Government of Tamil Nadu

Department of Employment and Training

Course : TNPSC Combined Civil Services Examination - IV(Group IV / VAO)

Subject : Physics

Topic : Magnetism, Electricity and Electronics

MAGNETISM, ELECTRICITY AND ELECTRONICS

MAGNETISM

Is a class of physical phenomena that includes force exerted by a magnet on other magnet.

It has its origin in electric currents and the fundamental magnetic moments of elementary particles.

These give rise to a magnetic field that acts on other currents and moments.

Magnetic Field

All materials are influenced to some extent by a magnetic field.

A magnetic field exists in the region surrounding a magnet, in which the force of the magnet can be detected.

Magnet

A compass needle is a small magnet. Its one end, which points towards north, is called a north pole, and the other end which points towards south is called a south pole.

Field lines

Field lines are used to represent a magnetic field. A field line is the path along which a hypothetical free north pole would tend to move.

The direction of the magnetic field at a point is given by the direction that a north pole placed at that point would take.

Field lines are shown closer together where the magnetic field is greater.

A metallic wire carrying an electric current has associated with it a magnetic field.

The field lines about the wire consist of a series of concentric circles whose direction is given by the right hand rule.

Magnetic flux

Magnetic flux is the number of magnetic field lines passing through a given area.

It is denoted by ϕ and its unit is weber (Wb).

Properties of magnetic lines of force

- Magnetic lines of force are closed continuous curves, extending through the body of the magnet.
- Magnetic lines of force start from the North Pole and end at the South Pole.
- Magnetic lines of force never intersect.
- They will be maximum at the poles than at the equator.
- The tangent drawn at any point on the curved line gives the direction of magnetic field.

Electromagnetic Induction

The phenomenon of electromagnetic induction is the production of induced current in a coil placed in a region where the magnetic field changes with time.

The pattern of the magnetic field consists of a core of soft iron wrapped around with a coil of insulated copper wire.

DIAMAGNETISM

Diamagnetism appears in all materials, and is the tendency of a material to oppose an applied magnetic field, and therefore, to be repelled by a magnetic field.

However, in a material with paramagnetic properties (that is, with a tendency to enhance an external magnetic field), the paramagnetic behavior dominates.

Thus, despite its universal occurrence, diamagnetic behavior is observed only in a purely diamagnetic material.

In a diamagnetic material, there are no unpaired electrons, so the intrinsic electron magnetic moments cannot produce any bulk effect.

In these cases, the magnetization arises from the electrons' orbital motions, which can be understood classically as follows:

When a material is put in a magnetic field, the electrons circling the nucleus will experience, in addition to their Coulomb attraction to the nucleus, a Lorentz force from the magnetic field.

Depending on which direction the electron is orbiting, this force may increase the centripetal force on the electrons, pulling them in towards the nucleus, or it may decrease the force, pulling them away from the nucleus.

This effect systematically increases the orbital magnetic moments that were aligned opposite the field, and decreases the ones aligned parallel to the field (in accordance with Lenz's law).

This results in a small bulk magnetic moment, with an opposite direction to the applied field.

In paramagnetic and ferromagnetic substances, the diamagnetic effect is overwhelmed by the much stronger effects caused by the unpaired electrons.

PARAMAGNETISM

In a paramagnetic material there are *unpaired electrons*, i.e. atomic or molecular orbitals with exactly one electron in them.

While paired electrons are required by the Pauli Exclusion Principle to have their intrinsic ('spin') magnetic moments pointing in opposite directions, causing their magnetic fields to cancel out, an unpaired electron is free to align its magnetic moment in any direction.

When an external magnetic field is applied, these magnetic moments will tend to align themselves in the same direction as the applied field, thus reinforcing it.

FERROMAGNETISM

A ferromagnet, like a paramagnetic substance, has unpaired electrons.

However, in *addition* to the electrons' intrinsic magnetic moment's tendency to be parallel to *an applied field*, there is also in these materials a tendency for these magnetic moments to orient parallel to *each other* to maintain a lowered-energy state.

Thus, even when the applied field is removed, the electrons in the material maintain a parallel orientation.

Every ferromagnetic substance has its own individual temperature, called the Curie temperature, or Curie point, above which it loses its ferromagnetic properties.

This is because the thermal tendency to disorder overwhelms the energy-lowering due to ferromagnetic order.

Some well-known ferromagnetic materials that exhibit easily detectable magnetic properties (to form magnets) are nickel, iron, cobalt, gadolinium and their alloys.

FERRIMAGNETIC ORDERING

Like ferromagnetism, ferrimagnets retain their magnetization in the absence of a field.

However, like antiferromagnets, neighbouring pairs of electron spins like to point in opposite directions.

These two properties are not contradictory, because in the optimal geometrical arrangement, there is more magnetic moment from the sublattice of electrons that point in one direction, than from the sublattice that point in the opposite direction.

Most ferrites are ferrimagnetic. The first discovered magnetic substance, magnetite, is a ferrite and was originally believed to be a ferromagnet; Louis Néel disproved this, however, after discovering ferrimagnetism.

SUPERPARAMAGNETISM

When a ferromagnet or ferrimagnet is sufficiently small, it acts like a single magnetic spin that is subject to Brownian motion.

Its response to a magnetic field is qualitatively similar to the response of a paramagnet, but much larger.

ELECTROMAGNET

An electromagnet is a type of magnet whose magnetism is produced by the flow of electric current.

The magnetic field disappears when the current ceases.

Electromagnet attracts a paper clip when current is applied creating a magnetic field.

The electromagnet loses them when current and magnetic field are removed.

Applications of Electromagnets

Electromagnetism has created a great revolution in the field of engineering applications. In addition, this has caused a great impact on various fields such as medicine, industries, space etc.

1. Speaker

Inside the speaker, the electromagnet is placed in front of a permanent magnet. The permanent magnet is fixed firmly in position whereas the electromagnet is mobile. As pulses of electricity pass through the coil of the electromagnet, the direction of its magnetic field is rapidly changed. This means that it is in turn attracted to and repelled from the permanent magnet vibrating back and forth.

The electromagnet is attached to a cone made of a flexible material such as paper or plastic which amplifies these vibrations, pumping sound waves into the surrounding air towards our ears. An electric bell contains an electromagnet, consisting of coils of insulated wire wound around iron rods. When an electric current flows though the coils, the rods become magnetic and attract a piece of iron attached to a clapper. The clapper hits the bell and makes it ring.

2. Magnetic Levitation Trains

Magnetic levitation (Maglev) is a method by which an object is suspended with no support other than magnetic fields. In maglev trains two sets of magnets are used, one set to repel and push the train up off the track, then another set to move the floating train ahead at great speed without friction. In this technology, there is no moving part. The train travels along a guideway of magnets which controls the train’s stability and speed using the basic principles of magnets.

3. Medical System

Medical equipments such as hyperthermia treatments for cancer, implants and magnetic resonance imaging (MRI) are using electromagnets. In a, sophisticated equipments working based on the electromagnetism can scan minute details of the human body.

Many of the medical equipments such as scanners, x-ray equipments and other equipments also use principle of electromagnetism for their functioning.

OTHER TYPES OF MAGNETISM

- Molecular magnet
- Metamagnetism
- Molecule-based magnet
- Spin glass

MAGNETIC DIPOLES

A very common source of magnetic field shown in nature is a dipole, with a "South pole" and a "North pole", terms dating back to the use of magnets as compasses, interacting with the Earth's magnetic field to indicate North and South on the globe.

Since opposite ends of magnets are attracted, the north pole of a magnet is attracted to the south pole of another magnet.

The Earth's North Magnetic Pole (currently in the Arctic Ocean, north of Canada) is physically a south pole, as it attracts the north pole of a compass.

A magnetic field contains energy, and physical systems move toward configurations with lower energy.

When diamagnetic material is placed in a magnetic field, a *magnetic dipole* tends to align itself in opposed polarity to that field, thereby lowering the net field strength. When ferromagnetic material is placed within a magnetic field, the magnetic dipoles align to the applied field, thus expanding the domain walls of the magnetic domains.

MAGNETIC MONOPOLES

Since a bar magnet gets its ferromagnetism from electrons distributed evenly throughout the bar, when a bar magnet is cut in half, each of the resulting pieces is a smaller bar magnet.

Eventhough a magnet is said to have a north pole and a south pole, these two poles cannot be separated from each other.

A monopole — if such a thing exists — would be a new and fundamentally different kind of magnetic object.

It would act as an isolated north pole, not attached to a south pole, or vice versa.

Monopoles would carry "magnetic charge" analogous to electric charge.

Magnetoception

Some organisms can detect magnetic fields, a phenomenon known as magnetoception.

Magnetobiology studies magnetic fields as a medical treatment; fields naturally produced by an organism are known as biomagnetism.

ELECTRICITY

A stream of electrons moving through a conductor constitutes an electric current.

Conventionally, the direction of current is taken opposite to the direction of flow of electrons.

Electric charges

Inside each atom there is a nucleus with positively charged protons and chargeless neutrons and negatively charged electrons orbiting the nucleus.

Usually there are as many electrons as there are protons and the atoms themselves are neutral.

As electrons are revolving in the orbits of an atom, they can be easily removed from an atom and also added to it.

If an electron is removed from the atom, the atom becomes positively charged. Then it becomes a positive ion.

If an electron is added in excess to an atom then the atom is negatively charged. This atom is called negative ion.

Electric charge is measured in coulomb and the symbol for the same is C.

Electric force

Among electric charges there are two types of electric force (F). One is attractive and another is repulsive. The like charges repel and unlike charges attract. **The force existing between the charges is called as 'electric force'.**

Electric field

The region in which a charge experiences electric force forms the 'electric field' around the charge.

'Electric Lines Of Force'

The electric lines of force are straight or curved paths along which a unit positive charge tends to move in the electric field.

Electric lines of force are imaginary lines. The strength of an electric field is represented by how close the field lines are to one another.

Electric potential

Electric potential is a measure of the work done on unit positive charge to bring it to that point against all electrical forces.

Electric current

When the charged object is provided with a conducting path, electrons start to flow through the path from higher potential to lower potential region.

Normally, the potential difference is produced by a cell or battery.

When the electrons move, we say that an electric current is produced. That is, an electric current is formed by moving electrons.

The SI unit of electric current is ampere.

Ammeter is an instrument used to measure the strength of the electric current.

Electromotive force (e.m.f)

The e.m.f of an electrical energy source is one volt if one joule of work is done by the source to drive one coulomb of charge completely around the circuit.

Potential difference

For each coulomb of charge passing through any appliances, the amount of electrical energy converted to other forms of energy depends on the potential difference across the electrical device or any electrical component in the circuit. The potential difference is represented by the symbol V.

$$V = W/q$$

where, W is the work done, that is the amount of electrical energy converted into other forms of energy measured in joule and q is amount of charge measured in coulomb.

The SI unit for both e.m.f and potential difference is the same in volt (V).

Resistance

Resistance is a property that resists the flow of electrons in a conductor.

It controls the magnitude of the current.

The SI unit of resistance is ohm.

OHM'S LAW

The potential difference across the ends of a resistor is directly proportional to the current through it, provided its temperature remains the same.

$$V = IR$$

Where,V – Potential difference, I – Current and R – Resistance which is constant.

The resistance of a conductor depends directly on its length, inversely on its area of cross section, and also on the material of the conductor.

The equivalent resistance of several resistors in series is equal to the sum of their individual resistances.

A set of resistors connected in parallel has an equivalent resistance Rp given by

$$1/R_p=1/R_1+1/R_2+1/R_3+\ldots$$

The electrical energy dissipated in a resistor is given by

$$W= V \times I \times t$$

The unit of power is watt (W).

One watt of power is consumed when 1A of current flows at a potential difference of 1 V. The commercial unit of electrical energy is kilowatt hour(kWh).

$$1kWh= 3600000\ J=3.6 \times 10^6\ J.$$

Joule's Law of Heating

Joule's law of heating states that the heat produced in any resistor is:

- directly proportional to the square of the current passing through the resistor.
- directly proportional to the resistance of the resistor.
- directly proportional to the time for which the current is passing through the resistor.

ELECTRIC POWER

In general, power is defined as the rate of doing work or rate of spending energy.

Similarly, the electric power is defined as the rate of consumption of electrical energy. It represents the rate at which the electrical energy is converted into some other form of energy.

The SI unit of electric power is watt.

Resistor

Used to fix the magnitude of the current through a circuit

Variable resistor or Rheostat

Used to select the magnitude of the current through a circuit.

Voltmeter

Used to measure the potential difference.

Galvanometer

Used to indicate the direction of current.

A diode

A diode has various uses, which you will study in higher classes.

Light Emitting Diode (LED)

A LED has various uses which you will study in higher classes.

Potentiometer

The Potentiometer is an instrument used for the measurement of potential difference.

ELECTRONICS

Electronics is that field of science which deals with the motion of electrons under the influence of applied electric and/or magnetic field. Electronics can be classified into two branches: Physical Electronics and Electronics Engineering.

Physical electronics deals with the motion of electronics in a vacuum, gas or semiconductor.

Electronics has evolved around three components; vacuum tubes, transistor, and integrated circuits.

Electron

Electron is a subatomic particle, with negative elementary electric charge. The electron is one of the fundamental particles constituting the atom. The charge of an electron is negative and is denoted by ‘e’. The magnitude of e is 1.6 x 10^{19}coulomb.

Semiconductor Materials

In general, semiconductors are special class of elements having a conductivity between that of a good conductor and that of an insulator.

Semiconductor materials fall into one of two classes: Single crystal and Compound.

Single crystal semiconductor such as germanium (GE) and silicon (Si) have a repetitive crystal structure, whereas compound semiconductors such as gallium arsenide (GaAs), cadmium sulphide (CdS),gallium nitride (GaN), and gallium arsenide phosphide (GaAsP) are constructed of two or more semiconductor materials of different atomic structure.

The three semiconductors used most frequently in the construction of electronic device are Ge, Si, and GaAs.

Intrinsic Semiconductor

An extremely pure semiconductor is called intrinsic semiconductor.

Extrinsic Semiconductor

Although an intrinsic semiconductor is capable to conduct a little current even at room temperature but as it is, it is not useful for the preparation of various electronic devices. To make it conductive a small amount of suitable impurity is added. It is then called extrinsic (impure) semiconductor.

Doping :

The process by which an impurity is added to a semiconductor is known as doping.

The amount and type of such impurities have to be closely controlled during the preparation of extrinsic semiconductor.

Generally one impurity atom is added to 10^8 atoms of a semiconductor.

Thus, a semiconductor to which an impurity at controlled rate is added to make it conductive is known as an extrinsic semiconductor.

Depending upon the type of impurity added extrinsic semiconductor may be classified as :

(i) n- type semiconductor

(ii) p-type semiconductor.

PN Junction Diode (Semiconductor Diode)

It is also known as crystal diode since it is grown out of a crystal (like germanium of silicon).

A semiconductor diode has two terminals. Its symbol is shown in fig.-6. It conducts only when it is forward biased i.e when terminal connected with overhead is at higher potential than the terminal connected to the bar. However when it is reversed biased practically it does not conduct any current through it.

Zener Diode

A specially designed silicon diode which is optimised to operate in the breakdown region is known as as zener diode.

Application

(i)Meter Protection

(ii)Voltage Regulator

(iii) Wave Shaping Circuit

Photo Diode

When light energy falls on a pn junction, it also imparts energy to dislodge valence electron. In other words the amount of light striking on the junction can control the reverse current in a diode. A diode that is optimised for its sensitivity to light is known as photo diode.

LED (Light Emitting Diode)

When a diode is forward biased the potential barrier is lowered. The conduction band free electrons from n- region cross the barrier and enter the p-region, as these electrons enter the p- region they fall into the holes lying in the valence band. Hence they fall from a higher energy level to a lower energy level in the process they radiate energy.

The LED are different. These are made of gallium arsenide phosphide (GaAsP) and gallium phosphide (GaP).

In LED the energy is radiated in the form of light and hence they glow. A manufacturer can produce LED that radiate red, green, yellow, blue, orange light.

Application:

Instrument display, panel indicators, digital watches, calculator etc

Points to Remember:

- Magnetic field lines do not intersect.
- Two parallel wires carrying current in the same directions attract each other.
- Two parallel wires carrying current in the opposite directions repel each other.
- Direction of the force in a current carrying conductor is determined by Fleming’s Left Hand Rule.
- Electric motor is a device which converts electrical energy into mechanical energy.
- Direction of induced current in a conductor is determined by Fleming’s Right Hand Rule.
- Electric generator is a device used to convert mechanical energy into electrical energy.
- Electric generator works on the principle of electromagnetic induction.

- Transformer is a device which converts low alternating current to high alternating current and vice versa.
- Transformer transfers electric power from one circuit to another.
- The four main components of any circuit are: cell, connecting wire, switch and resistor.
- In a parallel circuit there is more than one path for the electric charge to flow.
- The main effects when current flows in a circuit are heating, chemical and magnetic effects.
- There are two distinct types of electric currents that we encounter in our everyday life: direct current (dc) and alternating current (ac).