WHITEPAPER

Unlocking the Power of Spintronics

"Reimagining Electronics with Spin"

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1. Executive Summary

The rise of spintronics-an approach that manipulates the spin of electrons rather than their charge-promises transformative advances in data storage, power efficiency, and device speed. This whitepaper explores recent breakthroughs in p-wave magnetism and their implications for ultrafast, low-power, and scalable spintronic devices. The foundational physics of charge and current, as well as the nature of resistive and inductive loads, are also discussed to contextualize spintronic innovation within traditional electrical systems.

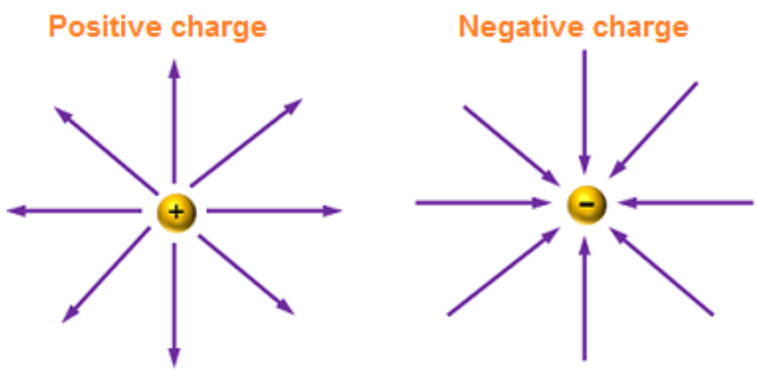
2. Introduction: From Classical Current to Quantum Spin

Conventional electronics rely on the movement of electric charges-primarily electrons and holes-to generate current. The properties of these carriers, governed by atomic structure and energy levels, are the basis for modern circuit design.

a. Electric Current: The flow of charge carrier, mainly electrons in conductors and both electrons and holes in semiconductors.
b. Charge Carriers: Electrons (negative), protons (positive, but immobile), and holes (positive charge carriers in semiconductors).
c. Current Flow: Electron flow is from negative to positive; conventional current direction is defined from positive to negative.

3. What is an electric charge?

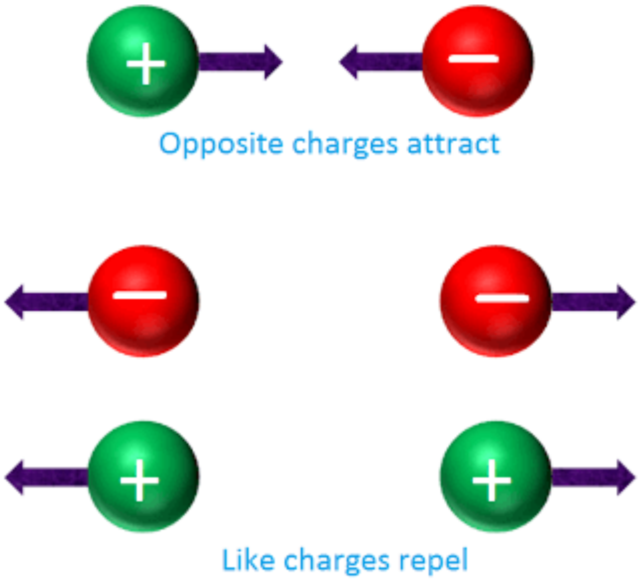
Electric charge is the fundamental property of particles such as electrons and protons. Electric charge can neither be created nor destroyed. That means, if there is an electron or a proton then there is a charge.



Electrons have a negative charge, and protons have a positive charge. Protons are much heavier than electrons. However, the charge of a proton is equal to the charge of an electron.

We know that if two opposite charges are placed close to each other they get attracted. On the other hand, if two same or like charges are placed close to each other they get repelled.

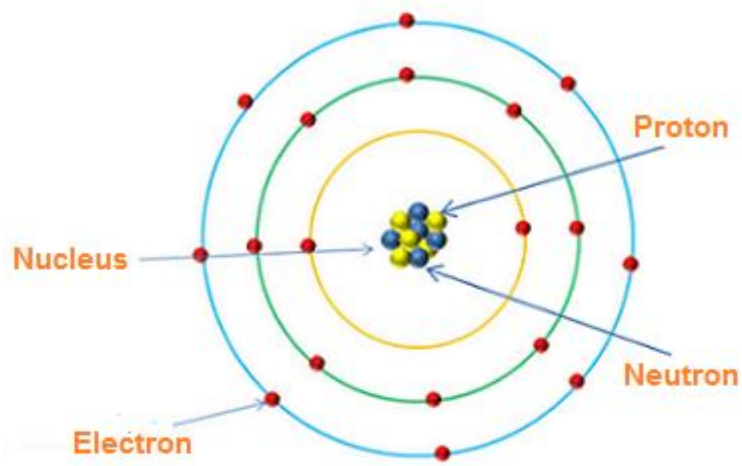
When a proton is placed closer to an electron, they get attracted. On the other hand, when two protons or two electrons are placed close to each other, they get repelled.



4. How electric current is generated?

Atoms are the basic building blocks of matter. Every object in the universe is made up of atoms. Atoms are the tiny particles. Their size is in nanometers.

Each atom consists of subatomic particles such as electrons, protons, and neutrons. These subatomic particles are smaller than the atom.



Electrons are the negatively charged particles, protons are the positively charged particles, and neutrons are the neutral particles (no charge).

Protons and neutrons are much heavier than electrons. So the protons and neutrons always reside at the centre of the atom. The strong nuclear force between the protons and neutrons make them always stick together.

Protons have positive charge and neutrons have no charge. So the overall charge of the nucleus is positive.

Electrons always revolve around the nucleus because of the electrostatic force of attraction between them.

The electrons revolve around the nucleus in different orbits. Each orbit has an energy level associated with it.

The electrons revolving at a close distance from the nucleus have very low energy. On the other hand, the electrons revolving at a greater distance from the nucleus have very high energy.

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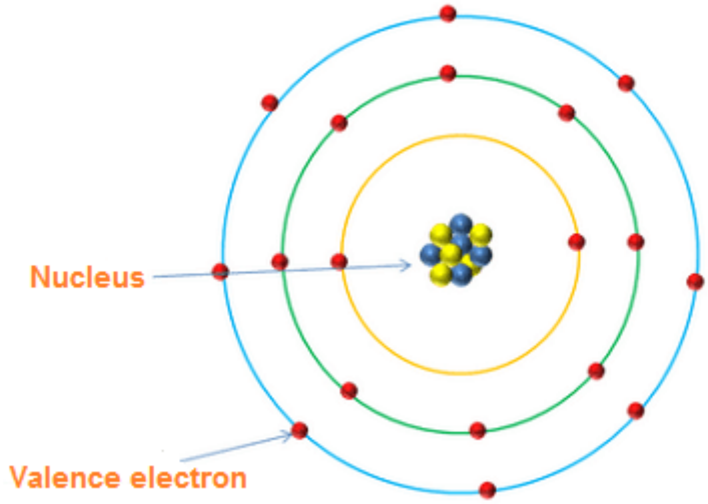
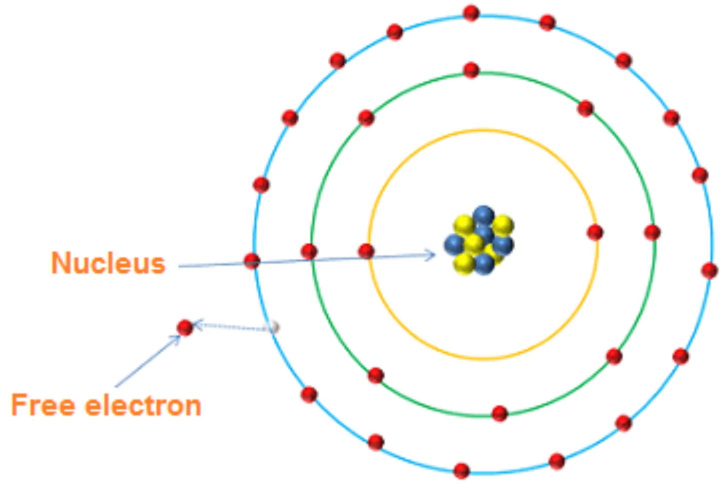


The electrons in the outermost orbit of an atom are called valence electrons. These electrons are very loosely attached to the parent atom. So applying a small amount of energy is enough to make them free from the parent atom.

When a small amount of energy in the form of heat, light, or electric field is supplied to the valence electrons, they gain sufficient energy and then separate from the parent atom.

The electrons that are separated from the parent atom are known as free electrons. These electrons move freely from one place to another place.



We know that electrons have a negative charge. So, the free electrons carry negative charge from one place to another place.

We know that electric current means a flow of charge. So the electrons moving freely from one place to another place will conduct electric current.

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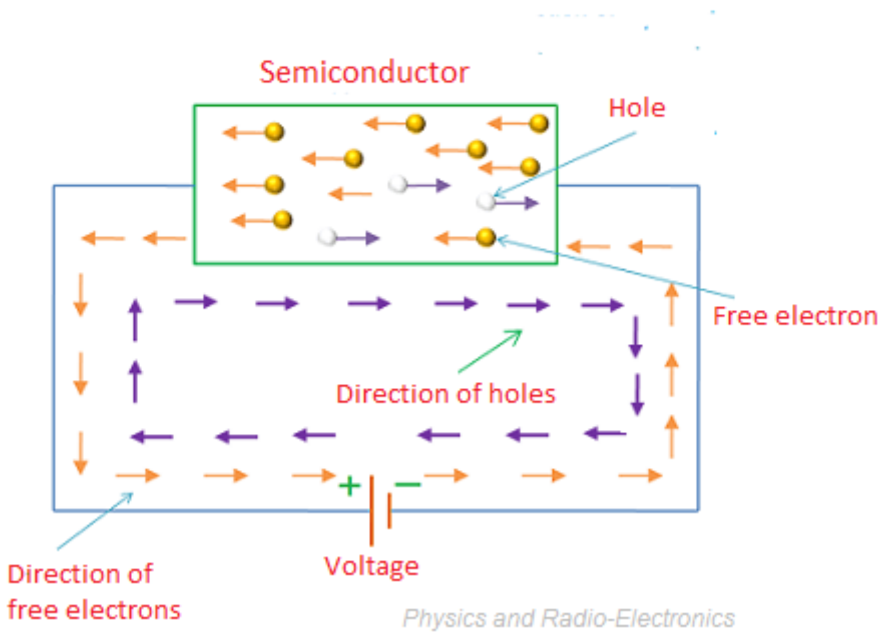
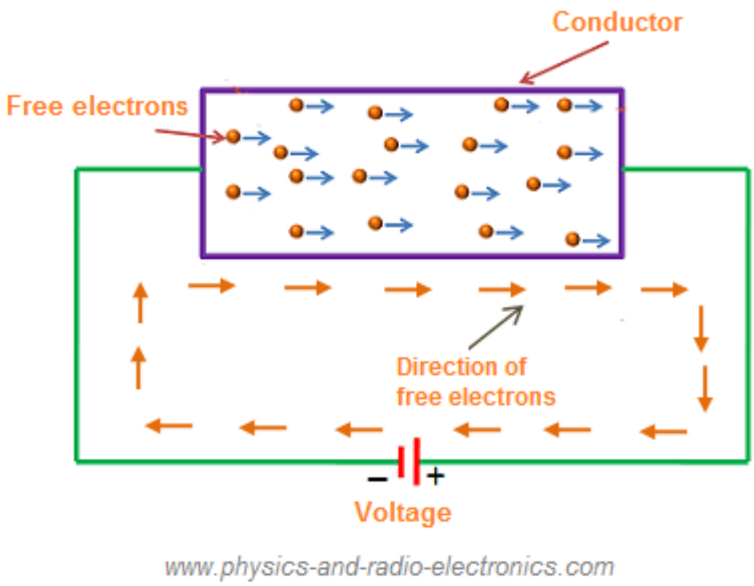


In semiconductors, both free electrons and holes are present. Free electrons are the negatively charged particles. So they carry a negative charge (electric current). Holes are the positively charged particles. So, they carry a positive charge (electric current).

Thus, both free electrons and holes conduct electric current in semiconductors.

In conductors, holes are negligible. So, the free electrons conduct electric current.



Protons also have the ability to conduct electric current. However, protons cannot move freely from one place to another place like electrons. They always held in a fixed position. So the protons do not conduct electric current.

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5. Fundamentals of Electric Charge, Current, and Current Density

Electric current is the rate at which charge flows through a material, typically carried by electrons in conductors and by both electrons and holes in semiconductors. To analyze current behavior in materials, especially in micro- and nanoscale systems, we use the concept of current density.

Current Density (J) is the amount of electric current per unit cross-sectional area:
$J = I / A$

Microscopically, it is expressed as:
$J = nqv_d$

Where:
- n: carrier concentration
- q: charge per carrier
- v_d: drift velocity

This is vital for modeling current in materials like nickel iodide used in spintronic devices.

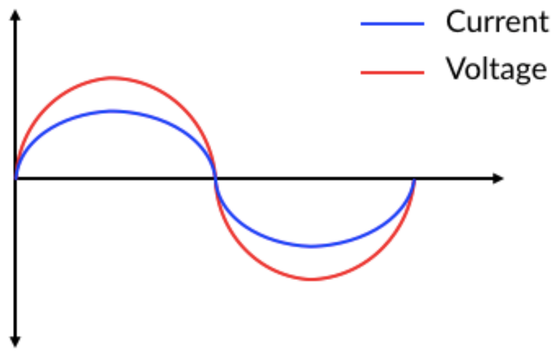
6. Load Characteristics in Electrical Systems

Electrical loads are categorized by how they consume power-either as resistive or inductive. Understanding this is crucial when designing circuits or switching to spintronic alternatives.

Resistive Loads:

a. Consume active power only

b. Voltage and current are in phase



c. Examples: incandescent bulbs, heaters

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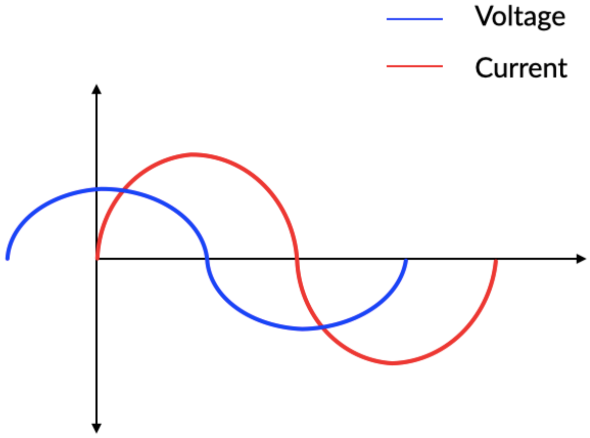
Inductive Loads:

d. Consume reactive power

e. Voltage leads current by 90 degrees



f. Examples: motors, fans, transformers

g. Create switching difficulties due to out-of-phase waveforms

7. Spintronics: Beyond Charge

Spintronics introduces a new paradigm-storing and manipulating data using the spin of electrons, not just their movement. Spin is an intrinsic quantum property, akin to a tiny magnetic orientation (like a compass needle).

a. Ferromagnets: Spins align parallel

b. Antiferromagnets: Spins alternate, canceling out net magnetism

c. Spintronics leverages spin alignment for data storage and transmission

8. Breakthrough in P-Wave Magnetism

Nickel iodide (NiI2) exhibits a new form of magnetism-p-wave magnetism. Electrons in NiI2 form spiral spin structures that can be switched using a small electric field. This enables spin-switching without moving charge, reducing power use drastically.

a. Mirror-image spiral patterns (left- and right-handed)

b. Switchable spin alignment using low-voltage fields

c. Confirmed via circularly polarized light experiments

7. Connecting Classical and Quantum Domains

The evolution from resistive/inductive systems to spintronic devices requires understanding both classical and quantum domains.

Comparison:

Feature	Classical	Spintronic
Carrier	Charge (e-)	Electron spin
Power use	High	Ultra-low
Switching	Slow	Ultra-fast
Heat	Significant	Minimal
Scalability	Limited	Nanoscale possible

8. Spin Direction

It has been found that when the direction of the electric field was in line with the direction of the spin spiral, the effect switched electrons along the route to spin in the same direction, producing a current of like-spinning electrons.

With such a current of spin, you can reduce heat losses. These spintronic effects are more efficient than conventional electronics because you're just moving spins around, rather than moving charges. That means you're not subject to any dissipation effects that generate heat, which is essentially the reason computers heat up.

P-wave magnets could save five orders of magnitude of energy.

9. Conclusion

Spintronics, powered by p-wave magnetism, signals a shift from charge-based electronics to spin-driven devices. With the ability to manipulate spins using low electric fields.

more efficient.

10. References (APA)

Comin, R., et al. (2022). Magnetic behavior of NiI2 in two-dimensional lattices. *Nature Physics*.
Fernandes, R., et al. (2023). Theory of p-wave magnets in layered materials. *Physical Review Letters*.
Song, Z., et al. (2024). Electric-field control of spin spirals in NiI2. *Science Advances*.
Electronics Tutorials. (n.d.). Inductive and Resistive Loads. Retrieved from https://www.electronics-tutorials.ws/
Semiconductor Physics Lecture Notes. (2021). Charge Carriers and Current Density. University Publishing.