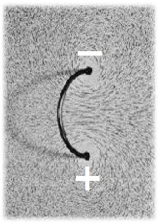
SPH3U UNIVERSITY PHYSICS

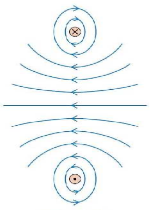
ELECTRICITY & MAGNETISM

☞ Magnetic Field of a Coil (P.559-562)

Magnetic Field of a Loop

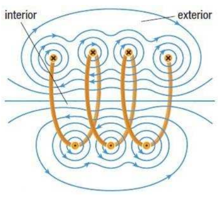
The magnetic field around a straight conductor can be intensified by bending the wire into a loop. Note that in the centre of the loop, the magnetic field points straight through. The positive and negative signs denote the direction of the conventional current from positive to negative.

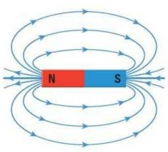




Magnetic Field of a Solenoid

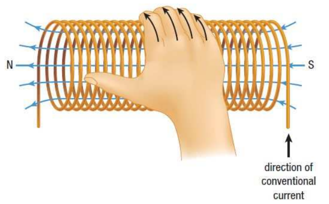
The magnetic field can be further intensified by combining the effects of a large number of loops wound close together to form a coil, or ***solenoid****. The circular magnetic fields around each loop combine to form an overall magnetic field that is a close approximation to the magnetic field of a bar magnet. The magnetic field is strongest at the poles or ends of the coils and is weakest at the sides.*





Right-Hand Rule for a Solenoid

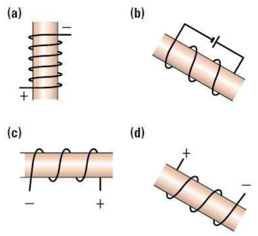
There is another right-hand rule to help you remember the relationship between the direction of the conventional current through a coil and the direction of the coil's magnetic field The ***right-hand rule for a solenoid*** *states that if the fingers of your right hand wrap around a coil in the direction of the conventional current, your thumb will point in the direction of the north magnetic pole of the coil.*



Magnetic Field of a Solenoid

PRACTICE

1. The following diagram shows coils of wire wound on cardboard cylinders. Copy the diagrams into your notebook, and on each diagram mark:
   (i) the direction of electric current, and
   (ii) the N-pole and S-pole of the coil.

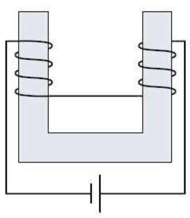


Magnetic Field of a Solenoid

PRACTICE

2. Determine the polarity of the poles of the electromagnet shown.

   N S

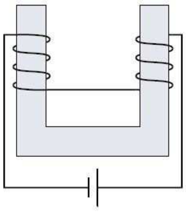


Magnetic Field of a Solenoid

PRACTICE

3. What happens if the current flow through the coil is reversed?

   the direction of the field lines (and thus the poles) is also reversed



Solenoids

Solenoids are important because not only can the magnetic field they create be turned on or off, but the strength and direction of the magnetic field can also be changed. For example,

1. *the magnetic field strength varies directly with the current in the coil: doubling the current doubles the magnetic field strength (i.e.* $F \propto I$*)*
2. *the magnetic field strength varies directly as the number of loops per unit length: doubling the number of loops doubles the magnetic field strength (i.e.* $F \propto N$*)*
3. *the magnetic field strength varies directly as the permeability of its core material: doubling the relative magnetic permeability of the core material doubles the magnetic field strength (i.e.* $F \propto \mu$*)*

Solenoids

SOLENOID (ELECTROMAGNET)

- loop of wire that produces a magnetic field when an electric current passes through it
- useful because the magnetic field created can be controlled
  - can be turned on or off
  - direction can be changed by changing the direction of current
  - strength can be changed by changing:
    (i) the number of loops ($F \propto N$)
    (ii) the current ($F \propto I$)
    (iii) the core material ($F \propto \mu$)

Solenoids

PRACTICE

4. Calculate the effect on the strength of the magnetic field in a coil when each of the following separate changes is made:
   (a) the current in the coil is increased from 2.0 A to 5.0 A;
   (b) the number of loops in the coil is changed from 4400 to 1100; the length of the coil is unchanged;
   (c) the core is changed from steel with a relative magnetic permeability of 3000 to iron with a relative magnetic permeability of 8000.

   (a) x 2.5 ☞ 5.0/2.0
   (b) x 0.25 ☞ 1100/4400
   (c) x 2.7 ☞ 8000/3000

Solenoids

PRACTICE

5. An electromagnet is able to exert a force of 150 N when lifting an object. The electromagnet has 1000 turns, a current of 1.5 A, and a material in the core with a relative magnetic permeability of 2000. What force will the electromagnet exert if the following changes are made, each considered separately?
   (a) The current is increased to 6.0 A?

   (a) 600 N

Solenoids

PRACTICE

5. An electromagnet is able to exert a force of 150 N when lifting an object. The electromagnet has 1000 turns, a current of 1.5 A, and a material in the core with a relative magnetic permeability of 2000. What force will the electromagnet exert if the following changes are made, each considered separately?
   (b) The number of turns in the coil is increased to 1400 without increasing the length of the coil.

   (b) 210 N

Solenoids

PRACTICE

5. An electromagnet is able to exert a force of 150 N when lifting an object. The electromagnet has 1000 turns, a current of 1.5 A, and a material in the core with a relative magnetic permeability of 2000. What force will the electromagnet exert if the following changes are made, each considered separately?
   (c) Both (a) and (b) simultaneously.

   (c) 840 N

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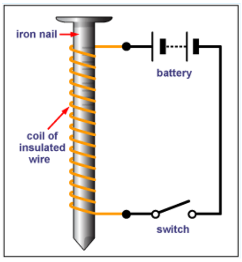
Applications of Solenoids

A solenoid has many uses because it operates like a bar magnet, but it can be switched on and off. So a solenoid can be used to turn things on and off, pick up things and to then let go, or to cause motion and then reverse the motion. Solenoids are used in many devices, such as audio speakers, electric bells, and cars.



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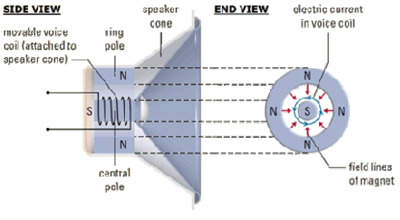
Applications of … – Subwoofers

The subwoofer has a cone made from paper or plastic that quickly moves outward to cause a compression and then quickly moves inward to cause a rarefaction. To move the cone, a permanent circular magnet surrounds a solenoid called the voice coil (which is connected to the cone). Current is directed through the voice coil by an amplifier.



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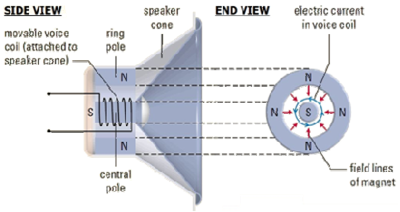
Applications of … – Subwoofers

This current produces a magnetic field that repels the voice coil and the cone away from the magnet. The amplifier then reverses the direction of the current and produces a magnetic field that attracts the voice coil and the cone towards the magnet. This process repeats continually, producing compressions and rarefactions to create sound.



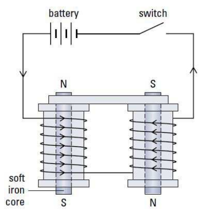
Applications of … – Lifting Electromagnet

Large steel plates, girders, and pieces of scrap iron can be lifted and transported by a lifting electromagnet. A soft ferromagnetic core of high relative magnetic permeability is wound with a copper conductor. The ends of the coil are connected to a source of electric potential through a switch. Closing the switch causes an electric current in the coil, and the soft iron core becomes a very strong induced magnet.

Applications of … – Lifting Electromagnet

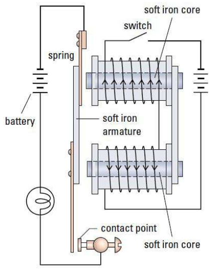
When the switch is opened and the electric current stops, the soft iron core becomes demagnetized and releases its load.

NOTE!
A U-shaped core is often used, with a coil wrapped around each leg of the device. If the coils are wound in opposite directions, the legs become oppositely magnetized and the lifting ability of the magnet is doubled.



Applications of Solenoids – Electromagnetic Relay

A relay is a device in which a switch is closed by the action of an electromagnet. When the switch is closed, current is directed to the solenoids, and the soft iron U-shaped core becomes magnetized. The magnetized core attracts the soft iron armature and pulls it to the right until it touches the contact point, completing the circuit. Now there is a current in the left-hand circuit, and the lamp goes on.

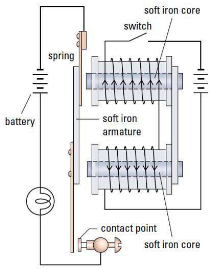


Applications of … – Electromagnetic Relay

When the switch is opened, the electric current drops to zero, the core becomes demagnetized, and the armature is released. When the spring pulls the armature away form the contact point, current drops to zero in the left-hand circuit and the lamp goes off.

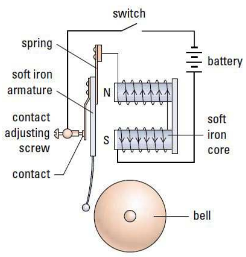
NOTE!

There are many places in cars where an electromagnet is used – the starter, the automatic door locks, the transmission, …



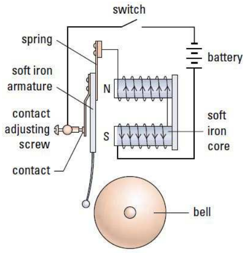
Applications of … – Electric Bell

In an electric bell, when the switch is closed, an electric current flows through the contacts and the spring to the solenoids, and the soft iron cores become magnetized. The cores attract the iron armature, which moves toward the electromagnet, causing the hammer to strike the bell. As the hammer strikes the bell, the movement of the armature opens the contacts and the circuit is broken.



Applications of … – Electric Bell

As a result, the electric current stops flowing to the coils and the soft iron cores become demagnetized, releasing the armature. A spring pulls the armature back to re-establish contact, thereby completing the circuit, and the entire cycles begins again. Small sparks, evidence of charge jumping across the gap, can be observed at the contact points as the circuit is alternately completed and broken.



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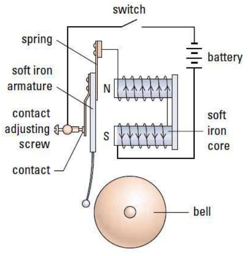
Applications of … – Electric Bell

PRACTICE

6. Describe how you could adapt an electric bell to become a flashing light. Explain or draw your diagram of your adaptation.



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Applications of Solenoids

SOLENOIDS (continued …)

- used in many technologies including:
  - subwoofers
  - electric bells
  - car starter motors
  - car-door locking/unlocking mechanism

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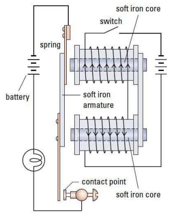
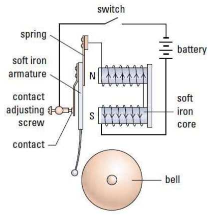
Applications of Solenoids

PRACTICE

7. In both electromagnetic relays and doorbells, soft iron cores are used in the solenoids. If a hard iron core is used, what would happen in:
   (a) a relay that is used to turn a light on and off.
   (b) an electric bell.

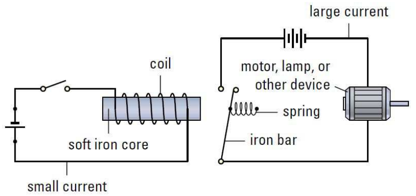




Applications of Solenoids

PRACTICE

8. The diagram below shows one design of an electric relay. Describe the sequence of events that occur when the switch in the left-hand circuit is closed. (Note that this design allows a small and large current to be separate.)



✔ Check Your Learning

TEXTBOOK

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