Introduction: Magnetism & Electromagnetism

Unit: Magnetism & Electromagnetism

Topics covered in this chapter:

This chapter discusses electricity and magnetism, how they behave, and how they relate to each other.

- *Magnetism* describes properties of magnets and what causes objects to be magnetic.
- *Magnetic Fields & Magnetic Flux* explains magnetic fields and magnetic flux and how it is calculated.
- *Electromagnetism* describes the relationship between electric fields and magnetic fields, and how changes in one induce changes in the other.
- *Devices that Use Electromagnetism* lists devices that combine electricity and magnetism and explains how they work.

One of the challenges encountered in this chapter is understanding which set of equations applies to a given situation.

Standards addressed in this chapter:

NGSS Standards/MA Curriculum Frameworks (2016):

HS-PS2-5. Provide evidence that an electric current can produce a magnetic field and that a changing magnetic field can produce an electric current.

HS-PS3-5. Develop and use a model of magnetic or electric fields to illustrate the forces and changes in energy between two magnetically or electrically charged objects changing relative position in a magnetic or electric field, respectively.

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AP® Physics 2 Learning Objectives/Essential Knowledge (2024):

12.1.A: Describe the properties of a magnetic field.

12.1.A.1: A magnetic field is a vector field that can be used to determine the magnetic force exerted on moving electric charges, electric currents, or magnetic materials.

12.1.A.1.i: Magnetic fields can be produced by magnetic dipoles or combinations of dipoles, but never by monopoles.

12.1.A.1.ii: Magnetic dipoles have north and south polarity.

12.1.A.2: A magnetic field is a vector quantity and can be represented using vector field maps.

12.1.A.2.i: Magnetic field lines form closed loops.

12.1.A.2.ii: Magnetic fields in a bar magnet form closed loops, with the external magnetic field pointing away from one end (defined as the north pole) and returning to the other end (defined as the south pole).

12.1.B: Describe the magnetic behavior of a material as a result of the configuration of magnetic dipoles in the material.

12.1.B.1: Magnetic dipoles result from the circular or rotational motion of electric charges. In magnetic materials, this can be the motion of electrons.

12.1.B.1.i: Permanent magnetism and induced magnetism are system properties that both result from the alignment of magnetic dipoles within a system.

12.1.B.1.ii: No magnetic north pole is ever found in isolation from a south pole. For example, if a bar magnet is broken in half, both halves are magnetic dipoles.

12.1.B.1.iii: Magnetic poles of the same polarity will repel; magnetic poles of opposite polarity will attract.

12.1.B.1.iv: The magnitude of the magnetic field from a magnetic dipole decreases with increasing distance from the dipole.

12.1.B.2: A magnetic dipole, such as a magnetic compass, placed in a magnetic field will tend to align with the magnetic field.

12.1.B.3: A material's composition influences its magnetic behavior in the presence of an external magnetic field.

12.1.B.3.i: Ferromagnetic materials such as iron, nickel, and cobalt can be permanently magnetized by an external field that causes the alignment of magnetic domains or atomic magnetic dipoles.

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12.1.B.3.ii: Paramagnetic materials such as aluminum, titanium, and magnesium interact weakly with an external magnetic field, in that the magnetic dipoles of the material do not remain aligned after the external field is removed.

12.1.B.3.iii: All materials have the property of diamagnetism, in that their electronic structure creates a usually weak alignment of the dipole moments of the material opposite the external magnetic field.

12.1.B.4: Earth's magnetic field may be approximated as a magnetic dipole.

12.1.C: Describe the magnetic permeability of a material.

12.1.C.1: Magnetic permeability is a measurement of the amount of magnetization in a material in response to an external magnetic field.

12.1.C.2: Free space has a constant value of magnetic permeability, known as the vacuum permeability μ_o, that appears in equations epresenting physical relationships.

12.1.C.3: The permeability of matter has values different from that of free space and arises from the matter's composition and arrangement. It is not a constant for a material and varies based on many factors, including temperature, orientation, and strength of the external field.

12.2.A: Describe the magnetic field produced by moving charged objects.

12.2.A.1: A single moving charged object produces a magnetic field.

12.2.A.1.i: The magnetic field at a particular point produced by a moving charged object depends on the object's velocity and the distance between the point and the object.

12.2.A.1.ii: At a point in space, the direction of the magnetic field produced by a moving charged object is perpendicular to both the velocity of the object and the position vector from the object to that point in space and can be determined using the right-hand rule.

12.2.A.1.iii: The magnitude of the magnetic field is a maximum when the velocity vector and the position vector from the object to that point in space are perpendicular.

12.2.B: Describe the force exerted on moving charged objects by a magnetic field.

12.2.B.1: Magnetic forces describe interactions between moving charged objects.

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12.2.B.2: A magnetic field may exert a force on a charged object moving in that field.

12.2.B.2.i: The magnitude of the force exerted by a magnetic field on a moving charged object is proportional to the magnitude of the charge, the magnitude of the charged object's velocity, and the magnitude of the magnetic field and also depends on the angle between the velocity and magnetic field vectors.

12.2.B.2.ii: The direction of the force exerted by a magnetic field on a moving charged object is perpendicular to both the direction of the magnetic field and the velocity of the charge, as defined by the right-hand rule.

12.2.B.3: In a region containing both a magnetic field and an electric field, a moving charged object will experience independent forces from each field.

12.2.B.4: The Hall effect describes the potential difference created in a conductor by an external magnetic field that has a component perpendicular to the direction of charges moving in the conductor.

12.3.A: Describe the magnetic field produced by a current-carrying wire.

12.3.A.1: A current-carrying wire produces a magnetic field.

12.3.A.1.i: The magnetic field vectors around a long, straight, current-carrying wire are tangent to concentric circles centered on that wire. The field has no component toward, away from, or parallel to the long, straight, current-carrying wire.

12.3.A.1.ii: At a point in space, the magnitude of the magnetic field due to a long, straight, current-carrying wire is proportional to the magnitude of the current in the wire and inversely proportional to the perpendicular distance from the central axis of the wire to the point.

12.3.A.1.iii: The direction of the magnetic field created by a current-carrying wire is determined with the right-hand rule.

12.3.A.1.iv: The direction of the magnetic field at the center of a current-carrying loop is directed along the axis of the loop and can be found using the right-hand rule.

12.3.A.1.v: The magnetic field at a location near two or more current-carrying wires can be determined using vector addition principles.

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12.3.B: Describe the force exerted on a current-carrying wire by a magnetic field.

12.3.B.1: A magnetic field may exert a force on a currentcarrying wire.

12.3.B.1.i: The magnitude of the force exerted by a magnetic field on a current-carrying wire is proportional to the current, the length of the portion of the wire within the magnetic field, and the magnitude of the magnetic field, and also depends on the angle between the direction of the current in the wire and the direction of the magnetic field.

12.3.B.1.ii: The direction of the force exerted by the magnetic field on a current-carrying wire is determined by the right-hand rule.

12.4.A: Describe the induced electric potential difference resulting from a change in magnetic flux.

12.4.A.1: Magnetic flux is a description of the amount of the component of a magnetic field that is perpendicular to a cross-sectional area.

12.4.A.2: Magnetic flux through a surface is proportional to the magnitude of the component of the magnetic field perpendicular to the surface and to the cross-sectional area of the surface.

12.4.A.2.i: The area vector is defined to be perpendicular to the plane of the surface and directed outward from a closed surface.

12.4.A.2.ii: The sign of the magnetic flux indicates whether the magnetic field is parallel to or antiparallel to the area vector.

12.4.A.3: Faraday's law describes the relationship between changing magnetic flux and the resulting induced emf in a system.

12.4.A.4: Lenz's law is used to determine the direction of an induced emf resulting from a changing magnetic flux.

12.4.A.4.i: An induced emf generates a current that creates a magnetic field that opposes the change in magnetic flux.

12.4.A.4.ii: The right-hand rule is used to determine the relationships between current, emf, and magnetic flux.

12.4.A.5: A common example of electromagnetic induction is a conducting rod on conducting rails in a region with a uniform magnetic field.

Skills learned & applied in this chapter:

- Working with material-specific constants from a table.