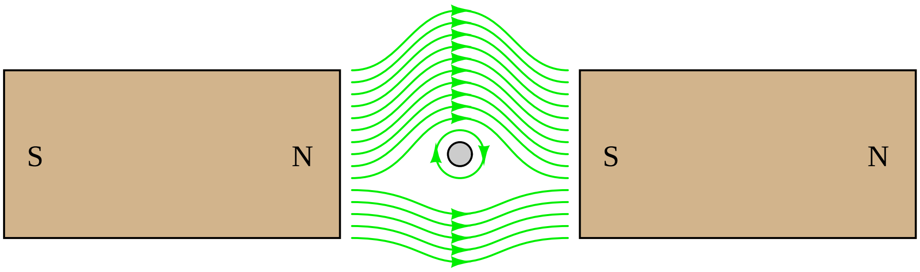
DC motor theory

Resources and methods for learning about these subjects (list a few here, in preparation for your research):

Questions

Question 1

If we were to analyze the magnetic flux lines of a current-carrying conductor, oriented perpendicularly to a magnetic field between two bar magnets, the interaction would look something like this:

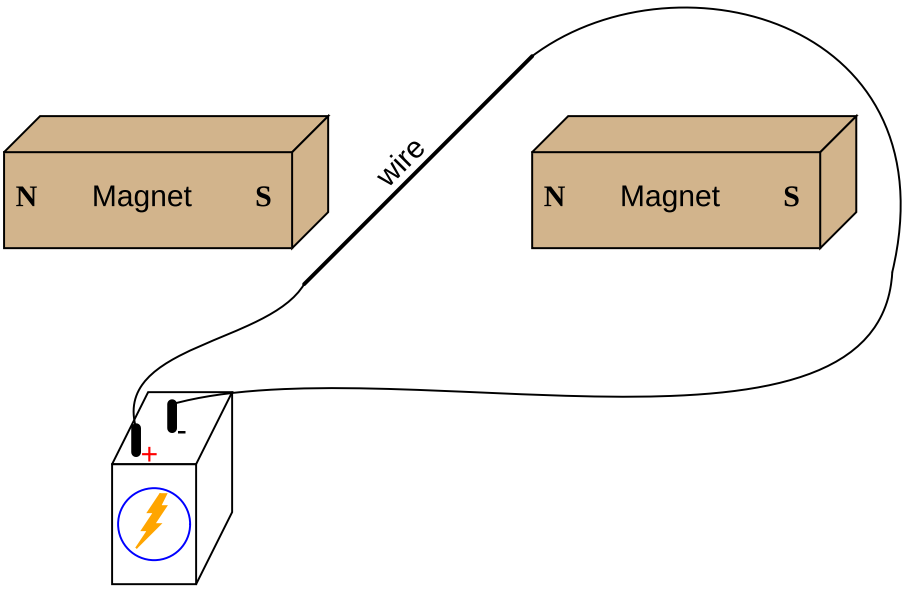


This interaction of magnetic flux lines (the bar magnets' straight lines versus the wire's circles) will produce a mechanical force on the wire (called the *Lorentz* force). Which direction will this force act? Also, determine the direction of current through the conductor (seen from an end-view in the above illustration) necessary to produce the circular magnetic flux shown.

file 00396

Question 2

If an electric current is passed through this wire, which direction will the wire be pushed (by the interaction of the magnetic fields)?

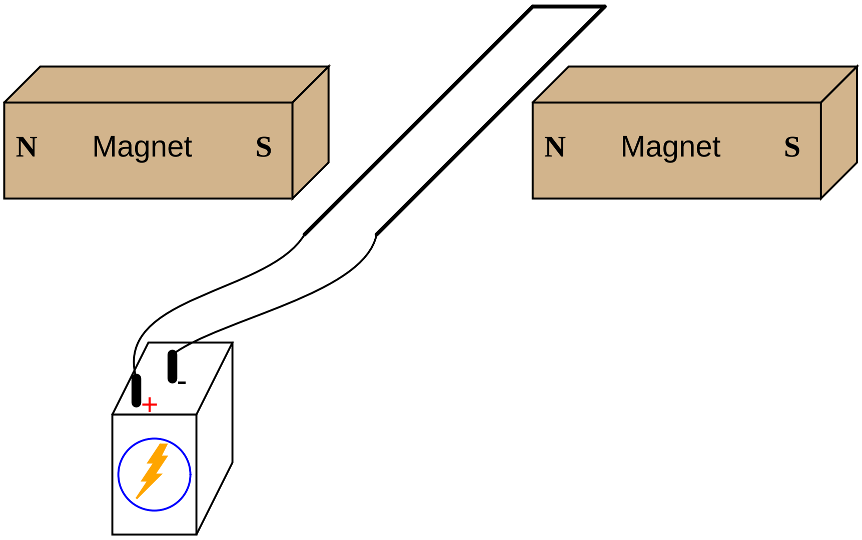


Is this an example of an electric *motor* or an electric *generator*?

file 00382

Question 3

If current is passed through a loop of wire, as shown, which direction will the loop rotate?



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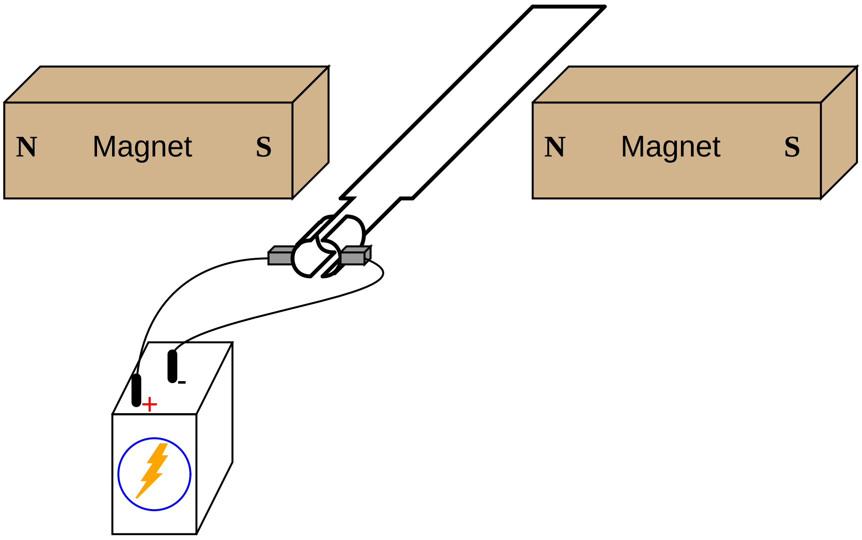
Question 4

If the ends of a wire loop are attached to two half-circular metal strips, arranged so that the two strips almost form a complete circle, and those strips are contacted by two "brushes" which connect to opposite poles of a battery, which way will the wire loop rotate?



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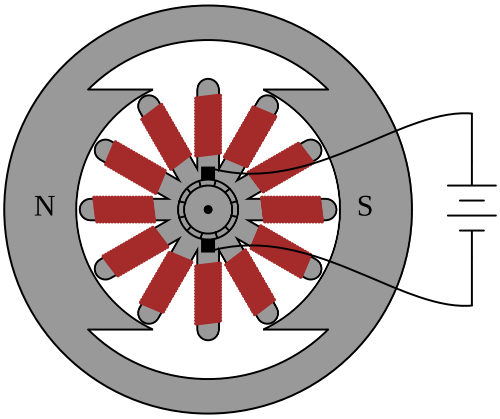
Question 5

A DC motor may be thought of as a series of electromagnets, radially spaced around a common shaft:



This particular motor is of the "permanent magnet" type, with wire windings only on the armature.

Write the necessary magnetic polarities ("N" for north and "S" for south) on the armature's electromagnet pole tips, in order to sustain a *clockwise* rotation.

file 00394

Question 6

Define the following DC motor terms:

- Field
- Armature
- Commutator
- Brush

file 00393

Question 7

When a DC motor is running, sparks may generally be seen where the carbon brushes contact the "commutator" segments. Explain why this sparking occurs, and also define the word "commutation" in its electrical usage.

What does this phenomenon indicate about the longevity of DC motors, and their suitability in certain environments?

file 00385

Question 8

As the armature coils in a DC motor rotate through the magnetic flux lines produced by the stationary field poles, voltage will be induced in those coils. Describe how this phenomenon relates to Faraday's Law of electromagnetic induction, specifically in regard to what variables influence the magnitude of the induced voltage:

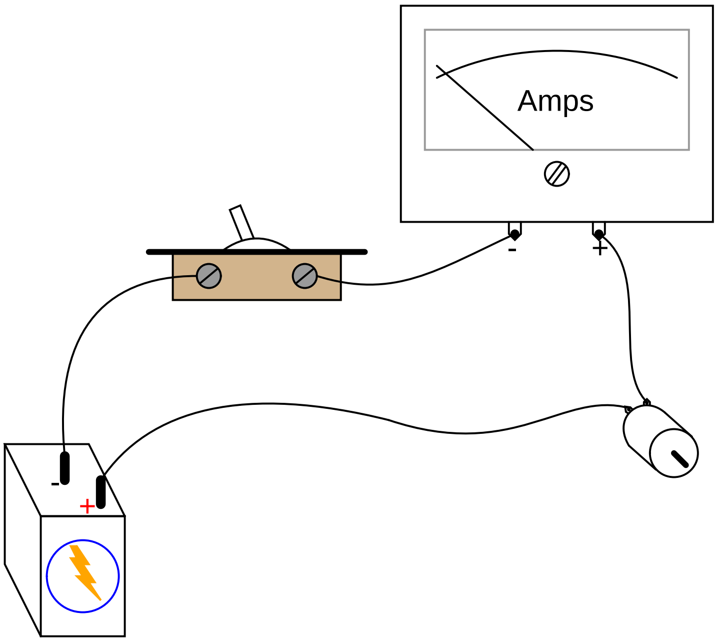
$$e = N\frac{d\phi}{dt}$$

The self-induced voltage produced by a rotating armature is often called the *counter-voltage*, or *counter-EMF*. Why would it be called "counter"? What is implied by this terminology, and what electromagnetic principle is illustrated by the "counter" nature of this induced voltage?

file 00397

Question 9

When the switch closes, the ammeter will initially register a large amount of current, then the current will decay to a much lesser value over time as the motor speeds up:



In view of Ohm's Law, where current is supposed to be a direct function of voltage and resistance ($I = \frac{E}{R}$), explain why this happens. After all, the motor's winding resistance does not change as it spins, and the battery voltage is fairly constant. Why, then, does the current vary so greatly between initial start-up and full operating speed?

What do you think the ammeter will register after the motor has achieved full (no-load) speed, if a mechanical load is placed on the motor shaft, forcing it to slow down?

file 00395

Question 10

A DC electric motor spinning at 4500 RPM draws 3 amps of current with 110 volts measured at its terminals. The resistance of the armature windings, measured with an ohmmeter when the motor is at rest, unpowered, is 2.45 ohms. How much counter-EMF is the motor generating at 4500 RPM?

How much "inrush" current will there be when the motor is initially powered up (armature speed = 0 RPM), once again assuming 110 volts at the terminals?

file 00398

Question 11

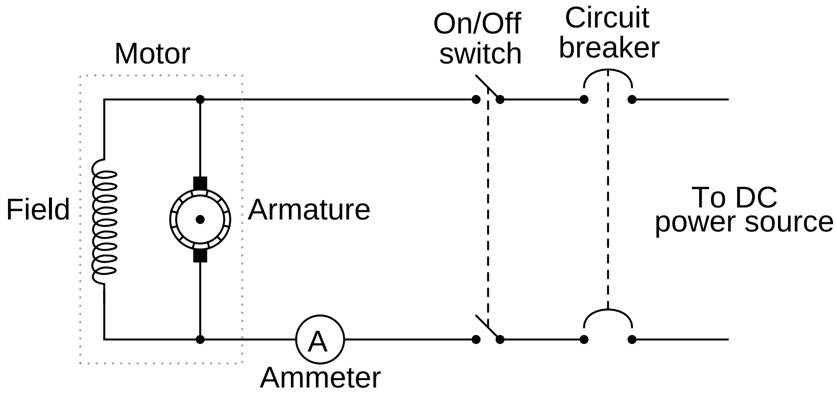
The amount of voltage applied to a permanent-magnet DC motor, and the amount of current going through the armature windings of a permanent-magnet DC motor, are related to two mechanical quantities: maximum speed, and torque output (twisting force).

Which electrical quantity relates to which mechanical quantity? Is it voltage that relates to speed and current to torque, or visa-versa? Explain your answer.

file 00399

Question 12

A problem has developed in this motor circuit. When the switch is turned "on", the motor does not turn. It does, however, draw a lot of current (several times the normal operating current) as indicated by the ammeter:

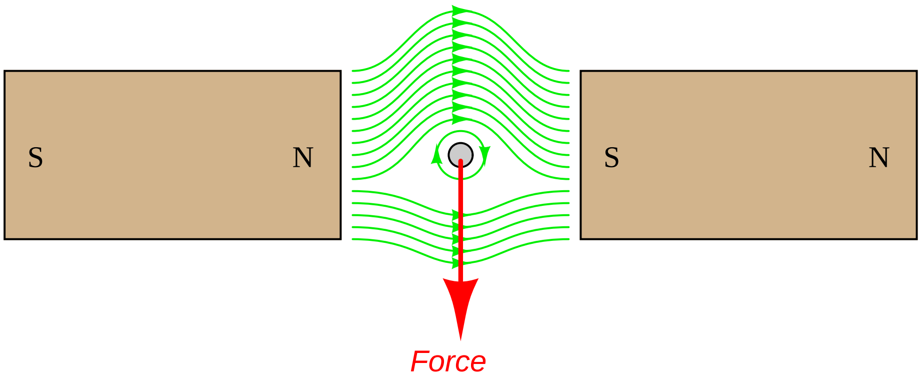


Based on this information, what do you think may be wrong with the circuit? Is there anything we know for sure is *not* failed in the circuit? Explain your answers.

file 00400

Answers

Answer 1



Answer 2

The wire will be pushed *up* in this *motor* example.

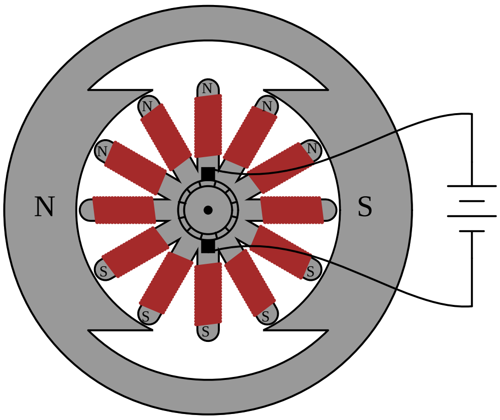
Answer 3

Clockwise, one-quarter turn (90 degrees).

Answer 4

Clockwise, continuously.

Answer 5



Follow-up question: suppose this motor did not rotate like it was supposed to when energized. Identify some possible (specific) failures that could result in the motor not moving upon energization.

Answer 6

- Field: *the portion of the motor creating the stationary magnetic field*
- Armature: *the rotating portion of the motor*
- Commutator: *copper strips where the armature coil leads terminate, usually located at one end of the shaft*
- Brush: *a stationary carbon block designed to electrically contact the moving commutator bars*

Answer 7

To "commutate" means "to reverse direction," in the electrical sense of the word. The result of the commutator bars and brushes alternately making and breaking the electrical circuit with the armature windings invariably causes some degree of sparking to occur.

Follow-up question: identify an environment where a sparking motor would be unsafe.

Answer 8

Counter-EMF varies directly with armature speed, with the number of turns in the armature windings, and also with field strength. It is called "counter-" EMF because of Lenz' Law: the induced effect opposes the cause.

Answer 9

Motor current is inversely proportional to speed, due to the counter-EMF produced by the armature as it rotates.

Follow-up question: draw a schematic diagram showing the equivalent circuit of battery, switch, ammeter, and motor, with the counter-EMF of the motor represented as another battery symbol. Which way must the counter-EMF voltage face, *opposed* to the battery voltage, or *aiding* the battery voltage?

Answer 10

$E_{counter} = 102.65$ V @ 4500 RPM
$I_{inrush} = 44.9$ A

Answer 11

The amount of voltage applied to a permanent-magnet DC motor determines its no-load speed, while the amount of current through the armature windings is indicative of the torque output.

Answer 12

One likely cause is either the field winding or something in the armature (a brush, perhaps) failed open. Internal motor problems are not the only possibilities, however!

Notes

Notes 1

This question serves as a good application of the right-hand rule (or left-hand rule, if you follow electron flow notation).

Notes 2

A visual aid to understanding the interaction of the two magnetic fields is a diagram showing the lines of flux emanating from the permanent magnets, against the circular lines of flux around the wire. Ask those students who came across similar illustrations in their research to draw a picture of this on the board in front of the class, for those who have not seen it.

Notes 3

Ask your students to identify the poles of the electromagnetic field produced by this current-carrying wire loop, and then its direction of torque may become easier to understand.

Notes 4

Challenge your students with this question: is there any way we can get the wire loop to continuously rotate without using those half-circle metal strips to make and break contact with the battery? Ask your students what the two half-circle metal strips are called, in electric motor/generator terminology.

Notes 5

The illustration shown in both the question and the answer provides a good medium for discussing commutation. Discuss with your students how, in order for the motor's rotation to be continuous, the electromagnets radially spaced around the shaft must energize and de-energize at the right times to always be "pulling" and "pushing" in the correct direction.

Be sure to spend time on the follow-up question with your students, considering non-electrical as well as electrical fault possibilities.

Notes 6

Students may find pictures of DC electric motors in their search for these terms' definitions. Have them show these pictures to the class if possible. Also, a disassembled electric motor is a great "prop" for discussion on electric motor nomenclature.

Notes 7

If your students find themselves working in some sort of electrical maintenance jobs, what types of routine maintenance do they think they might have to do on DC electric motors, given the presence of sparking at the commutator? Ask them what safety issues this sparking could present in certain environments. Ask them if they think there are any environments that would be especially detrimental to a motor design such as this.

Notes 8

The principle I wish to communicate most with this problem is that every motor, when operating, also acts as a generator (producing counter-EMF). This concept is essential to understanding electric motor behavior, especially torque/speed curves.

Notes 9

The so-called "inrush" current of an electric motor during startup can be quite substantial, upwards of ten times the normal full-load current!

Notes 10

This calculation helps students realize just how significant the "inrush" current of an electric motor is.

Notes 11

This question asks students to relate concepts of electromagnetism and electromagnetic induction together with voltage and current. While the permanent-magnet style of DC motor exhibits almost linear relationships between these variables, all DC electric motors exhibit the same general pattern: more voltage, more speed; more current, more torque; all other variables being equal.

Notes 12

This question is an exercise in diagnostic thinking. Always challenge your students to try diagnosing the nature of a problem with the given information before taking further measurements or observations. Far too often people take more measurements than necessary to troubleshoot electrical systems, because they do not think carefully enough about what they are doing.