Holes and the Spin Separation of Orbital Electrons

David Lindsay Johnson

Overview (Abstract)

Semiconductor theory relies on **holes** to act as the positive charge equivalents of **electrons** so as to support **diffusion** and **drift** across the depletion zone of a **p-n junction**. Holes need to be capable of movement to act as positive charge carriers, and to be involved in random collisions to produce the Brownian motion required to support diffusion and drift. Lack of movement, or even the required type of movement, is a major problem for semiconductor theory.

The **Pauli Exclusion Principle** indicates that, if an atomic orbital is occupied by an electron of one-half spin state, the orbital may only be shared by an electron of opposite spin (i.e. negative one-half spin). An atomic orbital is full when it is occupied by a pair of electrons of opposite spin, with no more electrons able to enter it until one of the pair vacates the orbital. This paper looks at the possibility and implications of extending the electron spin concept to free electrons within semiconductors, with positive and negative charge carriers simply being electrons with opposite spin.

The existence of two physically different charge carriers in the form of opposite-spin electrons, which requires only minor terminology adjustments to semiconductor theory, provides a better explanation of the formation and nature of electric fields; capacitor charge/discharge; and micro/radio wave generation. Also, the concept of electric currents being the one-way movement of generic electron charge carriers, which totally ignores electron spin, is challenged.

The Hole Story

In 1759, working in conjunction with Benjamin Franklin, Robert Symmer suggested that two component forms (or fluids) constituted electricity, but this model never gained prominence. With the development of nuclear atomic model, the nucleus of atoms within matter was considered to provide positive charge and the electron the negative charge. Because metal atoms within conductors such as copper wire are stationary, it was logical to describe and attribute electricity simply to the movement of electrons from a negative terminal to a positive terminal. One legacy of Franklin (and indirectly to Symmer) is that, for his one-fluid explanation for electric current, the fluid was considered to move from positive to negative, and this interpretation has been adopted as the convention for the design and implementation of electrical devices.

In 1939 the electrical world was reliant upon inefficient bulky vacuum tubes (thermionic diodes) for rectification, when Russel Ohl, working at Bell Laboratories, noticed the unexpected generation of a voltage across a cracked high-purity silicon crystal when exposed to light. This discovery led to the development of the **p-n junction** and the **n-p-n transistor** by William Shockley in 1951, which led to a wide range of modern day semiconductor devices and related technologies. However, the one-way movement of electrons used to explain electric currents in 1939 could not explain the unexpected electrical characteristics of semiconductors.

A p–n junction is a semiconductor device (usually referred to as a **diode**) which is created by joining p-type and n-type semiconductor materials. The semiconductor materials are silicon (or germanium) wafers doped with small measured quantities of foreign contaminant atoms. For **n-type** semiconductors the dopant is typically **phosphorus**, and for **p-type** semiconductor material the dopant is typically **boron**.

A **neutral phosphorus atom** has 5 valence band electrons, 4 of which are used to bond with adjacent silicon atoms, each of which also have 4 valence electrons. The fifth electron ends up in the **conduction band** and becomes readily available to freely move about within the silicon substrate, with the electron-deficient phosphorous atom becoming a **cation** (a positive ion) which is locked into the n-type silicon crystal structure.

A **neutral Boron atom** has only 3 valency electrons and requires an additional valency electron to form four covalent bonds when it is a silicon dopant. When it does acquire the needed electron (it is called an **acceptor** atom because it accepts the extra electron), possibly from an adjacent silicon atom, it becomes an **anion** (a negative ion) and the **donor** silicon atom itself becomes a positively charged atom (i.e. a cation) as shown in the figure 1. The donor/acceptor exchange is considered to be dynamic and thus the cations involved in such exchanges are called **holes**.

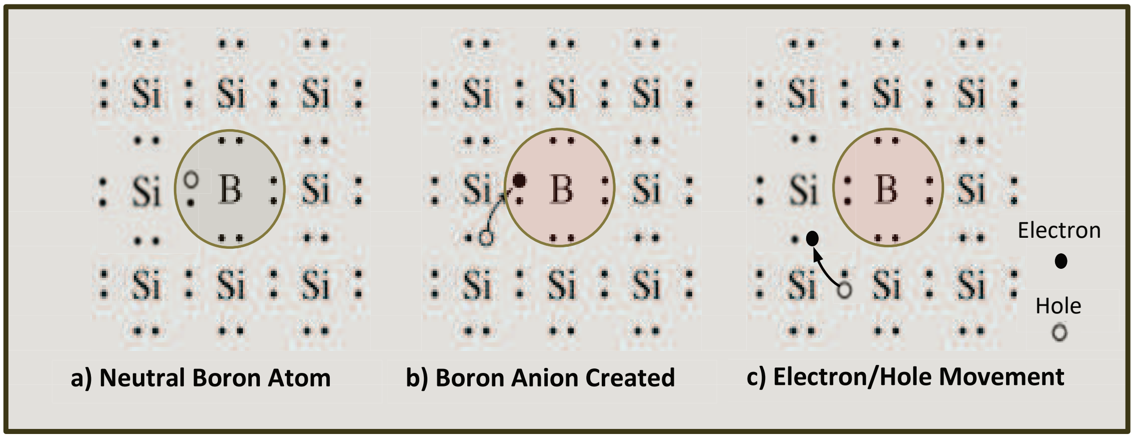

Figure 1: Electron/Hole Movement in p-type Semiconductor

A **positive hole** thus represents a missing electron from the **valency band** of an atom that is fixed and unable to move within the semiconductor substrate. New holes can appear when neutral silicon atoms lose a valency electron to the conductions band, and existing holes can disappear by accepting an electron to convert it back into a neutral silicon atom. This hole-appear and hole-disappear process is considered to happen rapidly and randomly throughout the p-type substrate so as to provide the appearance of random hole movement.

However, as at night you might turn one light off and another on as you move from one room to another, nobody would suggest that darkness moves from one room into the other or that the light bulbs have moved. That would be ridiculous. In a similar vein, LED Christmas lights can be made to rhythmically flicker and move by being rapidly turned on and off in sequence, but nobody, apart from a young child perhaps, would suggest that the light bulbs were moving. Similarly, random hole appearance (cation creation) and hole disappearance (cation neutralisation) involves no movement of positively charged holes, although some animated gifs and dynamic presentations may produce the visual effect that there is positive hole movement.

Even when electrons move in a consistent direction so as to turn holes on (i.e. neutral silicon atoms become cations) and off (i.e. they resume a neutral status) as they move, the only charge movement is that of negative charge associated with the electron movement. There is no movement of positive charge in the opposite direction due to the movement of the electrons - just an illusion of positive charge movement.

Synchronised hole movement is analogous to the scrolling of a message across a computer screen: the pixels (or holes) have fixed positions on the screen and are illuminated (turned on and off) in a sequence similar to the frames of a moving film sequence to emulate movement of the message across the screen. It is simply an illusion of movement that is totally different to writing the message on a piece of paper using ink molecules and physically moving the ink molecules from one side of the screen to the other by moving the paper.

Even the 'step analogy', commonly used to explain apparent hole movement, does not work. This analogy relates to electrons moving up a flight of stairs, and having to wait for an empty step (a hole) to move up. The empty steps (holes) appear to move downwards as the electrons work their way upwards. The steps (holes) do not move - just the electrons. This simulation is similar to the step analogy, and it is clear that the holes are not physically moving, and is thus simply another example of the hole-movement illusion.

Within an electrolyte solution, anions (negative ions) and cations (positive ions) can move freely but, within a silicon wafer, anions and cations are fixed within the silicon crystal structure and only negative charge in the form of free electrons are able to move. Whereas electrolyte batteries have positive and negative charge carriers in the form of ions in solution, semiconductors only have electrons as charge carriers, and **holes** have been promoted as representing the much needed **positive charge carriers**.

The problem is that although electrons can move and thus be negative charge carriers, holes do not move and thus cannot be positive charge carriers. At best, the migration of the electrons from one side of a semiconductor to the other can produce a negative charge concentration and leave behind an area of positive charge. However, no matter how hard the case for the apparent movement of holes is argued, such a charge transfer process simply involves the leaving behind of electron-deficient atoms without there being any movement of holes carrying positive charge in that direction.

And no, we are not just talking about semantics: if charge transfer is solely down to the movement of electrons then it is not possible to explain the processes of **diffusion** and **drift** that are well documented as the main mechanisms that provide the electrical characteristics of p-n junctions. So let's have a look at diffusion to see why there is such a huge problem with the hole approach.

Within a p-n junction electrons are mainly sourced from the dopants and thus are relatively sparse in number compared with a metallic conductor such as copper wire. At room temperature the **thermal velocity** of electrons within a silicon substrate is in the order of 2×10^5 m/sec, which is surprisingly fast but is still about is about 1000 times slower than the speed of light (3×10^8 m/sec). At such velocities, electrons that are sparsely scattered throughout the n-type semiconductor randomly buffet and deflect each other and Brownian motion develops, which is analogous to the random thermal movement of molecules within a volume of gas.

For Brownian motion within a gas there is no net movement of the gas molecules unless differences in their concentration arise. Movement of gas molecules due to **concentration gradients** is called diffusion and is described by Fick's first law which states that **Diffusion Flux** (**J**), as measured in density per unit area per unit time, is proportional to the concentration gradient. For the random movement of sparse numbers of free electrons within an n-type semiconductor substrate, Fick's law can be expressed as **J = qDdn/dx**, where **q** = electron unit charge (- for electrons); **D** = the diffusion coefficient for the electrons; d**n**/d**x** = electron concentration gradient in direction **x**.

Within an n-type semiconductor the majority of mobile charge particles are electrons, and thus Brownian motion based diffusion is possible. However, within p-type substrate there are very few free electrons because free electrons are considered to quickly become 'fixed' by being acquired by the much more plentiful holes to form neutral atoms. Thus, should holes be unable to move, there are no mobile charge carriers that can move in a random fashion to physically buffet and deflect each other so as to produce Brownian motion as do electrons on the n-side. In short, there could be an illusion of random movement of holes as explained above, but no random collisions or deflections of small particles that could justify the use of Fick's diffusion law.

But diffusion is evident within both the p and n-side of a p-n junction. So, you can choose to believe that diffusion can be accounted for by the smoke-and-mirrors illusion of hole-movement, which is what most texts and video presentations exhort their audiences to do; or you can look for another feasible solution involving a particle that can act as a positive charge carrier **and** display Brownian motion. A closer look at electron orbitals and the **Pauli Exclusion Principle** is a good place to start should you wish to pursue the latter option.

The Pauli Exclusion Principle

The Pauli Exclusion Principle is the quantum mechanical principle which states that two or more identical fermions (i.e. have the same half-integer spin) cannot occupy the same quantum state within a quantum system simultaneously. This principle was formulated by Austrian physicist Wolfgang Pauli in 1925 for electrons, and later extended to all fermions by 1940.

An electrically neutral atom contains a number of bound orbital electrons equal to the number of protons in the nucleus. As identical fermions cannot occupy the same quantum state, if an orbital contains an electron (a fermion) of plus one-half spin state, it may only be shared by an electron of a negative one-half spin state, and vice versa. The Pauli Exclusion Principle thus helps to explain a wide variety of physical phenomena, including the elaborate SPDF electron shell structure of atoms and the way atoms can share electrons to bond.

The wave function is antisymmetric for fermions so that if the space and spin coordinates of one of two identical fermion particles are interchanged (i.e. the spin direction reversed), then the total wave function changes its sign: this is true for fermions but not for bosons. In order to distinguish the two electron spin forms within this paper the term **Cetron** has been used for spin-up electrons (i.e. with spin quantum number $m_s = +1/2$) and **Aptron** for spin-down electrons (spin quantum number $m_s = -1/2$), as shown in the figure 2. This figure also shows examples of allowed and disallowed electron combinations.

Cetrons and Aptrons are both electrons. By convention, when looking towards the tip of the spin arrow, the cetron is an electron with **C**lockwise spin (hence the '**C**' of **C**etron) and the aptron is an electron with **A**nticlockwise spin (the '**A**' of **A**ptron). Also, by convention, aptrons will be considered to be the major particle carriers on the p-side of a p-n junction, with the '**P**' of ap̲tron suggesting that it is a p̲ositive charge carrier. Similarly the '**E**' of ce̲tron suggests that it is a ne̲gative charge carrier. And to allow cetrons and aptrons to be collectively referenced without confusion with the more generic term 'electron', the transgender term **bitron** is used.

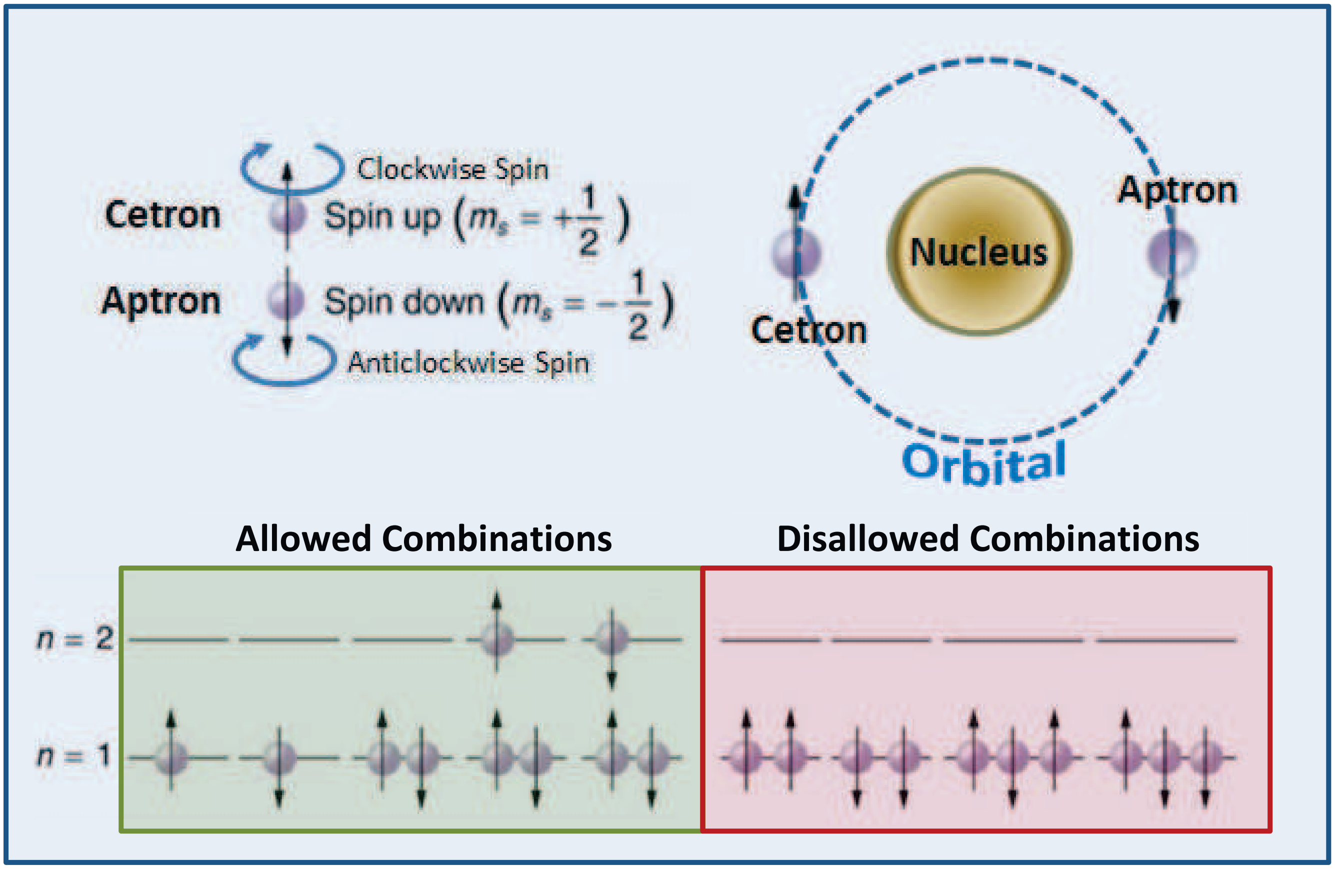

Figure 2: Electron Spin and Electron Orbitals

We shall now explore the dynamics of the p-n junction in terms of cetrons and aptrons as the charge carriers.

Diffusion, Drift and Depletion Zone Formation within P-N Junctions

For this discussion both the positive and negative charge carriers are considered to be electrons: the **cetron**, a +1/2 spin electron, the **negative charge carrier** (majority carrier within the n-type substrate); and the **aptron**, a -1/2 spin electron, the **positive charge carrier** (the majority carrier within the p-type substrate).

As the bitron particle concentrations within p-type and n-type wafers have been derived from the dopants, their concentration is quite low compared with their concentration within metal conductors. Thus unlike metal conductors, thermal energy causes them to move randomly, buffeting and deflecting each other as do molecules within a volume of gas. Thus, when as part of the p-n junction manufacturing process, p-type and n-type substrates are joined by gluing them together, significant concentration gradients are created across the join, and **diffusion** takes place in accordance with Fick's Law that is applicable to gases. As cetrons start to diffuse from the n-side to the p-side, aptrons start to diffuse in the opposite direction as shown in figure 3.

As the positive and negative charge carriers intermix evenly, their local net charge is zero and the dopant ions emerge as the prominent charge fields close in the region of the join, which causes an **emf** to develop directed from the n-side (positive ions) to the p-side (negative ions). The ion-generated emf called a **barrier field** (or **built-in field)**, and it has the effect of opposing the movement of bitrons by diffusion.

As the barrier field grows, quite soon it prevents further diffusion which leaves some **minority carriers** on each side of the join: cetrons on the p-side and aptrons on the n-side. The next phase of the post-join process is that the barrier field further asserts itself by pushing those bitrons within its influence back to their respective major carrier side. This process is called **drift**, and as drift acts in the opposite direction to diffusion (see figure 3), it results in the effective removal and repatriation of all bitrons in a narrow zone around the join which is called the **space charge region** or the **depletion zone**.

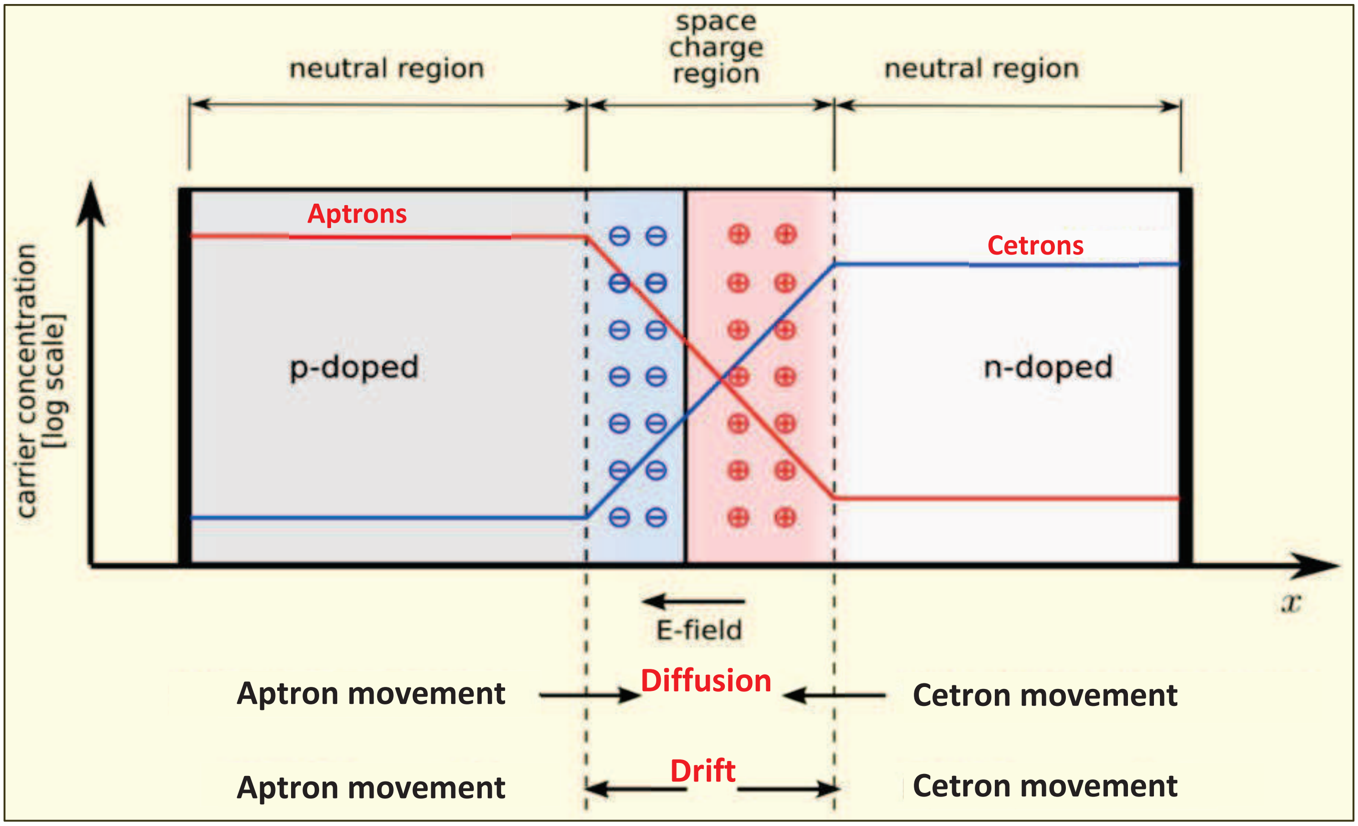

Figure 3: Diffusion, Drift and the Space-Charge Region (Depletion Zone)

As drift is in the opposite direction to diffusion, in the dark and removed from externally applied electric fields, **equilibrium** is soon reached so that there are no charge carriers within the depletion zone and no movement of charge across it: thus there is voltage across the depletion zone (the barrier field voltage) but with no current flow.

Diffusion and drift represent significant processes that cause charge flow within p-n junctions and they act in opposite directions to each other. As discussed earlier, **diffusion** is sensitive to **charge density gradient** (**dn**/**dx**), whereas **drift** is sensitive to the **emf** (**E**) across the depletion zone as indicated by the expression **J = qpμE**, where **q** = bitron unit charge (+ for aptrons and - for cetrons); **p** = Charge density; and **E** = electric-field-generated emf. And both diffusion and drift apply equally to both cetrons and aptrons.

The **depletion zone** now acts as a porous barrier that separates the majority carriers: cetrons on the n-side and aptrons on the p-side, plus some remnant minority carriers left trapped on each side (i.e. aptrons on the n-side and cetrons on the p-side). Next we will consider what happens should an external power source be at applied to a p-n junction.

Reverse Bias

In **reverse bias** a voltage is applied across the p-n junction by connecting the positive terminal to the n-side and the negative terminal to the p-side so the electric field across the depletion zone increases, so increasing the width of the depletion zone as shown in the lower graphic of figure 4.

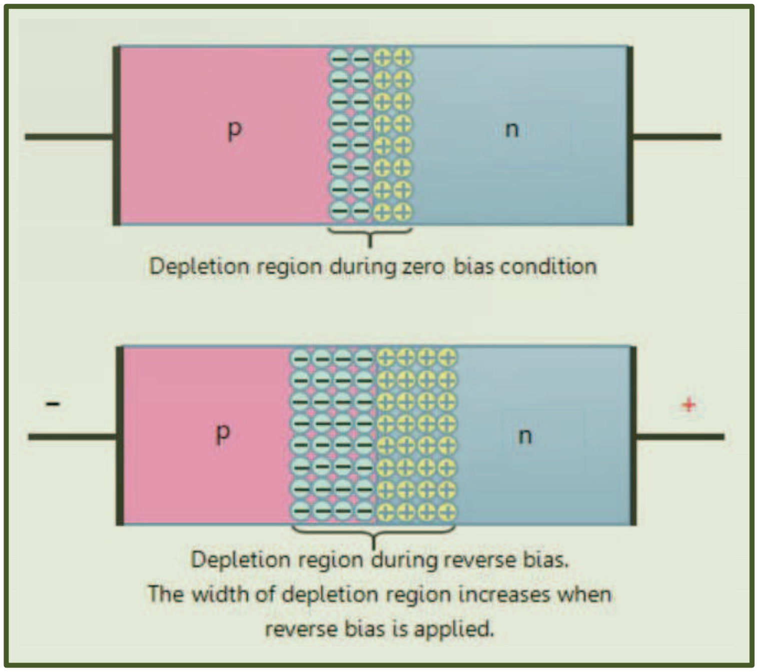

Figure 4: Diode Equilibrium and under a Reverse Bias

The increased width of the barrier zone reduces the bitron concentration gradient (**dx** has increased significantly) so that diffusion is not an issue, and increased strength of the barrier field, as supplemented by the reverse bias voltage, increases the drift of minority carriers across the depletion zone. As minority carrier cetrons drift out of the p-side across the depletion zone, their exit allows more cetrons enter the p-side from the negative terminal of the power source, so maintaining a supply of minority carriers on the p-side. A similar process takes place with aptron minority carriers on the n-side, to generate of a weak electric current consisting of the two-way movement of charge carriers (aptrons and cetrons) in opposite directions.

As the number minority carriers on each side of the junction is a small proportion of the available bitrons, only a small drift current results even as the reverse bias emf is increased as shown in the blue section of figure 5. Should the **breakdown voltage** (V_{br}) is reached, the emf powering the bitrons being pushed towards the diode exceeds the capacity of the minority carriers to cope with the load, and like a bursting dam, a rapid uncontrolled surge of current results which irreparably damages the diode. This is the **Zener breakdown** or **Avalanche zone**.

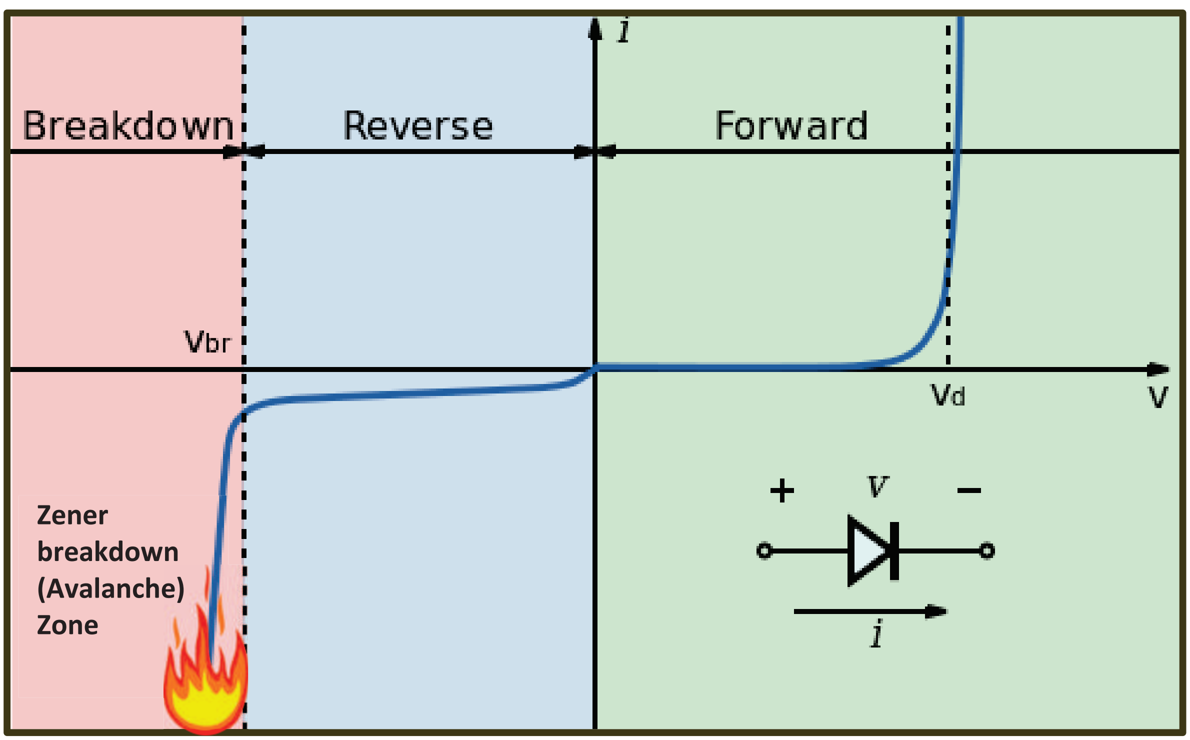

Figure 5: Characteristic Diode I-V Curve under Forward and Reverse Bias

Forward Bias

For **forward bias** the positive terminal of a power source is attached to the p-side of a p-n junction and the negative terminal to the n-side so that the applied voltage is in the opposite direction to the barrier voltage, which causes the width of depletion zone to decrease. For a silicon substrate, as the applied voltage increases towards 0.5 volts, the depletion region width reduces to zero and any potential drift thus ceases, and the diffusion is dominant with current flow increasing significantly at around 0.7 volts (V_d in figure 5).

With all opposing drift eliminated, charge movement is via diffusion of cetrons: the majority carriers on the n-side, to move towards the p-side and being replaced by cetrons being pumped down the wire from the negative terminal of the battery. Similarly aptrons diffuse from p-side to n-side region with aptron replenishment from the positive terminal of the battery, so creating an electric current consisting of the two-way movement of charge carriers (aptrons and cetrons) in opposite directions.

When the battery voltage is removed, although there is now a mixture of cetrons and aptrons on both sides of the join, the barrier voltage quickly re-establishes and any wrong-sided bitrons near the join drift back to their respective major carrier side as the depletion zone and equilibrium are re-established.

Key Issues and Problems

The problem with **holes** is that they are virtual (or quasi) particles that do not physically move, let alone carry their positive charge with them; and they certainly cannot and do not interact (i.e. collide and/or deflect) with other holes so as to generate the Brownian motion on which diffusion is dependent. Notwithstanding this, should holes be assumed to be capable of movement, including Brownian motion, then conceptually they neatly explain diffusion and drift within p-n junctions. But this overlooks the elephant in the room: that positive holes cannot and do not physically move. This represents a major dilemma for conventional Science.

The **bitron approach** emphasises and builds upon the spin differences of electrons, referring to the +1/2 spin electrons as **cetrons** and the -1/2 spin electrons to **aptrons**. Bitrons are considered to be the charge carriers and, being electrons, they are physical particles capable of supporting diffusion and drift within p-n junctions. However this approach raises a whole (with a 'w') new set of problems and issues that need to be addressed.

One issue is that the bitron approach challenges the widely held belief that positive and negative charges represent distinctly different forms of energy. Should positive and negative charges be considered to consist of the same type of energy, then a feasible structure is required to explain electric charge and field characteristics, including why opposite electric poles attract and like poles repel. And then there is the question of why, at close quarters, oppositely charged particles (i.e. cetrons and aptrons) do not attract each other within their host media (metal or semiconductor) and explosively wipe each other out, so releasing their energy in the form of light (photons) and heat.

The bitron approach considers **cetrons** to be negative charge carriers and **aptrons** positive charge carriers, and yet they are both electrons, which at first sight appears to be a contradiction of terms. Also, conventional Science considers the positively charged form of the electron to be the **positron**, the **anti-particle** of the electron. So, what is the difference between aptrons and positrons, and are aptrons present in orbitals? Or put another way, do atomic orbitals contain positive and negative particles? These are all valid questions that will be addressed.

The bitron approach implies that all electricity, regardless of how it is generated, consists of the two--way movement of cetrons and aptrons, a concept that flies in the face of the long held view that electricity consists of the one-way movement of generic one-type-fits-all electrons. The concept that electric current consists of the simultaneous two-way (i.e. duplex) movement of opposite spin electrons suggests that Robert Symmer's two-fluid model could have been right and Benjamin Franklin wrong. Some may possibly find such a two-way flow concept too contentious or non-intuitive to contemplate: but then, on the other hand, many people already believe that positive holes can move.

There are probably many other problems raised by the bitron approach to the p-n junction, but these seem to be the main ones that are immediately obvious. On the surface, the approach seems to raise more problems than the problem it claims to solve (viz. that holes cannot and do not moves as physical positive charge carriers). However, an attempt will be made to address and resolve all the above concerns. The first step of this process is to take a closer look at electrons, starting with electron models and behaviour.

Electron Models

For the purpose of discussing electric currents and sub-atomic particle interactions, electrons are often referred to as discrete particles and represented by a sphere as shown in figure 2, with an arrow sometimes included to indicate their spin-up or down status. On the other hand, the **Orbital Nuclear Atomic Model** (**ONAM**), which represents the classical (or conventional) Science view, assumes the **electron** to be a **point-form monopole particle** that carries a **negative charge** and which satisfies the **Dirac wave equation**. In terms of the wave equations, orbital electrons are considered to be a **wave-like**, rather than a particle-like, form of energy which has only a small probability of being at a defined location at any point in time, as defined by the elaborate twisty-balloon shaped SPDF orbitals.

Thus although the **electron** is a well-studied and documented **elementary particle**, the 'mainstream' models used vary and are somewhat inconsistent if not contradictory. To add to the confusion, there are several other well respected and documented alternative models to the classical ONAM approach(es). One such model is the **T**oroidal **S**olenoidal **E**lectron (**TSE**) model, which defines the electron as a **spinning point electric charge** that moves at high speeds in a solenoidal pattern in a torus-shaped pathway. More recently the **C**harged-**E**lectromagnetic-**W**ave-**L**oop (**CEWL**) model, which also satisfies the Dirac equation, differs from the TSE model in that the energy of its torus core is considered to have no solenoidal spin component.

ONAM, TSE and CEWL are all predicated upon the assumption that positive and negative charges are manifestations of fundamentally different energy forms, with **electrons** consisting of **negative energy** and **positrons**, the anti-particle of the electron, consisting of **positive energy**. Both the TSE and CEWL offer excellent framework to develop mathematical models for electrons displaying up and down-spin, but are based upon the assumption that all electrons consist of negative energy alone and thus neither up-spin nor down-spin electrons are capable of being a positive charge carrier.

The **STEM** (**S**pin **T**orus **E**nergy **M**odel) approach, which resembles the CEWL model most closely, contends that positive and negative electric fields represent the **same type of field energy** in **different chiral forms** (i.e. they have different **helicity**). With STEM, positive and negative charges are considered to be different only by representing **different patterns of field energy flow**. Thus cetrons and aptrons can be considered to be negative and positive charge-carriers due to their energy field flow patterns while still technically remaining free 'electrons' that have been released from atomic orbitals. Let's have a look at STEM's bitron structure to see how all this concept could possibly work.

The hypothetical STEM bitron consists of a torus core of concentrated energy with an outer shim of less concentrated field energy. The **energy core** is considered to behave more like a viscous liquid whereas the outer **field energy** more as a gas or a vapour-like liquid that is **polarised** to present as a cetron or an aptron flow patterns as shown in figure 6.

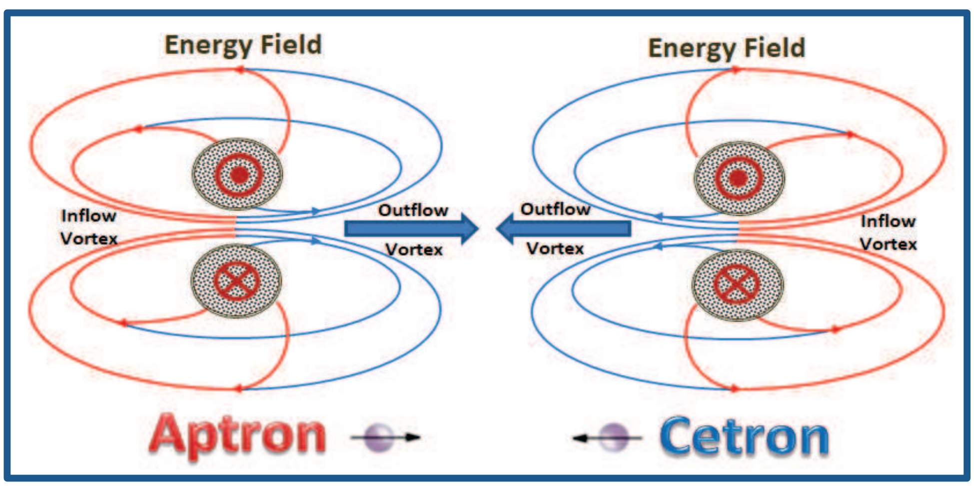

Figure 6: Bitron Energy Core and Chiral Energy Field Flow Patterns

The bitron's field energy is spinning at approximately the same speed of its torus energy core to form an **outer torus** of **field energy**: it has an **inflow vortex** at one end with the field energy spiraling through the centre of the torus core to form an **outflow vortex** on the other side. The outer torus of field energy has a solenoidal flow pattern that is **chiral**, with cetrons having one chiral pattern and aptrons another, as shown in figure 6. No matter which way a cetron or an aptron is turned, their flow pattern is different in the same way that left and right-hand screw threads are similar and yet incompatible. With STEM, cetrons and aptrons are electrons with opposite spin and which, due to their unique chiral energy field flow patterns, can act as negative and positive charge-carriers respectively.

So now we have two forms of the electron that are similar in appearance and contain the same amount of energy but which have incompatible energy field flows. The cetrons and aptrons are distinct physical particles that have opposite spin (+1/2 and -1/2 respectively) that satisfy the Dirac wave equation and can act as negative and positive charge carriers respectively. Next we need to look at the manner in which semiconductor wafers are manufactured to understand how cetrons become concentrated in n-type substrates and aptrons in p-type.

The Czochralski Process

Most silicon-based semiconductor substrate is produced commercially in bulk using the Czochralski process (named after Polish chemist Jan Czochralski who invented the technique). Measured quantities of **dopants** are added to a **silicon dioxide** molten mix at concentrations of about one dopant atom per five million silicon atoms. Within the melt, the silicon and oxygen bonds within silicon dioxide break down and release oxygen and lots of excited electrons in approximately equal numbers of cetrons and aptrons (i.e. up and down-spin electrons).

When the dopant is **phosphorous**, the excess valence band electron-type released is a cetron, which is equivalent to a negative charge. This leaves behind a potassium cation (a positive ion) and increases the count of free cetrons (i.e. the negative charge carriers) within the n-type crystal structure.

When the dopant is **boron**, the neutral boron atom acquires a cetron electron-type for its valence band, and it becomes a boron anion (a negative ion). The boron atom's acquisition of a cetron reduces the count of free cetrons (i.e. negative charge carriers) thus increasing the relative number of aptrons within the p-type crystal structure.

When the molten mix cools and solidifies, what is produced is doped silicon crystal with an excess of cetrons (potential negative charge carriers) within the n-type mix equal to the number of dopant phosphorous atoms. Correspondingly within the p-type mix there is an excess of aptrons (potential positive charge carriers) equal to the number of dopant boron atoms. All that needs to be done is to cut the crystal into thin slices (between 160 to 300 µm thick), cut them to size and glue matching pairs of each type together to produce p-n junctions. After a brief time after the join is made, diffusion and drift within the newly created p-n junction reaches equilibrium as described earlier.

STEM contends that cetrons and aptrons behave differently in different environments such as within metal conductors, semiconductor substrates, and as free electrons that have escaped their host matter. We will discuss some of these environment-specific aspects next.

Electron Behaviour

Free electrons (technically, electrons in the conduction zone) are considered to consist of equal numbers of cetrons (+1/2 spin electrons) and aptrons (-1/2 spin electrons). Within metal conductors (such as copper wire) cetrons and aptrons are in high concentrations and mixed in together, whereas within a p-n junction they are quite sparse, well separated and are mainly concentrated on opposite sides of the depletion zone. Thus it is not surprising that the behaviour of electrons within these different types of media is different.

In response to thermal energy, bitrons move leading with their outflow vortex as shown in figure 6. There are several possible reasons for this: one is that the strong twisting central flow of field energy through the energy core drags the core in that direction; another is the rapid screw-like action of the outer flow of the energy field worms and thrusts bitrons forward; and another possibility is Larmor precession which results from the magnetic moment of a particle about another magnetic field (the magnetic fields for a bitron are the linear axial component of its central flow and its gentler and more expansive outer flow region that has a vector flow direction oblique to the bitron's axial direction).

The speed of bitrons is temperature sensitive as the thermal energy is converted to kinetic energy. At room temperature (about 24^{O}C), semiconductor bitrons move at the brisk thermal velocity of about 2 x 10^5 m/sec within silicon, and randomly buffet and deflect each other to produce **Brownian motion** which is analogous to the behaviour of molecules within a volume of gas.

The reason why bitrons bounce and deflect each other when they are sparsely concentrated is because they move with their central outflow vortex foremost, which prevents direct contact of their energy cores: they simply deflect and push each other aside. The mutual repulsion and deflection of bitrons is compatible with the concept of electrons repelling each other: it is also somewhat anomalous because it applies to mixtures of cetrons (negative charge carriers) and aptrons (positive charge carriers) which, in classical terms, might be expected to attract each other.

Within metal conductors the bitrons are too concentrated for Brownian motion to occur. Instead, thermal energy causes bitrons to vibrate and to slowly shuffle around so as to form into like-spin and thus like-type **strands**. Strands form by the mutual attraction and alignment of like-spin bitrons facing and moving in approximately the same direction (i.e. their outflow vortices are closely aligned). The attraction causing strand formation is that the inflow vortex of the front bitron draws in field energy from the bitron behind it, which is somewhat compensated by the outer energy flow of the front bitron flowing on to the rear bitron. The net result is that strings of bitrons (i.e. strands) that form into a conga-like line as shown in figure 7.

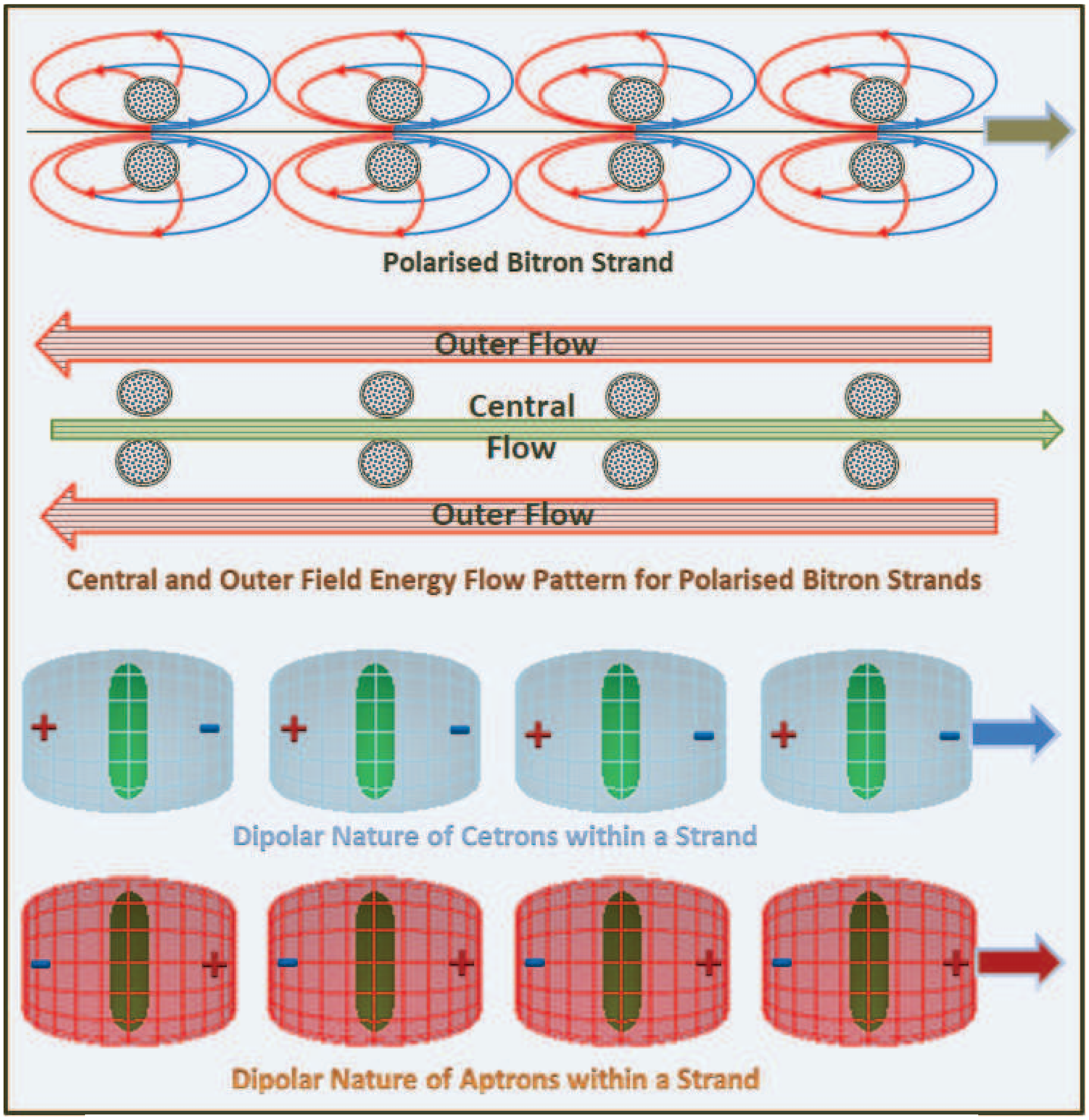

Figure 7: Bitron Strands

When bitrons are closely packed within a strand, their energy fields merge to form a narrow central flow of swirling high-speed field energy that acts as a turbo-charged stream of energy, plus a broader outer cylinder moving more sedately in the opposite direction. Both zones have circular and axial flow components that are most important for the explanation of electric fields and their behavioral characteristics.

Because, within copper wire, cetrons and aptrons are present in equal numbers, members of each population have equal probability of facing in either direction with respect to the long axis length of the wire. Thermal activity causes bitrons to self-organise (as explained above) into cetron and aptron strands. And because cetron stands can be facing either axial direction, as can aptron strands, there are four distinct strand groupings (see the top panel of figure 10), and each grouping is numerically equal (i.e. each strand grouping contain about 25% of the bitrons in the wire).

Once they are locked into a strand, bitrons can wriggle, precess and vibrate within the strand, but cannot move forward or backwards. For strand members to move, they need to be induced to move by an applied emf, and then can only do so if there is no break of circuit. And when an emf is applied only half of the available bitron strands are involved: for DC power, only those strands with spin compatible to that of the emf dictated by the power source's polarity; for AC power the sets of strands that are energised and move alternate for each reversal of emf direction.

When an emf (voltage) is applied to the wire from a power source, each terminal supplies bitrons that cause pressure and crowding within strands: aptrons from the positive terminal and cetrons from the negative terminal. As these 'new' bitrons join strands with the same spin direction and pointing away from their respective terminals and, in a process analogous to diffusion, the increased crowding bump-pushes existing strand members further along the strand and to produce an electric current. Thus an electric current consists of aptrons moving from the positive (source) terminal within their strands towards the negative (sink) terminal; simultaneously cetrons are moving within their strands from the negative source to their positive sink terminal as shown in the top panel of figure 8.

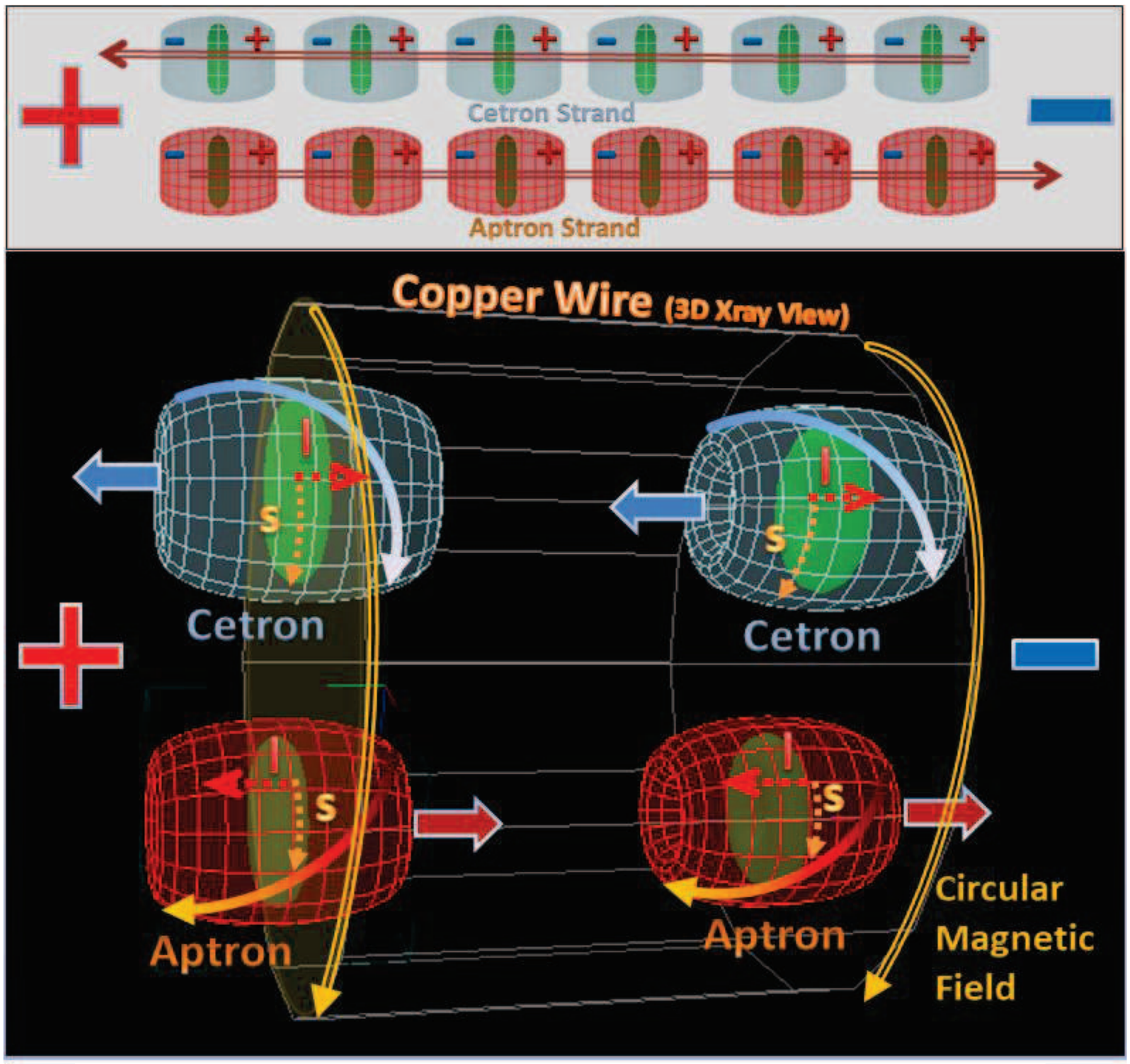

Figure 8: Emf-Induced Aptron and Cetron Movement

Because the up and down-spin electrons are moving in opposite directions, the circular **s**pin component (**s** in figure 8) of their field energy is in the same direction and combine and, due to the increased charge density related to their movement, a circular magnetic field forms around the current carrying wire as shown in figure 8. Knowing the direction of the terminal polarity, the direction of movement of the induced magnetic field can be determined using the **Maxwell Right-hand Grip rule**. Also, as the component of the energy fields of the moving aptrons and cetrons in the spin-axis direction (**l** in figure 8) is in opposite directions, they cancel each other out.

In the p-n junction context, with no externally applied voltage, junction equilibrium is achieved by is in terms of diffusion and drift adjustment currents; under reverse bias the small reverse current produced is due to drift; and under forward bias the initial current once the barrier field is overcome starts by diffusion but, soon after the 'knee' (V_d in figure 5), bitron movement becomes more strand-like and less random in nature. Each situation involves the simultaneous two-way (i.e. duplex) movement of cetrons and aptrons.

Strands are a permanent feature within a wire conductor, with only half of the strands (and thus only half of the contained bitrons) used to carry electric current in a particular direction. However, within a p-n junction, strands are only formed when a junction is forward biased well beyond the barrier voltage. Such strands are dynamically formed and can involve all the bitrons: due to the sparseness of the charge carriers such strands break down once the forward bias is removed, so allowing random Brownian motion to re-establish, with diffusion and drift restoring equilibrium.

Although the thermal velocity of bitrons about 2 x 10^5 m/sec within silicon, their velocity within copper wire as an electric current move is about 80 centimetres per hour, which suggests that bitrons move within their respective strands at a speed of approximately 40 centimetres per hour in opposite directions. The difference in speed is due to the considerable difference in bitron density within each medium.

By convention cetrons are negative charge carriers. However, within strands they act like **electric dipoles** and attract each other and so keep in line. Thus the leading polar end of a moving cetrons's energy field can be considered to be negative and its trailing polar end to be positive. The reverse applies to aptrons.

Due to the positive charge of a cetron's trailing polar end, when they try to escape from their host material (a metal foil for example), their positive pole is like-pole repelled by the predominantly positive field generated by the nucleus of the metal atoms: thus they get a little push assistance to help them escape. For aptrons the reverse applies: when they try to escape their trailing negative pole is opposite-pole attracted to the positive field generated by the nucleus of the metal atoms and they are more constrained. The dipolar nature of bitrons results in cetrons needing less than a quarter of the kinetic energy needed by aptrons to be able to escape from their host material.

The relative ease escape from their host medium by cetrons is exemplified by the photoelectric effect (via photon bombardment) and electron guns or cathode ray tubes (via the electrical heating of a wire element). Much higher levels of energy is required to provide aptrons with sufficient kinetic energy to escape from their host medium as **positrons**, with brute-force techniques being required such as the 200 MeV high -energy Large-Scale Collider art CERN. Fortunately, since 2013, more affordable and compact high-power benchtop lasers capable of delivering energy at the petawatt (1015W) level have become available kinetically free aptrons from their host material.

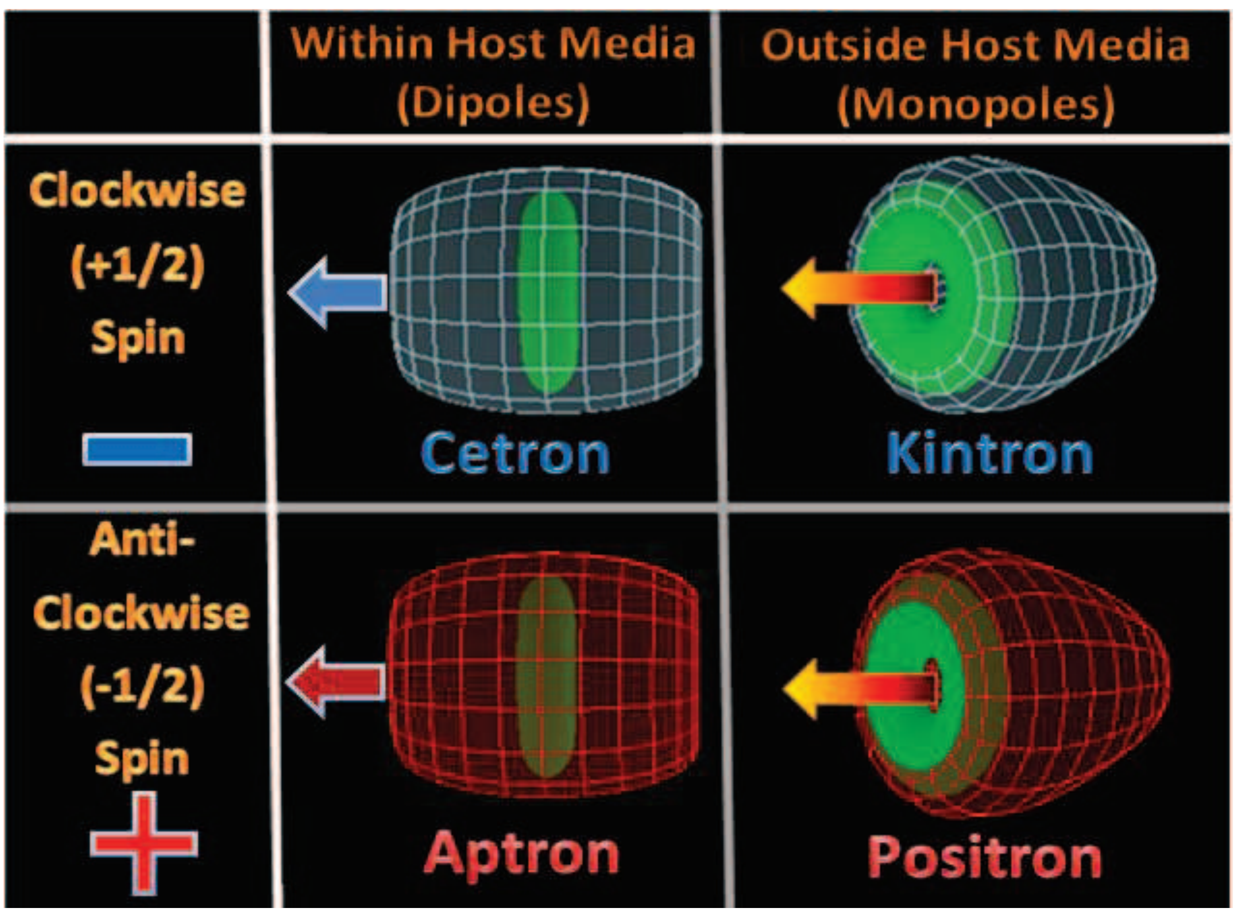

Figure 9: Bitrons and Their Kinetic Forms

Bitrons forcedly ejected from the host suffer the trauma of a violent high-impact process. Consequently, their energy fields become permanently distorted and asymmetric (see figure 9) compared with the symmetrical their energy fields of bitrons remaining within their metal and semiconductor host media. These battered, asymmetric bitrons are the **electrons** and **positrons** that are generated and studied in Physics laboratories, and they have different behavioral characteristics to their counterparts left behind in the host medium. To avoid confusion with the terms electron and cetron, STEM refers to such out-of-body electrons as **kinetic electrons**, or simply as **kintrons**.

The asymmetry of kintrons and positrons is largely due to the compression of their outflow vortices which are curtailed to the extent that they present as **electric monopoles**, and which renders their outflow vortices ineffective for preventing them colliding with each other. Collisions between a kintron and a positron can and does easily occur, resulting in **electron-positron annihilation** and the creation of a pair of **gamma rays** travelling in opposite directions to each other. The common spin direction of their energy fields of a kintron and positron approaching each other possibly acts as a home-in or lock-on mechanism that increases the probability of a collision, whereas the opposing spin of approaching same-type pairs of kintrons or of positrons under normal conditions (i.e. not a high energy environment such as in a particle collider) causes deflection and so prevents like-particle collision.

Electric Fields

When a pair of **probes** is attached to the opposite terminals of a DC power source, the energised strands (those with the appropriate spin) within the probes and attached wires become compacted, with the bitrons being pushed closer together as dictated by the strength of the emf being applied by the power source. Such bitron crowding increases the overlap of bitron energy fields, so increasing the central and outer zone energy flow rates of the energized strands.

The strong concentrated central field energy flow through the bitron cores extends well beyond the tip of the probes, and when the probe tips are close enough to each other, they extend to the other probe and become grounded by connecting to a compatible strand. Any central flow stream that spans the two probes is called a **thread** (see the cetron and aptron threads in the top panel of figure 10). An open-ended (or ungrounded) central energy stream is called a **wisp**.

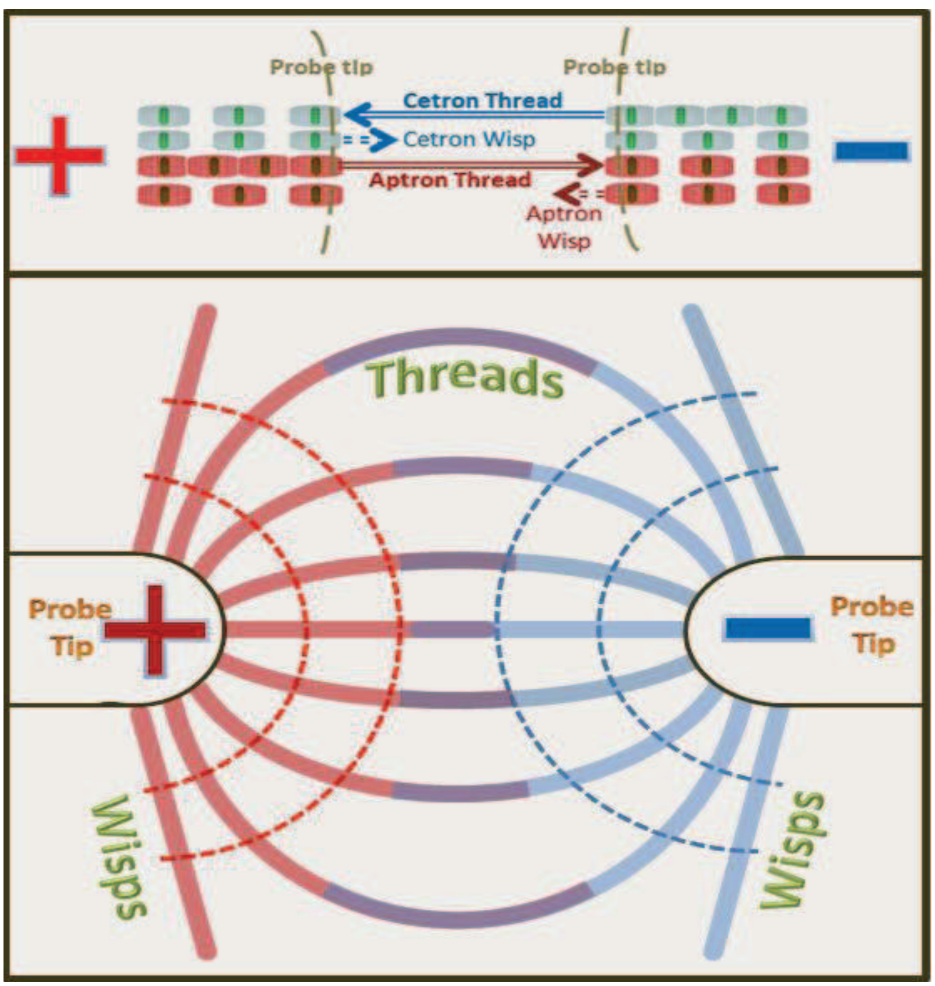

Figure 10: Electric Field Threads and Wisps

The upper panel of figure 10 shows how the two energised strands form into threads while the other two dormant strands form mini-wisps that are barely noticeable. The lower panel of figure 10 shows the broader scale thread and wisp pattern associated with the pair of probes: cetron and aptron threads have been merged for aesthetics with each red/blue combination represents an aptron thread from the positive side and a cetron thread from the negative side. The red dashed circles around the end of the probes represent a plot of the electric field's equipotential surfaces.

The wisp/thread pattern for a pair of reasonably close oppositely charged probe tips as shown in the lower panel of figure 10 corresponds to conventional Science's **electric field lines of force**. Between opposite-charge probes, threads act to as restraints that help to centre and align the probes as they are moved closer together. To counter the **energy out-flow** of the central flow zones, and so to maintain an **energy balance**, strands need to retrieve energy and do so via the outer-flow zones of the energised strands of both threads and wisps. These **energy return** (or **in-flow**) zones fan out around the central flows to produce pull on the field energy resource-in-common between and around the probes, which results in what we refer to as **opposite pole attraction**.

As a pair of oppositely charged probes move closer together the dynamics of the attraction change: the number of threads increases dramatically as does the mutual attraction between the probes. And when the probes are about to touch, the central energy outflow is so strong that some outer cetrons of cetron strands prematurely jump the gap. As they jump the gap these kinetically energised cetrons ionise air and water molecules along the way, so generating heat and light that ranges from an **electric spark** to an **electric arc**. As aptrons require much more encouragement to coerce them to leave the host material than do cetrons, mainly cetrons prematurely jump the gap from the negatively charged probe to the positively charged probe.

By the time that the two probes are in physical contact with each other, the circuit's energy now has a pathway that offers zero resistance and thus an un-moderated rapid transfer of energy results which is called a **short-circuit**.

It would seem that **magnetic fields** consist of the same type of field energy that forms **electric fields** but the two types of field are different due to the flow pattern of their field energy. As can be seen in the main panel of figure 8, within a current-carrying wire the component of the energy fields of the moving aptrons and cetrons in the spin-axis direction (**I**) is in opposite directions so that they cancel each other out. Thus the field energy forming the magnetic field has no circular or spin aspect: it simply consists of field energy moving in the direction of the field. Electric field energy, on the other hand, is more complex with a mix of spiraling energy flow (i.e. the flux energy has spin) and variable concentration, velocity and spin rates as exemplified by the inflow and outflow vortices of bitrons.

When a pair of positive (or negative) electric poles is placed in close proximity, threads do not form because the opposing wisps have opposite spin-direction to each other, and thus their circular-spin component cancels each other out. With no net circular-spin component, their field energy is very similar to magnetic field energy and acts in a similar fashion to a pair of opposite North magnetic poles. Thus, rather than forming threads, the opposing wisps deflect each other and push against each other, which push the poles apart as **like-pole repulsion**. The resulting lines of force pattern is thus similar to the flux line pattern for opposing North magnetic poles.

The formation of electric field threads and the direction of their spin are most important to explain how capacitors charge, hold charge and discharge charge as well as explaining the formation of man-made micro and radio waves. However those topics are outside the scope of this brief paper.

Overview

The dual nature of electrons was well established by 1925, as embodied in the widely accepted **Pauli Exclusion Principle**, but was not used to retrospectively revise the model used for charge movement in the form of electric currents or to provide a more comprehensive explanation for electric fields. Another opportunity arose but was missed in the 1940's with respect to the evolving semiconductor technologies: instead positive charge-movement was explained in terms of mythical hole-movement. It is amazing and somewhat ironical that Science's fundamental theory and understanding of electricity and semiconductors, two of the most important driving forces of the rapid and revolutionary advance of modern technologies such as computing and electronic communications, might be flawed.

Possibly the belief that negative and positive charges represent two distinctly different forms of energy, as reinforced by an atomic model (ONAM) with a positive nucleus and negative orbital electrons that are physically distinctly different to each other, clouded the issue. However, with +1/2 spin and -1/2 spin electrons, collectively referred to as

bitrons, released from the valence band of atoms and capable of being negative and positive charge carriers, electric currents can be comprehensively explained for both semiconductors and metal conductors without the need for holes. An excellent explanation for the formation and nature of electric fields is an added bonus.

Bitrons behave differently in different environments. Within a host material, bitrons have symmetrical energy fields that provide them with dipole-like attributes. In sparse concentrations, the thermal velocity of bitrons causes them to buffet and deflect each other, producing **Brownian motion** that results in **diffusion** and **drift**, the primary causes of charge transfer within **semiconductors**. Within a metal conductor, such as copper wire, bitrons are more populous and concentrated and, due to their dipolar nature, form into **strands**. When attached to a power source the applied emf causes bitrons to move within energised strands as an electric current; and if there is a break in circuit (e.g. across capacitor plates or a pair of attached probes) the energy fields of the energised strands generate an **electric field**.

Bitrons gain kinetic energy via collision, either from other excited bitrons or high impact collision with some other externally generated particle (e.g. light photons through to high energy laser beams). By the time a bitron gains sufficient kinetic energy to allow it to escape its host material, the impact trauma from collision distort its energy field so that it presents as a **monopole** particle: either as a kinetic cetron (a **kintron**) or aptron (a **positron**). Positrons need about four times more kinetic energy than kintrons to escape the positive field of atomic nuclei of the host medium.

The model of an electron that best explains its properties and behavioural characteristics as well as satisfying the Schrodinger and Dirac wave equations is **STEM** (the **S**pin **T**orus **E**nergy **M**odel). STEM is an **energy-centric** approach which contends that there is only one form of energy, with electrons being considered to consist of a concentrated torus-shaped **energy core** and an outer torus of less concentrated **field energy**. Furthermore, STEM contends that the **chirality** (or **helicity**) of an electron's energy field divides it into two distinct chiral forms: the **Cetron** that has +1/2 spin that displays left-handed or clockwise helicity and the **Aptron** with -1/2 spin that displays right-handed or anti-clockwise helicity. By convention cetrons are considered to be negative charge carriers and aptrons positive carriers.

The STEM approach is not as radical as it might first seem. Under the topic heading Chirality and Helicity, Wikipedia states that "helicity of a particle is **positive** ("right-handed") if the direction of its spin is the same as the direction of its motion. It is **negative** ("left-handed") if the directions of spin and motions are opposite". The quote is accompanied by the graphic of figure 11 that has only been modified by the addition of the labels **Cetron** and **Aptron**.

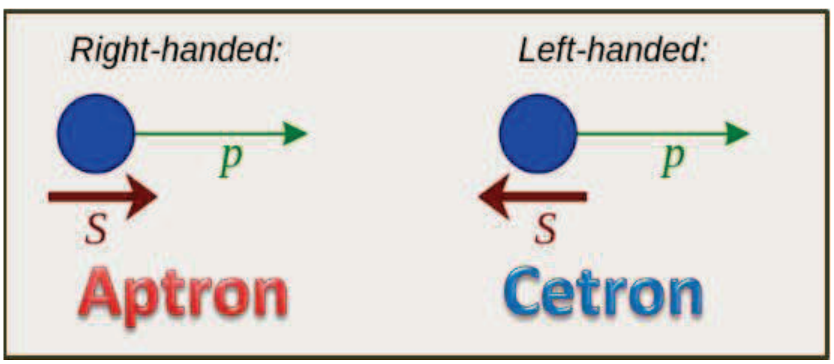

Figure 11: The Helical (i.e. Chiral) Forms of the Electron

Over time some aspects of the STEM approach may ultimately prove to be incorrect, but at this point in time it would seem to provide much-needed answers and explanations related to the varied characteristics of bitrons (or generic electrons if you prefer) both within a host and outside of a host medium; it provides an explanation of electrical fields; it provides an explanation for the similarities of electric and magnetic fields as well as their distinct differences; it satisfies the Schrodinger and Dirac wave equations; and it is fully compatible with the Pauli Exclusion Principle. Also it has fewer holes than the current conventional Science explanation for the electrical characteristics of semiconductors.

Should the STEM approach prove to be correct, even in essence rather than in every detail, then many textbooks, Science papers and lectures will require significant updates through to complete re-writes. And then there are the very real implications for Science and industry in terms of a new understanding of the nature of positive and negative charge, electric and magnetic fields, and electric charge movement within semiconductors and metal conductors.

David L Johnson

Perth, Australia