms vibrate at frequencies outside of phonon bands but do not migrate away from their equilibrium position in the lattice.[1] This means they are independent of thermal phonons, which endowers them with remarkable stability and long flight paths. Usually created charge-neutral, with total kinetic and potential energies up to about 10 eV. They are essentially a nano-scale packet of heat, with no known way to detect them within condensed matter. However, studies of unusual defects in crystals of muscovite mica showed quodons can trap and transport a unit of charge of either sign.[2-6] This enabled extensive studies of their physical properties.

Numerical studies of the motions of atoms within a quodon envelope have mainly focussed on their behaviour in the layered structure of muscovite mica. The unit cell of muscovite is complex with about 47 atoms, necessitating use of simplified quasi-two-dimensional crystal lattices. Their theoretical behaviour in non-crystalline materials is unknown, forcing reliance on the results of experiments. As a 5 eV quodon passes through condensed matter it causes the atoms to vibrate strongly, causing some to briefly have an energy of ~1

eV, equivalent to a temperature of order of ten thousand degrees K. This is likely to break bonds. Using a common NC03 radiation detector for beta, gamma and X rays, giving a background reading of 0.06 mSv/h, when placed in contact with an 8 mCi source of alpha particles, gave no detectable change of reading due to quodons.

With insufficient energy to ionize most biologically-relevant atoms, they are not a radiation hazard. They cannot exist in a vacuum or gas. They might extend a short distance into a liquid when total internal reflected at a surface, similar to an evanescent wave. Direct experimental evidence for quodons was obtained by bombarding a crystal of muscovite with alpha particles of 5 MeV energy from the radioactive isotope ^{241}Am.[7] The use of a radioactive source minimised electrical background noise from ion-beam equipment. However, quodons can be generated at a much lower energy, such as 1.5 keV Argon ions.[8] Since muscovite is an excellent electrical insulator, if a current is detected in absence of an applied voltage to the crystal, then it cannot be due to conduction. It led to the demonstration of low-loss transmission of charge by quodons at ambient temperature, called hyper-conductivity.[9,10] One complication in exploiting the unique properties of quodons is that no condensed matter was found that stopped their propagation. As a consequence, standard coaxial cables cannot be used for quodon-currents as they are shorted to ground through the cable insulation. To overcome this problem when doing experiments, samples under test are suspended vertically from the input terminal of a current meter. Alternatively, magnetic levitation can be used to support samples. Although quodons possess momentum they do not form classical particle beams. This is evident in experiments where they propagate through multiple Z-shaped paths. It is possible that they move in a percolation manner via scattering at lattice defects and at surfaces exposed to air or vacuum. Fossil tracks in muscovite mica of positively charged quodons show that they can create charge-neutral daughters. The neutrality is because a unit of charge on the primary quodon cannot be subdivided. A daughter soon traps a charge, typically after travelling less than 1 mm. Studies of the possibility that quodons might be degraded when crossing an interface between materials with different lattice structures revealed that they can anneal defects allowing more current to flow. Their transmission through multi-layers of different materials did cause attenuation but raised practical problems relating to the properties of the edges of such materials. This prompted study of their existence and propagation in complex structures existing in biological organisms.

EXPOSURE OF VIGNA RADIATA TO QUODONS

For this purpose, Vigna radiata (mung beans) from the Fabaceae species were chosen because they are relatively large, which facilitates experiments and measurements.[11,12] An account of the use of kinetic energy to modify germination and development of these beans used a source of ultrasound of 25 kHz frequency in water at a power of 41 W/lt.[13] The kinetic energy power of the source of quodons used in our study is of order 10^{-11} W/lt of water. The main reason for this large difference of power per litre of water to give comparable effects on seeds arises from the distributed nature of ultrasound, with wavelength of about 6 cm relative to the size of a quodon envelope of about 10^{-6} cm. The quodon envelope is of similar size as the proteins controlling the chemistry in seeds. Firstly, a test was made to see if quodons could propagate through a row of six beans. The sample is mounted inside a Faraday box, as shown in Figure 1.

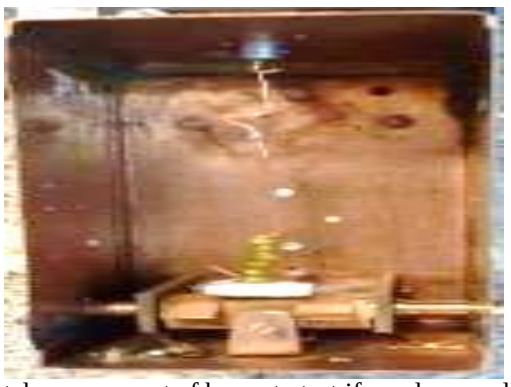


Figure 1: Experimental arrangement of beans to test if quodons could propagate through or over the surface of a stack of 6 beans cemented together with cyanoacrylate adhesive. The sample is hung vertically from the current meter. The stack is connected at the bottom to a piece of electrical insulating material to stop any electrons reaching the beans via the plasma created in the air by the alpha particles emitted from the radioactive source held in the grounded metal block connected to the Faraday box. The beans were dry and had not been treated to inhibit germination, so were suitable for planting.

As quodons cannot exist or propagate through air, no quodon-current flowed through the stack when the metal gate controlling the source of alphas was closed. The quodons created in the metal gate disperse to ground in the Faraday box. When the gate is opened, a quodon-current immediately starts to flow in absence of any externally applied voltage. The plot of quodon-current is shown in Figure 2. It lasted for about 26 seconds, as the quodons swept away free negative charges. Thereafter the current went negative as positive free charges were removed. The origin of the free charges is unclear; they are generated during manufacture of a material, by tribological action, by injection of charge or from cosmic radiation. In practice, drilling of holes or abrasion of a surface by sanding is sufficient for experimental purposes. The source of alphas was 7 mCi of foils impregnated with ^{241}Am, of which about 15% reached the target due to solid angle restrictions, generating about $4x10^4$ alphas per second in the target. Each alpha of 5 MeV generates about 1.10^4 quodons in the target, giving about $4x10^8$ quodons per second in the target. If each quodon captured one electron then the maximum transmitted current would be 60 pA.

The measured current was 11pA, showing the rarity of natural free charges. The injected current by the doubly charged alphas was constant at about $8x10^4/6.2x10^3$ or -13 fA. This is often reduced due to secondary emission of electrons at the surface of the target and changes in the solid angle presented by the target.

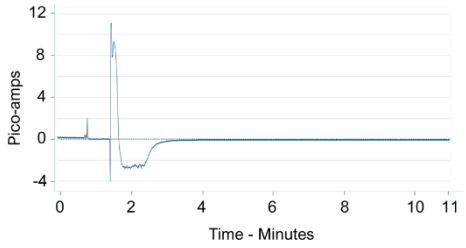


Figure 2 The current starts by first going briefly negative due to electrical noise as the alpha source is rotated in the metal block to let the alphas irradiate the bottom of the insulating plate. The quodon current then reached a peak of just over 11 pA, then decreased before going negative to – 2.3 pA, then decreasing towards a limiting current of about -4 fA. This rapid rise of current shows there was no conduction-current from build-up of a voltage across the beans due to the injected current. The peak current required slightly less than 10^7 quodons per second to transport the charge for a current of 11 fA.

Next, 20 beans were placed in three groups along the base of a polypropylene container of 12 cm length, as shown in Figure 3a. The container was made from 0.5 mm thick sheet. A source of alpha particles from 7 m Ci of ^{142}Am was placed under and in contact with the container in the middle. The sheet was of sufficient thickness to stop any alphas penetrating through the sheet to reach the beans in the central group. Water was then added to partially immerse all the beans and held at a temperature of 32° C. This arrangement created about 10^9 quodons per second entering the plastic base of the central group. Some then propagated through the plastic to the two outer groups.

The water level and temperature were held constant during the next 48 hours. The beans in the central group that had received the largest dose of quodons started to develop and increased in size but then did not continue germinating, as shown in Figure 3b. Whereas beans furthest from the source had shed their Testas and developed their radicles strongly up to a length of 42 mm before stopping the test. The central group stopped growing after 24 hours. The total number of quodons to kill 5 beans in central group was about $4x10^{13}$ or about $8 x10^{12}$ per bean.



Figure 3a: The beans in the central group were directly over the source of alpha particles that created quodons in the plastic sheet. The quodons had to propagate through the base of the plastic container to reach the two

outer groups, thereby reducing the quodon flux. The photo shows the initial arrangement of beans at the start of exposure to quodons.

Figure 3b: The quodon flux was held constant in time. The central beans were over exposed and failed to germinate. Those in the outer groups germinated rapidly. After 48 hours of exposure to quodons, the beans in the central group had died, whereas those exposed to a lower flux developed faster than usual.

This was followed by a test using two groups each of 100 beans, one exposed to quodons and the other a control group held under the same environmental conditions. The plastic containers used in this test had a flat base of rectangular shape with sides of 13 and 9 cm lengths. For this test the quodon flux was reduced by a factor of 8 by using only 1mCi of ^{241}Am, located under the centre of one group. The orientation of the beans was random so the embryo would not always be in close contact with the plastic base for quodons to enter the seed. The maximum length of radicles as a function of time for the group exposed to quodons and for those in the non-exposed control group is shown in Figure 4.

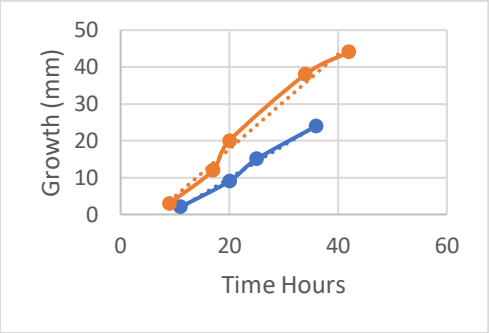


Figure 4: Plots of the maximum lengths of radicles as a function of time for beans exposed to quodons (orange) and those not exposed to quodons (blue). It shows that exposure to quodons can increase the rate of grow of radicles relative to the control group of zero exposure by almost a factor of two. It also shows that exposure to quodons causes the exposed beans to start germination earlier than those not exposed. The initial quiescent period relates to absorption of water through the Testa after the seeds are immersed in water.

The above demonstration of the effect of quodons on germination of a common seed provides a simple and cheap method for overcoming the difficulty of detecting neutral quodons. It is a modern version of the miner's canary. An alternative is to intimately attach a block of insulator near where quodons are being created and monitor current flowing through the insulator.

ELECTRICAL ASPECTS OF QUODONS

As the beans have no nervous system, these tests only examined the response to quodons over many hours. The initial generation of a quodon-current when irradiation starts and sweeps free charges away, as shown in figure 2, had no discernible effect on the beans. To explore this aspect, a preliminary study of the effects of initial current was made on fauna which possessed a nervous system. Woodlice (isopods suborder Oniscidea) was selected as they are mobile. A source of alpha particles of 8 mCi strength was used. Five lice were placed in a clear plastic cup of polypropylene of 0.5 mm thickness of walls and base to contain them for observation. It was found that they responded quickly to the initial peak of quodon-current, becoming paralyzed that lasted for less than 4 hours. Having removed the free charges, continued exposure to neutral quodons led to recovery of mobility but they eventually succumbed after 12 hours of quodon exposure. Evidence of death was contraction of legs and immobility.



Figure 5: The mass of the largest woodlouse was 0.074 g. It is reasonable to assume the dose received by the largest louse was proportional to the ratio of its area relative to the area of the irradiation source, or about 1/15. The source is the small circular disc. Quodons are highly stable and cannot escape in to the air, but can propagate back to the base supporting the source and the cup. Hence, their density in the plastic of the cup might have increased above their rate of creation. This makes estimating the total terminal dose uncertain. The flux of quodons entering the cup was about 10^9 per second, suggesting a total of about 3.10^{12} quodons resulted in fatality, of similar order as for the beans above.

The creation of a quodon-current by sweeping away of free charges when a sample of condensed matter is first irradiated with alpha particles, is expected to cause a reaction in organic bodies with a nerve system. The initial effect is predicted to be an increase in pain within a few seconds after starting irradiation, reaching a maximum within about ten seconds later and thereafter a slow decrease down to a low normal level after a few hours. This is the experience of one of the authors who had a medial unicompartmental knee replacement, introducing about 500 grams of metal, which inevitably had many free charges introduced during manufacture. Seven days after the operation, when the pain level was at 2/10 in absence of pain killing drugs, a 7 mCi source of alpha particles was placed against the skin at the knee for ten seconds. As predicted, the pain in the leg rapidly rose to about 8/10 within five seconds. It then began a slow decrease, reaching the residual level of 2/10 after about four hours. Similar irradiation of the right normal knee caused no reaction, as expected. This is reported only to show that the effects observed in inorganic materials also carry over to biological matter.

BACKGROUND LEVELS OF QUODONS

Although quodons are produced by collisions of high energy particle passing through condensed matter, they are mainly created by the lower energy particles in cascades generated by the primary energy particle. Numerical modelling shows they are the result of nonlinear interatomic interactions via the electromagnetic force at energies below about 1 keV. This explains why a single primary particle of 1 MeV creates about a thousand quodons of mean energy about 5 eV. The efficiency of creation is not high because the conditions for creating a quodon involving nonlinear interactions are complex. This is because the vibration of atoms in a quodon envelope must synchronize at above phonon levels to achieve their high stability. The number of quodons generated by a 5 MeV alpha particle has been examined in detail for samples of condensed matter ranging from low atomic mass polymers up to tungsten. In an organic material like flesh, the number of quodons created per 5 MeV ion is about $5x10^4$. This enables estimates to be made of the background flux of quodons reaching humans.

The flux of muons at sea level is about 1 per cm^2 per minute. Muons impact isotropically due to scattering in air. Humans have about 1 m^2 of body area, giving a total flux of about 170 per second. The mean energy of muons at sea level is about 4 GeV. They lose about 100 MeV in passing through a human, equivalent in radiation damage to 20 particles of 5 MeV, about $20x170x5.10^4$ or $1.7\ x10^8$ quodons per second. A 1mCi source of alpha particles produces about 2.10^9 quodons in condensed matter, indicating the natural muon flux is equivalent to about one tenth of a 1mCi source. Based on the dose of quodons needed to kill the beans, the expected damage to a human by the quodons created by cosmic rays is very small but not zero.

There is a fundamental difference between conventional irradiation damage to cells caused by a moving non-relativistic ion or atom and that caused by a quodon. The former is limited to just a few cells whereas all quodons are highly mobile. This was demonstrated by measuring the quodon-current flowing through a sample of flesh of 4 cm length at ambient temperature when exposed to quodons, shown in figure 6. The quodons were generated in a slab of PTFE and fed into the flesh by direct contact at one end. The arrangement of the sample is shown in Figure 7. The slab of PTFE stops any conduction-current flowing in the flesh. The peak current was 48.7 pA. Assuming the average cell size is about 20 mm, then each quodon would pass through at least 2000 cells in propagating 4 cm.

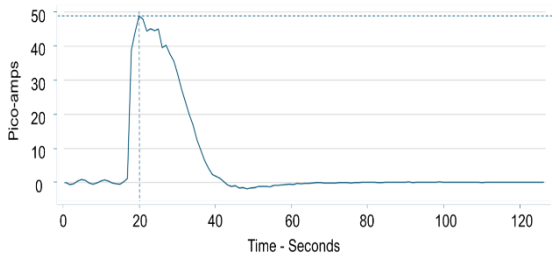


Figure 6: Plot of the curent carried by quodons flowing through a strip of flesh 4 cm long by 0.3 cm^2 cross-section area when irradiated with quodons. The alpha particles were produced by a source of 7 mCi strength but only about 15% reach the PTFE. The flux of quodons flowing through the sample remains constant in time, at the peak rate or above.



Figure 7: Sample of meat held by two clips, connected to a slab of PTFE at one end and to the current meter at the other end. The sample is 4 cm long.

QUODONS GENERATED BY PROTONS PROPAGATING IN BIOLOGICAL MATTER

Historically, the discovery of radioactivity led to localized quantities of radium placed in close contact with the organ to be treated. As the range of alpha particles is less than 0.1 mm, the source had to be physically moved to different parts of the organ, which was impractical and discontinued. The use of beams of high-energy- protons of order 60 MeV for treating prostate cancer is well established and throughly studied.[14] The principal challenge is to minimise collateral damage to surrounding organs. The Bragg peak helps but cannot eliminate in-flight damage. Extensive independent studies using numerical modeling of how particles lose energy when propargating through condensed matter describe the typical sequence of ionization, X-rays, atomic cascades, displacements, and phonons.[15] Depending on the energies of the colliding particles, the interactions involve both linear and nonlinear forces via the electromagnetic force. Damage to cells range from massive disruption to low energy disturbance of enzyme actions down to localized themperature fluctuations. The damage done by the primary particles in flight to the target, the collateral damage, can be distributed to some degree by changing the geometry of the flightpaths by focusing a broad beam on to the target. The most successful method is by sweeping the focused beam over the available part of the 4p sr solid angle. Unfortunately, this still involves high irradiation doses in organs close to the target organ. The discovery of quodons allows a paradigm change in treatement of localized cancers. All high energy particles that interact via the electromagnetic force can create quodons. A 60 MeV proton propagating through flesh is approximately equivalent to a sequence of 12 protons of 5 MeV energy. Experiments on the creation of quodons by collisions with individual particles in condensed matter show that a 5 MeV proton will lose energy at about half the rate of a Helium ion of the same energy, creating about 10^4 quodons of mean energy 5 eV.[16] The experiments described above show that quodons of this energy are capable of disrupting the performance of cells.

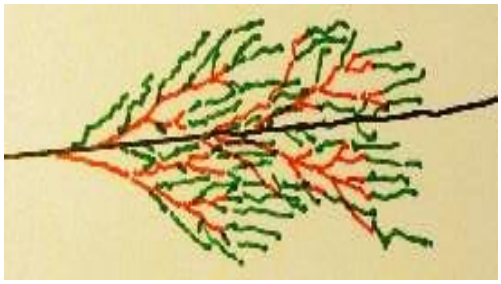


Figure 8: illustrates the generation of a large number of quodons by a single high energy proton, such as used in prostate tumour therapy.

Figure 8 Sketch of energy loss processes of a high energy proton when moving through condensed matter. The single proton (black) is moving form L to R, the multiple cascades (red) have ranges of about 100 atoms but the vast number of quodons (green) can propagate at least 4 cm as shown in Figure 7.

As the process of ionization and the motions of atoms in atomic cascades are relatively localised compared to the long flightpaths of quodons, it is more likely that quodons are the dominant cause of cell damage. Of course, protons or other high energy ions are needed for creating quodons, but they can be created at much lower energies. The technology for separating quodons from the causative swift particles has been developed for minimizing collateral damage.[17] This technology can be used with existing sources of swift particles, such as cyclotrons and synchrotrons. However, the unique properties of quodons allows them to be generated using stronger primary currents of lower energy. When created at a point the flux decreases as $1/r^2$ or $1/r$ if created by a linear source, where r is the distance from creation, up to at least 4 cm in flesh. In contrast, the maximum range of 5 MeV alphas in flesh created by a radioactive source is less than 1 mm. The prostate gland weight is about 30 grams or about 400 times that of the biggest louse in the above experiment. Based on the dose for fatality of the louse, the estimated dose of quodons for killing the prostate gland is $400x3.10^{12}$ or about $1.2x10^{15}$. If treatment is carried out over one day, then the required amount of ^{241}Am is about 30 mCi. There are three unique advantages of the use of quodons for treating tumours. Firstly, they have insufficient energy to cause conventional tissue damage of ionization and creation of interstitials. Secondly, they pose no radiation hazard arising from ionization, cascades, X-rays or interstitials. Thirdly, they can be placed at specific localized regions in the tumour and thus minimize collateral damage.

CONCLUSION

The experimental results reported here indicate a previously unrecognized mode of charge and energy transport in condensed matter. Experiments have shown that 5.5 MeV alpha particles from ^{241}Am produce about 10,000 quodons per alpha when propagating in condensed matter. The quodons have mean energies of about 5 eV, similar to that of solar UV photons, known to be sufficient to disrupt cellular processes. Quodons are generated in discrete-particle collisions in condensed matter. They are usually created charge-neutral and thus extremely difficult to detect. This problem was resolved when it was found they could trap and carry a unit of charge. Studies of their behaviour in complex materials with multiple internal interfaces of progressively smaller size led to a study of organic materials of a biological nature. For the first time, it has been shown that quodons can influence the germination and development of the biological organism mung bean. It was found that low fluxes of quodons can enhance their development and high fluxes can be lethal. Exploratory tests on woodlice revealed a prompt response on exposure to quodons, causing temporary paralysis, thereafter reverting to similar response to quodons as mung beans until death after extended exposure. The protons used in prostate cancer therapy generate huge numbers of quodons which could be the dominant cause of cell death. The most important aspect of this research is the ability to separate quodons from high energy particles, thereby greatly reducing collateral damage.

EQUIPMENT

The sub-femtoampere transimpedance amplifier DDPCA-300 by FEMTO Messtechnik GmbH, was used for measuring very small currents with easily variable gain and very low noise level.

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