Electric Motors

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How do electric motors work?

The short answer to this question is that electric motors convert electrical energy into magnetic energy, and then into rotational force. But it is clearly not that simple. An electric motor is the fundamental electro-mechanical energy converter that uses the forces of electricity, magnetism, angular momentum, and inertia, as well as electro-magnetic theory, Faraday's theories of electric current, and Tesla's theories of alternating current.

Magnets? Why not electricity?

Electricity alone will not create rotation. The fundamental principle at work in an electric motor is magnetism. Imagine a paper clip on a table and a magnet is moved slowly towards it. As the magnet comes close to the paper clip, one of two things will happen. The paper clip will either jump toward the magnet, sticking firmly, or it will slide away from the magnet until it gets far outside of its magnetic field. If the magnet is turned around, the opposite will happen. This is called the magnetic moment, and regardless of its shape, size or material, the magnet will always have a "pulling" force on one side and a "pushing" force on the other.

Now imagine replacing the paper clip with a magnet. What would happen if the "pushing" side of the magnet being held was pointed at the magnet on the table? Again, it depends on the orientation of the magnet on the table. If the same side of this magnet (the "pushing" side) were pointed at the magnet being held, the magnet on the table would slide away, as expected. However, if the magnet on the table had the "pulling" side pointed at the same "pushing" side of the magnet being held, the magnet would then jump off of the table and stick to the magnet being held. The point here is that by changing the polarity (or pushing/pulling side) of the magnet, you can change the direction that the magnet moves. But how does that apply to motors?

A motor works exactly the same way by controlling the orientations of the magnets inside it for a specific result. Inside of an electric motor, there are essentially four magnets. Two are on opposite sides of the outer casing (the stator), with one that is "pulling" and one that is "pushing." Two other magnets are on opposite sides of the spinning shaft; these switch between one "pulling" and one "pushing" at the same time.

The idea is that one of the shaft magnets is set to "push" and the other to "pull," so they are pushed away from the closest stator magnet and pulled towards the next magnet. Just as they get to the halfway point between the two stator magnets, they switch polarity and are attracted to the next stator magnets. At the exact second that the shaft magnets are closest to the stator magnets, they switch again and are then repelled by the closest magnet and attracted to the next and continue to rotate. This happens forever as long as the mechanism exists to switch the polarity of the shaft magnets.

But why does the shaft continue to spin in the same direction? Why doesn't it get stuck in the middle or spin the other way when the polarity changes?

The shaft continues to rotate in the same direction because of angular momentum and inertia.

Inertia is the force that keeps things moving once started, and the force that makes it difficult to start, when something is stopped. Imagine riding a bicycle. It is hard to start moving, easy to continue moving one you have started, and then hard to stop once you are going.

Angular momentum is the force that makes a pendulum work, making a heavy object on a string spin. As an object is rotated through the air on a string, it spins around. When the rotation is stopped, the object continues to spin. It is because of this force that the magnets on the shaft, called the armature, keep going in the same direction after they have started moving.

The magnets don't get stuck because real motors actually have three armature magnets and only two stator magnets, called permanent magnets. In this case, there is always an imbalance of magnetic force as two of the armature magnets pull toward one permanent magnet, while only one repels it. This guarantees that the motor never gets stuck on one position.

But what about that polarity switching mechanism and all this talk of electricity?

The magnets in the armature aren't exactly your standard type of magnets. These are called electromagnets and work by the principle of electro-magnetism that states when electricity flows through a loop of wire, a magnetic field is generated.

This type of magnet is easy to build. All that is needed is an iron nail, a battery, and some bare copper wire. Wrap the wire around the shaft of the nail a dozen or so times, then connect the ends of the wire to a battery. The nail is now magnetic.

If the battery is turned around, the nail begins to repel metal objects. This is how the armature magnets work. A coil of wire is connected to the incoming power of the motor. As the power enters the loop, a magnetic field is generated for a moment in one direction. As the motor spins, the coil is disconnected from the power at the commutator and then reconnected backwards, thus creating the opposite polarity. This happens simultaneously with three coils of wire, some of which are connected forwards, and some backwards, creating rotation and a switching of the magnetic field.