Holes and the Spin Separation of Orbital Electrons

David L Johnson

Abstract

In order to explain **diffusion** and **drift** across the **depletion zone** of a **p-n junction**, semiconductor theory relies on **holes** which act as a positive charge equivalent of **electrons**. As positive charge carriers, holes need to physically move and be involved in random collisions to produce the **Brownian motion** required to explain diffusion. Any lack of hole-movement, or even the required type of hole-movement, represents 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 was followed by 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 valence electrons and requires an additional valence 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 with the cations involved in such exchanges being called **holes**.

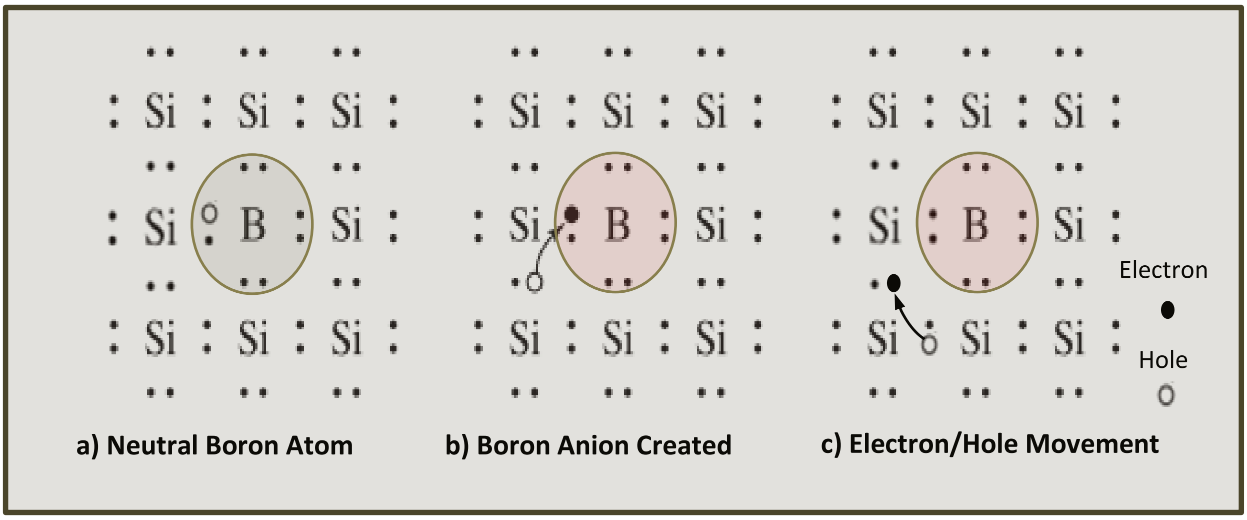

Figure 1: Electron/Hole Movement in p-type Semiconductor

A **positive hole** thus represents a missing electron from the **valence band** of an atom which itself is fixed and unable to move within the semiconductor substrate. New holes can appear when neutral silicon atoms lose a valence 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, a person may turn one light off and another on as they 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. Why then would the movement of electrons in one direction cause holes (the 'darkness') to move in the opposite direction except than by illusion? The random hole appearance (cation creation) and hole disappearance (cation neutralisation) involves only the movement of negatively charged electrons: in no way does it involve the movement of positively charged holes, although some animated gifs and dynamic presentations may produce the visual effects that suggest otherwise.

With animated gifs, TV and projection screens objects do not physically move across a screen. Movement is simply a series of slightly different images that are momentarily shown and removed in a sequence to provide to provide the illusion of movement. The same is true for holes in semiconductor substrate.

Even the '**step analogy**', commonly used to explain apparent hole-movement, does not work. This analogy relates to electrons moving up (or down) a flight of stairs, and having to wait for an empty step (a hole) to move up (or down). Each empty step (holes) appears to move downwards as an electron works its 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**. But holes just don't fill the bill.

At best, the migration of the electrons from one side of a semiconductor to the other can produce a negative charge concentration there 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 physical movement of holes to carry 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 x 10^5 m/sec, which is surprisingly fast but is still about is about 1000 times slower than the speed of light (3 x 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 there are differences in their concentration. The movement of gas molecules due to **concentration gradients** is called diffusion. Diffusion 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 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; **D** = the diffusion coefficient for the electrons; and 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 they would quickly become acquired (or '**fixed'**) by the much more plentiful holes, so becoming converted into neutral atoms. Thus, holes are the only possibility, but because they cannot physically move there are no mobile positive charge carriers within p-type semiconductor that can interact by physically buffeting and deflecting each other in a random fashion to produce the Brownian motion, as can occur with electrons on the n-side. There could be an illusion of random movement of holes as explained above, but **no random collisions** or deflections, let alone concentration gradients that could justify the use of Fick's diffusion law.

However, 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 audience to do. Alternatively 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 within orbitals.
Ce**trons** and Ap**trons** are both elec**trons**. 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 a**p**tron suggesting that it is a **p**ositive charge carrier. Similarly the '**E**' of c**e**tron suggests that it is a n**e**gative 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.

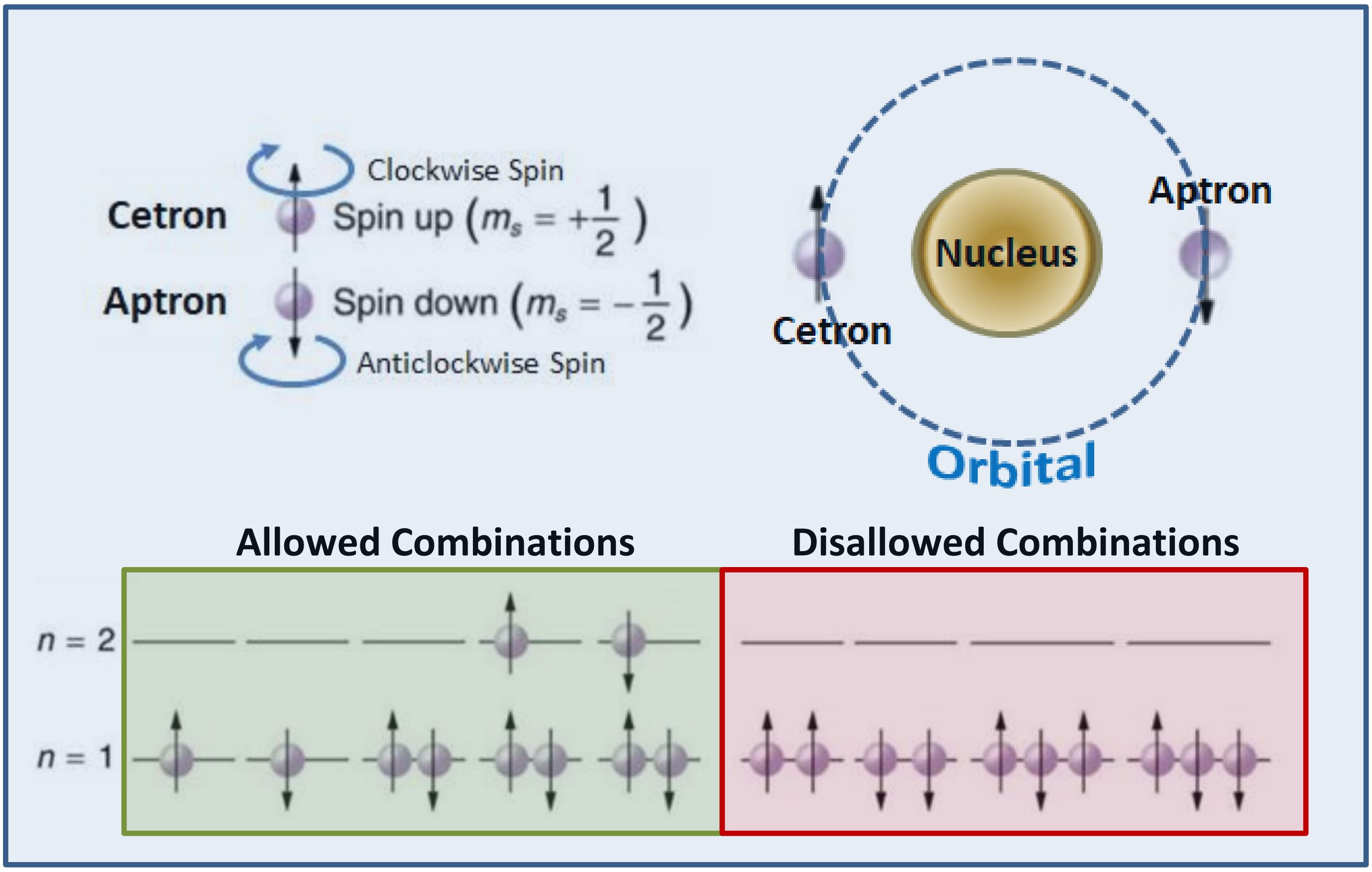

Figure 2: Electron Spin and Electron Orbitals

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 unmatched 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). Drift 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**.

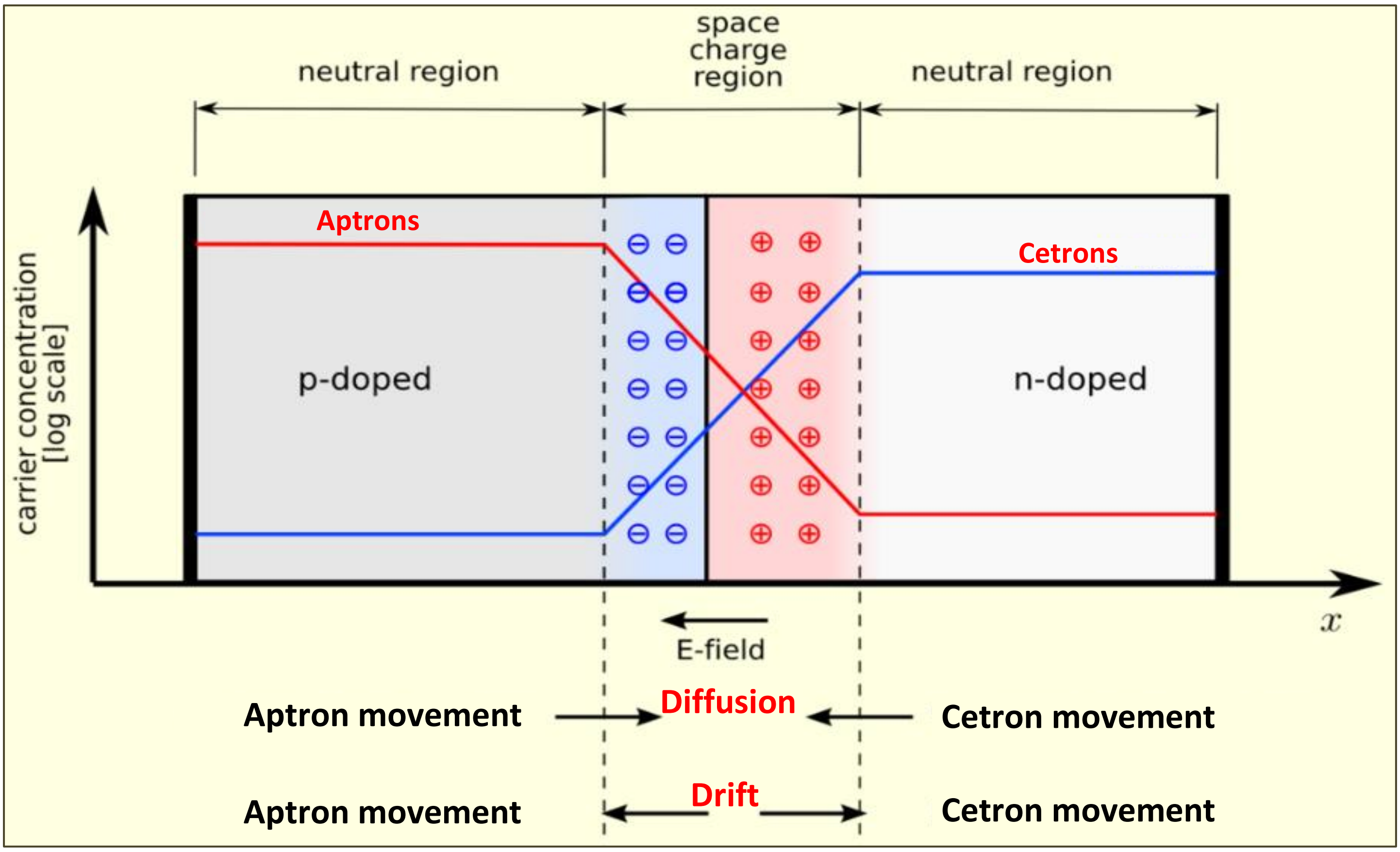

Figure 3: Diffusion, Drift and the Space-Charge Region (Depletion Zone)

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** (d**n**/d**x**), 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.

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.

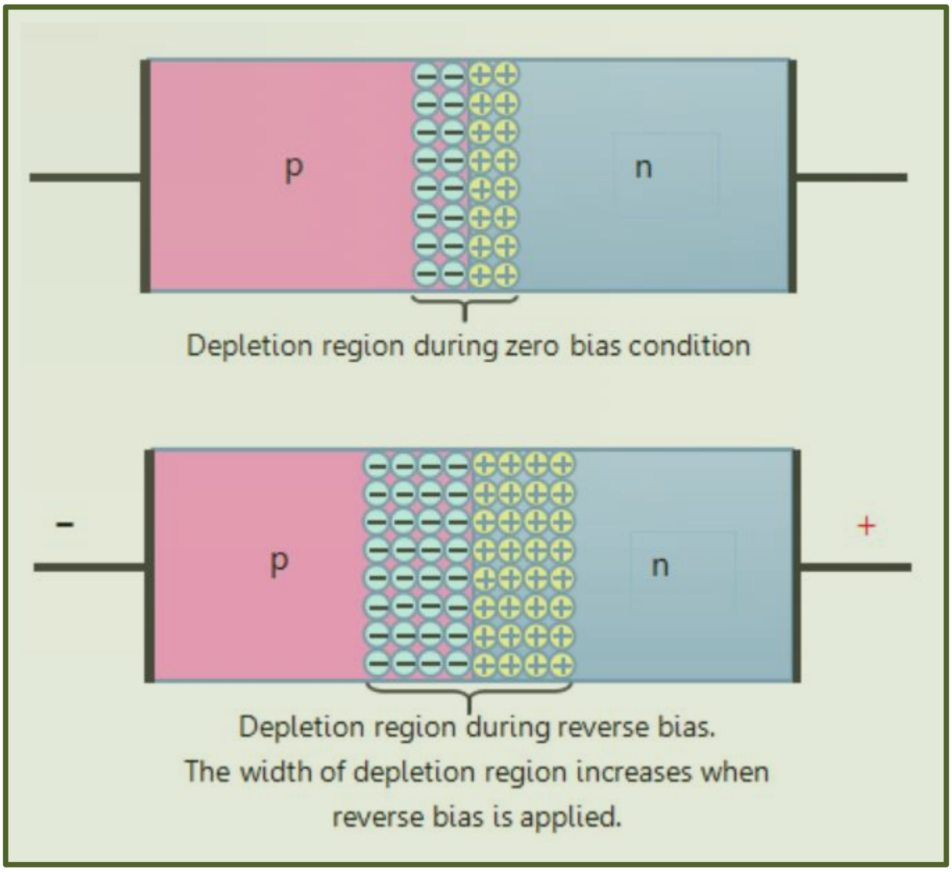

Figure 4: Diode Equilibrium and under a Reverse Bias

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**.

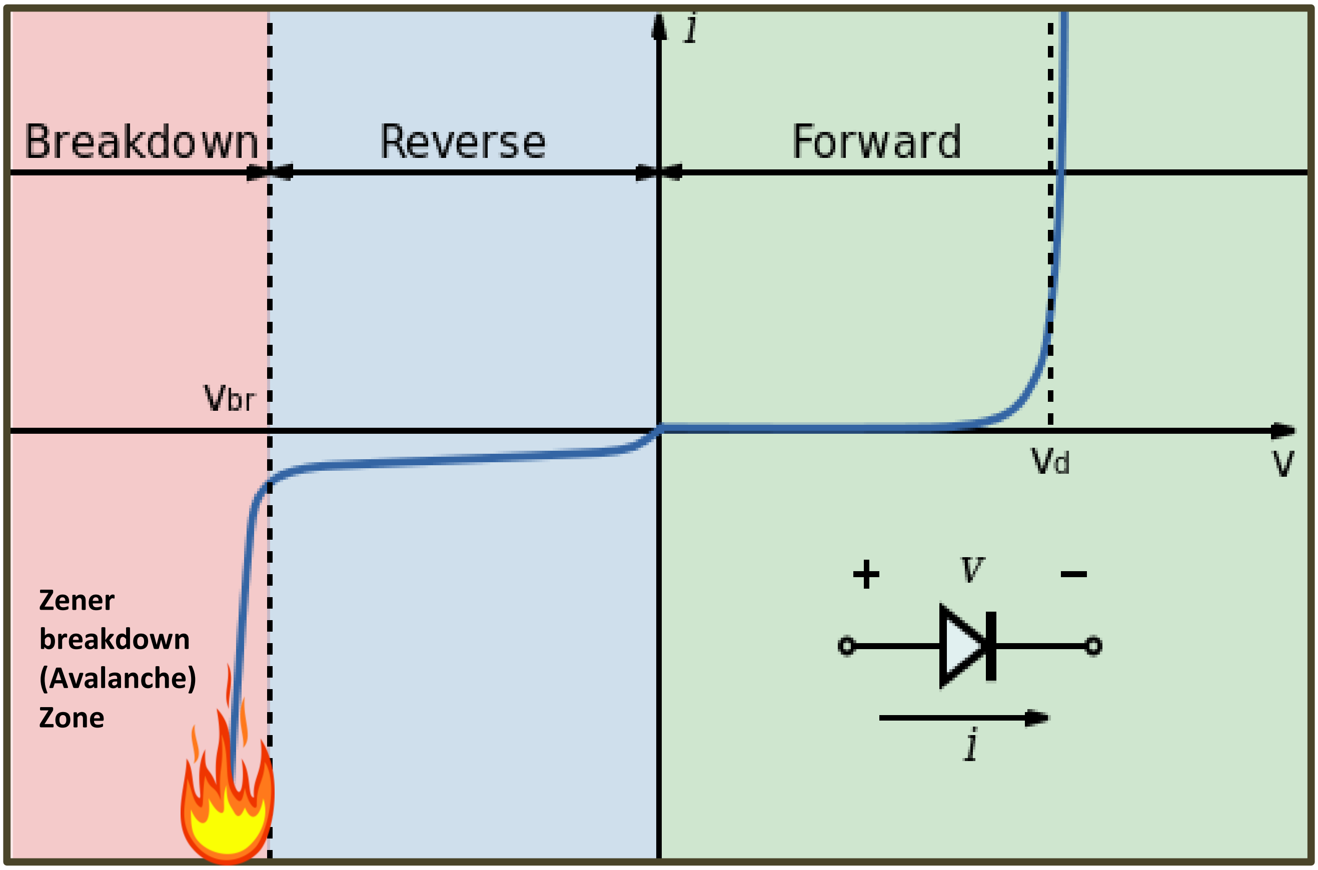

Figure 5: Characteristic Diode I-V Curve under Forward and Reverse Bias

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** is 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.

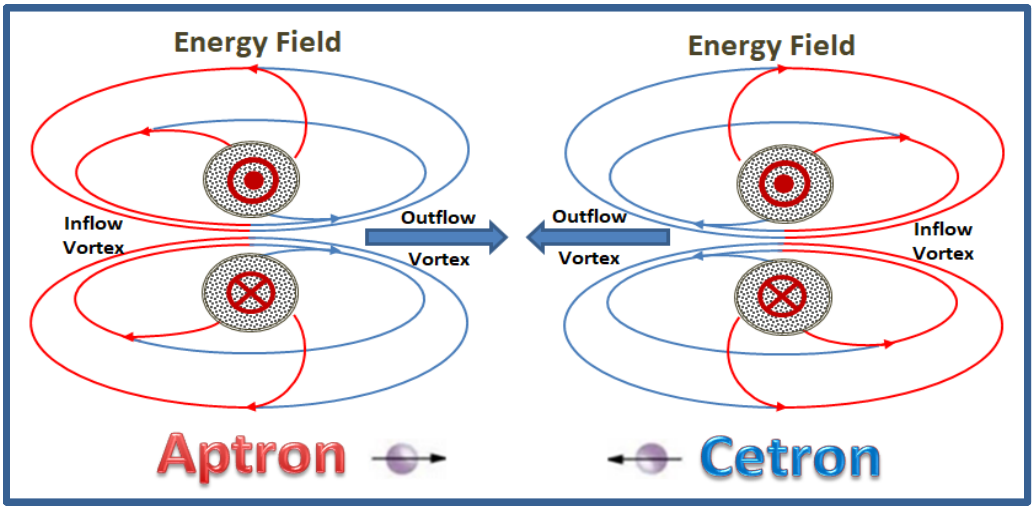

Figure 6: Bitron Energy Core and Chiral Energy Field Flow Patterns

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 thus increasing the relative number of aptrons (i.e. the positive charge carriers) 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** (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** (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

STEM considers that **free electrons** (conventionally these are electrons in the **conduction band**) may be either **cetrons** (+1/2 spin electrons) or **aptrons** (-1/2 spin electrons). Within **metal conductors** (such as copper wire) free cetrons and aptrons exist in equal numbers, are in **high concentrations**, and are inter-mixed. On the other hand, within p-n junctions and related semiconductor devices, they are relatively **sparse** and effectively separated with one type being more concentrated as the major (or dominant) charge carrier on opposite sides of the depletion zone. Thus it is not surprising to find that the behaviour of electrons within these different environments to be different.

In response to **thermal energy**, bitrons within sparsely populated media such as semiconductor substrate move leading with their outflow vortex as shown in figure 6. The main reason for this orientation is that the strong twisting central flow of field energy through the centre of energy core torus pushes the core in that direction; another possible reason is that 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), provides a more curved trajectory and a wriggle action that, in combination with the oblique screw-like outer energy field flow pattern, would help to provide forward-thrust.

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. This applies equally to cetrons and aptrons

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, but is also somewhat anomalous because it also applies to mixtures of cetrons (negative charge carriers) and aptrons (positive charge carriers) which, in classical terms, might be expected to attract and cancel each other out.

The story is completely different within metal conductors wherein 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 linked chains of same-type bitrons called **strands**. Strands form because same-type bitrons with a similar heading (i.e. with their outflow vortex pointing in approximately the same direction) mutually attract each other. Such attraction is caused by the inflow vortex of the front bitron drawing 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 the bitrons display **dipole** characteristics that cause the daisy-chain or conga-like stand to develop as shown in figure 7c.

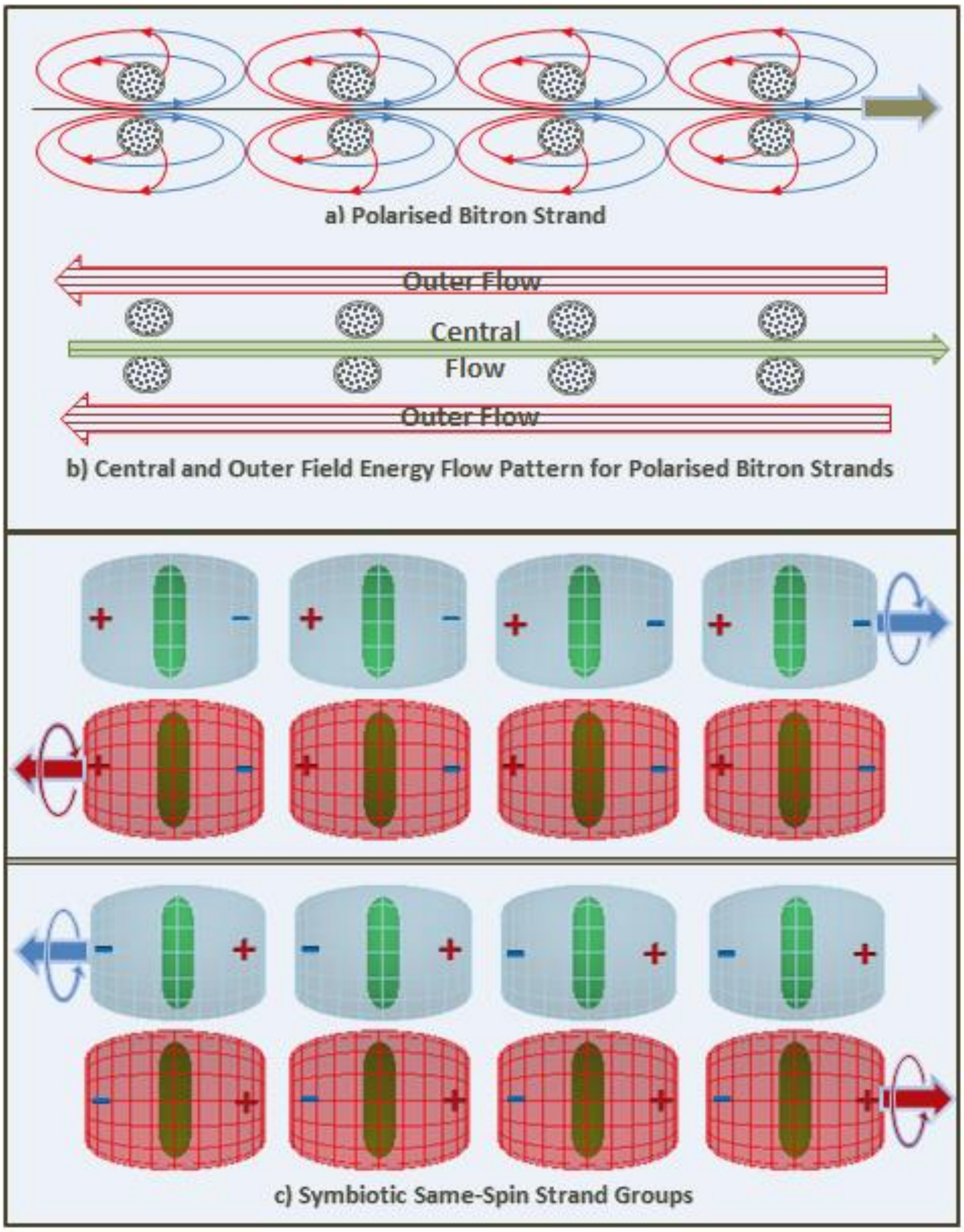

Figure 7: Bitron Strands

When bitrons are closely packed within a strand (figure 7a), their energy fields merge to form a central turbo-charged stream of swirling high-speed field energy, plus a broader and more sedate outer cylinder of field energy that swirls in the opposite axial direction as shown in figure 7b. Both zones have the same circular flow directional components that are most important for the explanation of electric fields and their behavioural 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 has just been explained) 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 figure 7c), and each grouping is numerically equal (i.e. each strand grouping contain about 25% of the bitrons in the wire). Within the four strand groupings there are two **same-spin strand groupings** (figure 7c) containing 50% 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.

Same-spin strands display **symbiotic behaviour**: an increase in their combined circular magnetic field strength causes increased forward- movement of bitrons within same-spin stands. Conversely, a change in bitron movement within any of the strands in the same-spin grouping is accompanied by corresponding change of the net circular magnetic field generated by the strands (∑**S** in figure 8). Symbiotic behaviour occurs because changes to the speed of the outer field energy the speed results in far greater changes in the speed and associated force exerted by field energy as it passes through the centre of the electron's torus core, which in turn affects the electron's forward speed.

When an emf (voltage) is applied to an open electric circuit, each terminal provides a ready supply of bitrons that cause pressure and crowding within strands in the wire directly attached to a power source: aptrons from the positive terminal and cetrons from the negative terminal. As these 'new' bitrons join spin-compatible strands, in a process analogous to diffusion, the increased crowding bump-pushes existing strand members further along the strand **away from** the source terminal. The movement of bitrons causes an increase of their circular magnetic field, which simultaneously causes the **symbiotic movement** of bitrons in associated same-spin strands to move in the opposite direction **towards** the terminal.

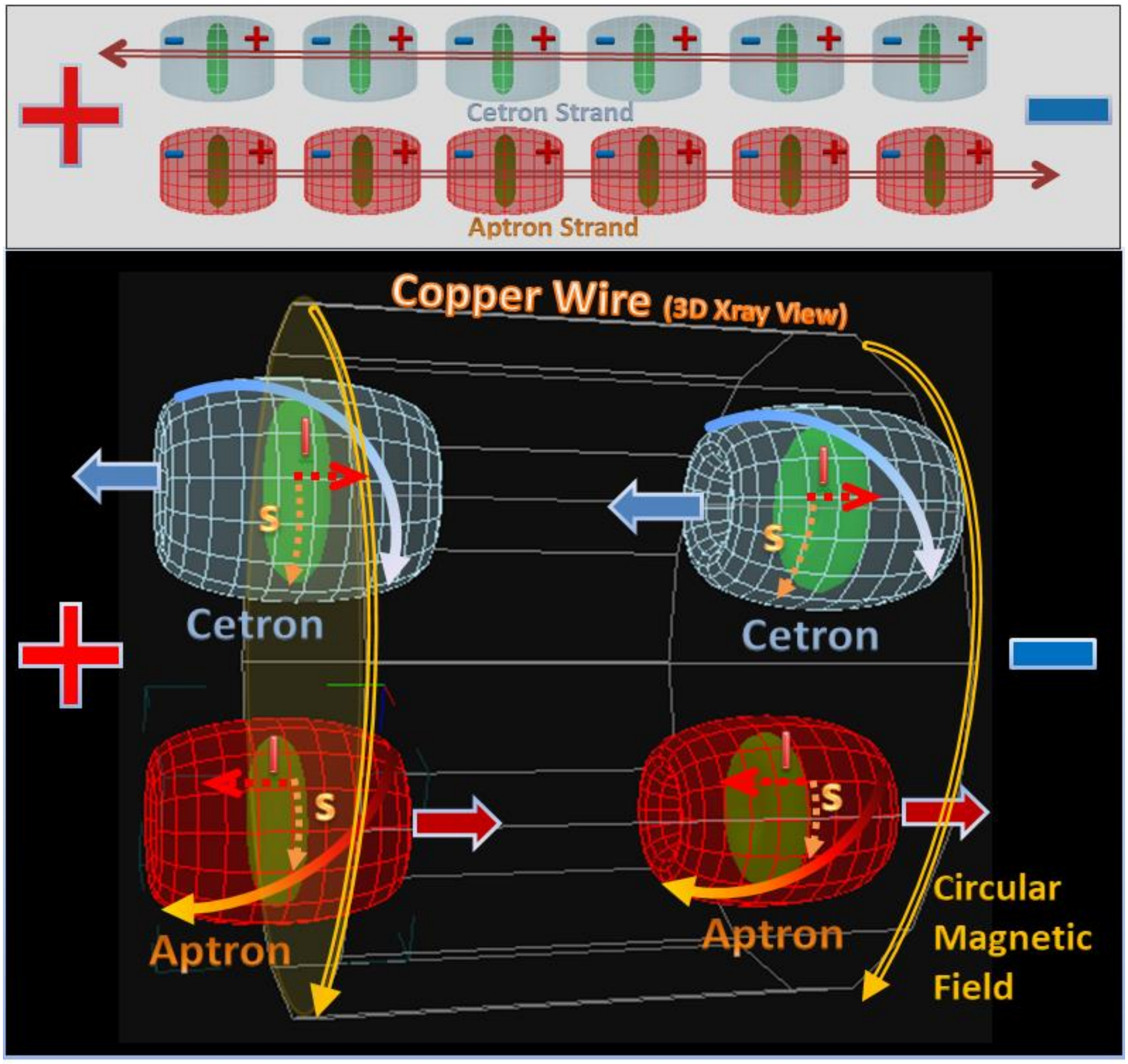

Figure 8: Emf-Induced Aptron and Cetron Movement

The net result of an **applied emf** is that each terminal represents a **source** (or **supplier**) and **sink** (or **consumer**) of opposite spin bitrons to generate an electric current. As shown variously in figure 8, **Aptrons** move from the **positive source** terminal towards the **negative sink** terminal, and **cetrons** simultaneously move from the **negative source** to the **positive sink** terminal. Even for an **induced electric current**, where the positive and negative terminals are **implied** rather than real, there is the simultaneous two-way (i.e. **duplex**) movement of aptrons and cetrons within strands.

Note that outer energy field of a bitron has a linear component (**L** in figure 8), and a spin component (**S**), with the linear component being in the opposite direction to bitron movement. As there are equal numbers of moving aptrons and cetrons facing opposite directions within paired strands, the linear flow components cancel each other out, and all that is left is a purely circular magnetic field (∑**S**).

STEM contends that any **electric current**, regardless of it source or transfer medium (i.e. metal conductor or semiconductor), or whether it is AC or DC power, is formed by the **duplex movement** of up-spin and down-spin electrons (i.e. bitrons), with **cetrons** moving from the **negative** terminal (actual or implied) towards the **positive** terminal and **aptrons** moving in the opposite direction.

For a **reverse biased p-n junction**, the bitron movement within the small **drift**-generated current, is quite random and does not involve the formation of strands within the junction itself. For a **forward biased p-n junction**, bitron movement is initially random for the small **diffusion**-generated current, but as the externally applied emf exceeds the **'knee' region** (**V_d** in figure 5), the bitrons align and start to form into **strands** which allows for a significant increase of the current flow. For strongly forward-biased p-n junctions, and all non-semiconductor electrical componentry, an electric current always consists of strand-bound bitrons.

Bitron strands occur naturally within a wire conductor, with 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** by an emf well beyond the barrier voltage. Such strands are thus **dynamically formed** and can involve all the available bitrons. However, once the forward bias is removed, due to the sparseness of the charge carriers within the semiconductor substrates, the strands quickly break up, with random Brownian motion re-establishing itself, which allows the processes of **diffusion** and **drift** to restore **equilibrium**.

Although the thermal velocity of bitrons about 2×10^5 m/sec within silicon substrate, 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. Although the same number of bitrons passes though both the p-n junction and the attached wires, 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 dipolar nature of bitrons, the trailing polar end of a **cetron** can be considered to have positive charge, and when it tries to escape from its host material (a metal foil for example), its positive tail is like-pole repelled by the predominantly positive field generated by the nucleus of the metal atoms: thus it gets a little **push assistance** to help it escape. For an **aptron** the reverse applies: when it tries to escape its trailing negative pole is opposite-pole attracted to the positive field generated by the nucleus of the metal atoms and it is more constrained. The dipolar nature of bitrons thus results in cetrons requiring less than a quarter of the kinetic energy required by aptrons to be able to escape from their host material.

One example of a cetrons requiring less energy to escape from its host than does an aptron is the formation of the p-type and n-type substrates. Within the n-type substrate neutral **phosphorous** dopant atoms preferentially release cetrons rather than aptrons, leaving behind potassium cations and increasing the count of free cetrons (the negative charge carriers). On the other hand **boron** dopant atoms preferentially acquire a cetron to become boron anions, which reduces the number of free cetrons and so increases the relative number of aptrons as the p-type crystal structure settle out.

Other examples of the relative ease of cetron escape from their host medium as free **electrons** are the **photoelectric effect** (i.e. release by photon bombardment), **electron guns** and **cathode ray tubes** (release by the electrical heating of a wire element). However much higher levels of energy is required to provide aptrons with sufficient kinetic energy to escape from their host medium as free **positrons**, with brute-force techniques being required such as the 200 MeV high -energy Large-Scale Collider at 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.

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** with opposite chirality 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.

Cetron-aptron annihilation, the equivalent of electron-positron annihilation of free kintrons and positrons, rarely occurs within semiconductor substrates at normal temperatures and never occurs within metal conductors.

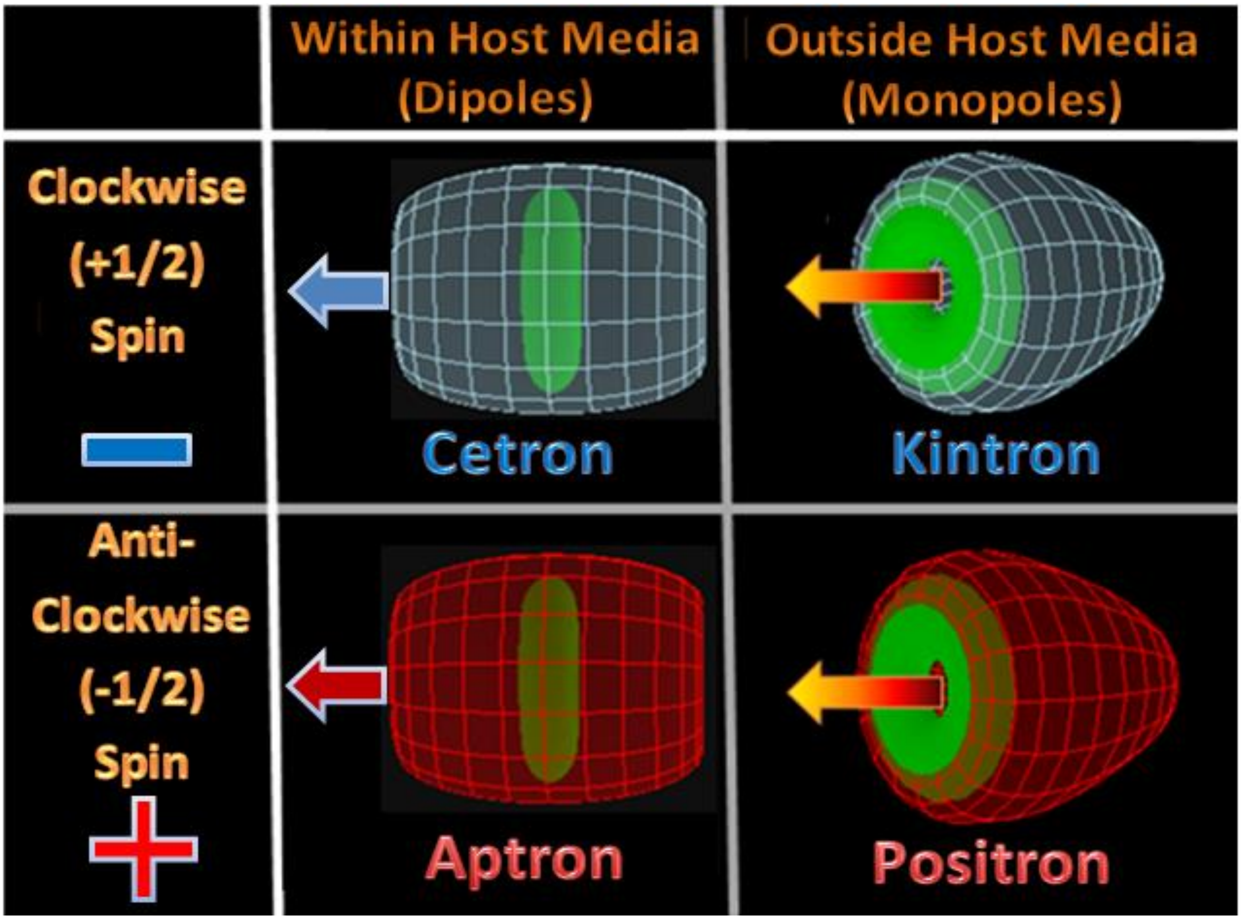

Figure 9: Bitrons and Their Kinetic Forms

Electric Fields

When a pair of metal **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. The increased bitron crowding within energised strands increases the overlap of bitron energy fields, so increasing the central and outer zone energy flow rates of these strands.

The strong concentrated field energy flow through the centre of 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 of field energy that spans the gap between 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**.

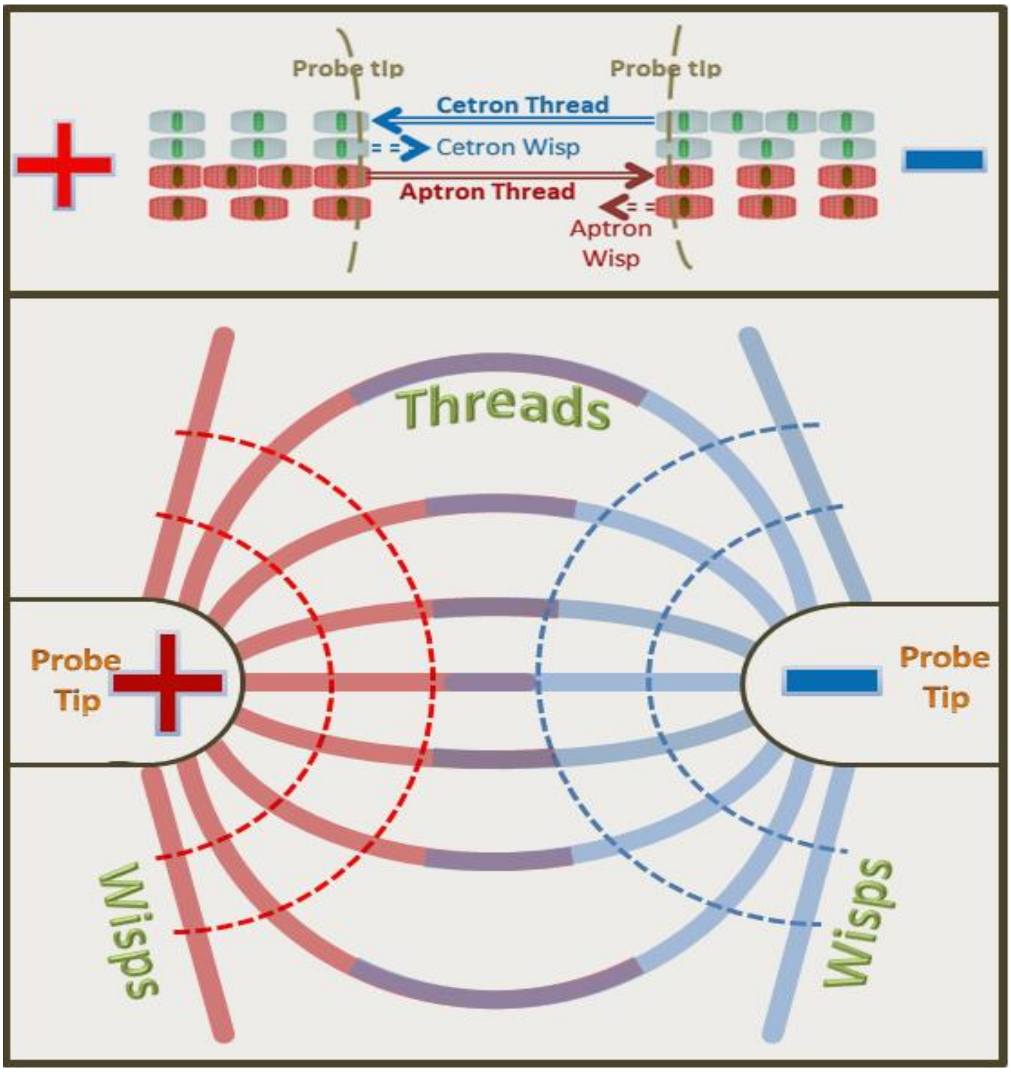

Figure 10: Electric Field Threads and Wisps

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 reasons of aesthetics and clarity, with each red/blue combination representing 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 **oppositely charged** probe tips that are reasonably close, as shown in the lower panel of figure 10, corresponds to conventional Science's **electric field lines of force**. To counter the **energy out-flow** of the central flow zones, and so to maintain an **energy balance**, strands need to retrieve field 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**.

STEM contends that **magnetic fields** consist of the same type of field energy that forms **electric fields** but the two types of field have different characteristics 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 circular magnetic field has no twist or spin aspect: it is simply field energy moving around the wire.

For an electric current carrying wire that has the form of a **loop**, the circular magnetic field generated by duplex movement of cetrons and aptrons around the loop concentrate centrally to generate **implied** North and South poles as shown in figure 11a. The magnetic lines of flux so produced are similar to those that form around a bar magnet. **Coils** consisting of multiple loops simply increase the intensity of the generated magnetic field, as does an increase in the electric current flow rate within the coils.

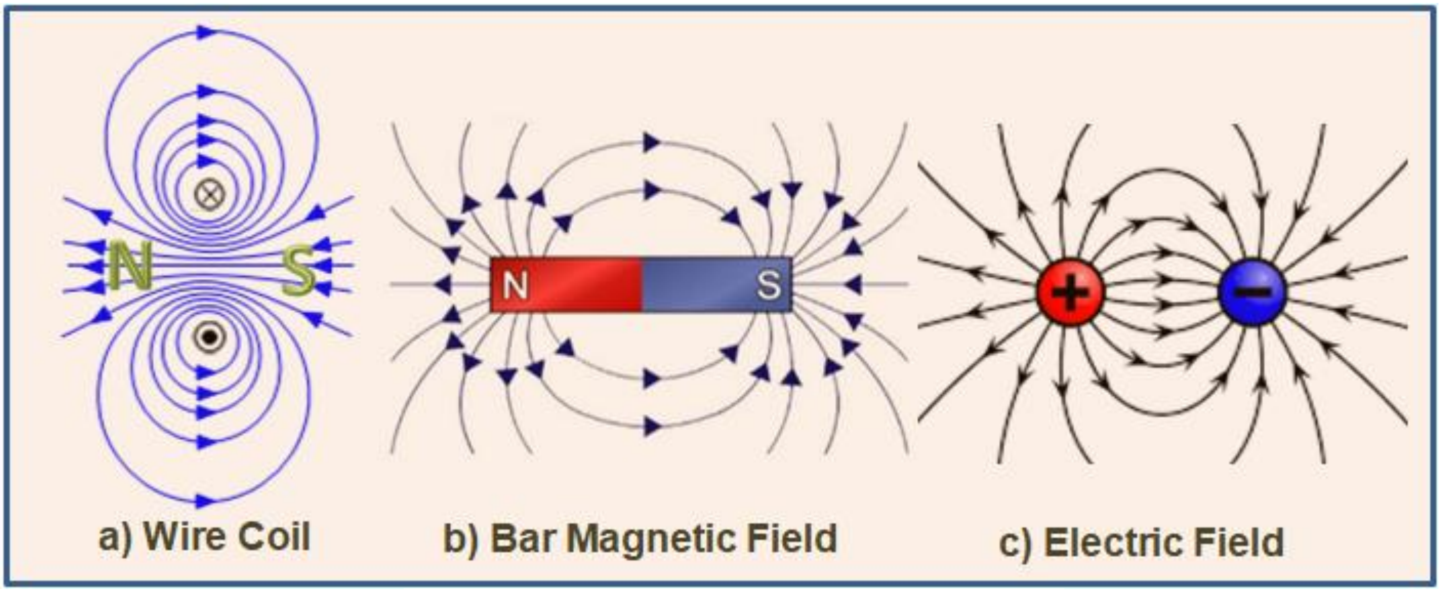

Figure 11: Electric and Magnetic Field Patterns

For **magnetic fields**, the **lines of flux** represent field energy flowing from a **divergent** magnetic North pole to a **convergent** South pole, as shown in figure 11b. The convention for electric fields is to show the **lines of force** moving divergently from a Positive pole and converging towards a Negative pole, as shown in figure 11c. Superficially the divergent flow pattern associated with North poles resembles that Positive poles, and conversely the convergent flows of South poles resemble that of negative poles.

However, as can be seen in the top panel of figure 10, there is two-way movement of field energy in the form of cetron and aptron threads. When the electric charges are of equal strength, the flow in each direction is equal and balanced. A free positive charge (e.g. a free aptron) under the influence of an aptron thread (or wisp) has a compatible chiral form, and moves with it away from the positive charge towards the negative charge (i.e. it receives a push in the flowline direction, but does not necessarily follow the flowline). Hence the **free aptron** can be interpreted as being **repelled** by the **positive charge** and **attracted** by the **negative charge**.

The reverse is true for a free cetron: it will move with a cetron thread (or wisp) away from the negative charge, apparently being repelled by it and being attracted by the positive charge. But electric lines of force only reflect the movement direction of a positive charge which, as stated above, is only half the story: it would be preferable to show no direction of flow as for the STEM lines of force diagrams (figure 10).

Electric field energy, on the other hand, is more complex with a mix of spiralling 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.

Discussion and Summary

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. 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 distinct and very different to each other, clouded the issue.

The **bitron approach** contends that when +1/2 spin and -1/2 spin electrons (collectively referred to as **bitrons**) are released from the valence band of atoms, they represent negative and positive **charge carriers**. This reasoning leads to a comprehensive explanation of electric currents within both semiconductors and metal conductors without a need for **holes**. As an added bonus, it offers a feasible explanation for the formation and nature of **electric fields**.

Bitrons behave differently in different environments. Within a host material, bitrons have a symmetrical energy field that provides 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 (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 distorts its energy field so that it presents as a **monopole** particle: either as a kinetic cetron (a **kintron**) or a kinetic 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 that best explains electron properties and behavioural characteristics, as well as satisfying the Schrodinger and Dirac wave equations, is the **S**pin **T**orus **E**nergy **M**odel (**STEM**). STEM is an **energy-centric** approach which contends that there is only one form of energy, and that electrons 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 which 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 represent negative charge carriers and aptrons positive carriers.

STEM provides 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, to the formation of electric current, and an explanation and comparison of electrical fields and magnetic fields. With STEM and electric current is due to the simultaneous two-way (**duplex**) movement of aptrons and cetrons: within **metal conductors** such movement is within same-spin bitron **strands**. And importantly, the STEM explanation for the electrical characteristics of semiconductors has fewer holes than the current conventional Science explanation.

It is amazing and somewhat ironical that conventional 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.

David L Johnson

Perth, Australia