Skulls in the Stars

The intersection of physics, optics, history and pulp fiction

Physics demonstrations: Faraday disk

Posted on August 27, 2014 by skullsinthestars

I'm prepping a new course to teach this semester: undergraduate Electromagn together some nice simple demos to illustrate principles in the class, and I'll blo are interesting.

When Michael Faraday discovered the phenomenon of electromagnetic inductio complete unification of electricity and magnetism, he came up with a variety of e effect.

One of them is now known as the Faraday disk, and it is very easy to construct — My version is shown below.

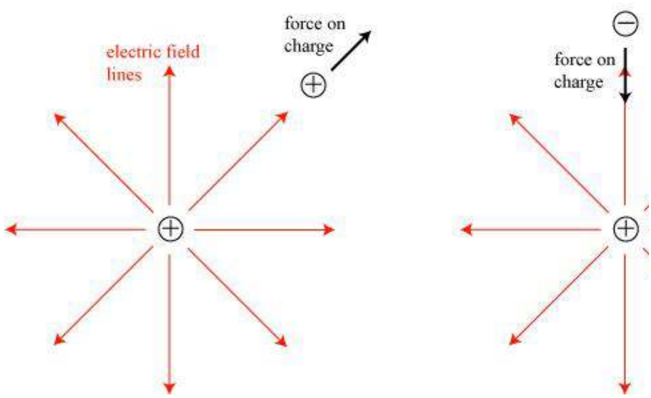
All of the parts are visible in this photo. By turning a hand crank, one rotates a c magnets (the black disks), one generates an electrical current that runs from the central axis. Wires connected to these two points runs to the red and black plugs

the voltage difference generated. It isn't a spectacular amount — I measured abo
demonstrates the phenomenon known as *rotational electromotive force*.

As we have noted, however, Faraday interpreted his disk experiment as electrom
emf. It turns out that he was kinda wrong — but he was also kinda right! The ex
experiment involves some rather deep concepts in physics, and inevitably leads u
relativity.

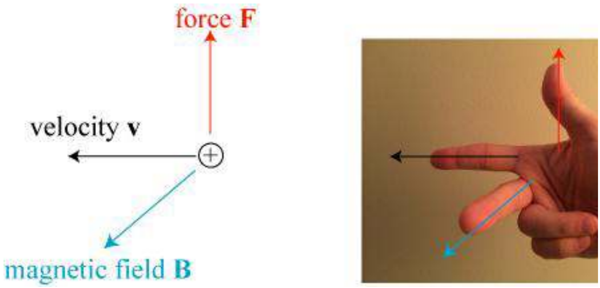
To understand the operation of the Faraday disk, we first need to understand the
microscopic level. It will initially look very different from the "bar magnet and c
grew up with, but we will make the connection once we have some information.

Let's start, however, even simpler: with electricity. Most people are roughly fam
between electric charges: opposite charges attract, like charges repel, and the for
charges. We typically break this process into two parts: one charge emits an elec
attracted or repelled by the electric field, depending on its sign.



Magnetism can also be consider a force between charges; however, the force only
moving. We will not worry ourselves with how magnetic fields are created — tha
explanation — and will only worry about how a moving charge interacts with an

It is an experimental fact that a positive electric charge moving in a magnetic fiel
perpendicular to both the direction of the magnetic field and the direction that t
that leaves two possible directions; the correct one is specified by the "right-hand
finger along the velocity of the particle and your right middle finger along the dir
force on the particle then roughly points along the direction of the thumb.

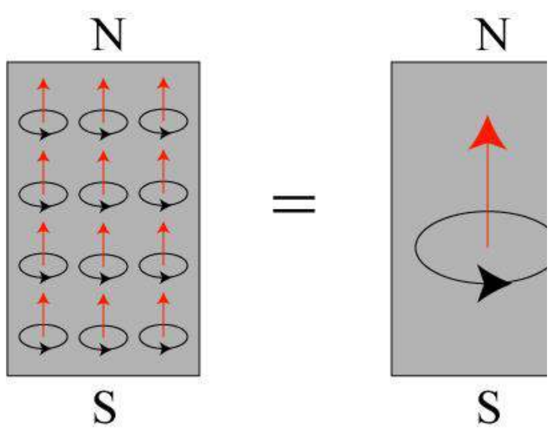


A lovely hand model illustrates the right-hand rule for magnetic force.

A little more detail here will help in a moment: the force is strongest when the m
completely perpendicular to each other, and the force is zero when the velocity is
magnetic field.

As already noted, this picture seems strikingly different from the behavior of ord
North and South pole: like poles repel, and opposite poles attract. There are not
these magnets, either.

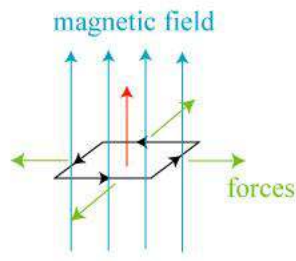
On an atomic level, however, we can imagine that electrons orbiting atomic nucl
current. In a magnetized piece of iron, these little current loops are all aligned, r
big current loop.



The black loops represent an electrical current going in a circle; the red lines, wh
represent the direction of "magnetization" of the atoms and, consequently, the w

So what happens when one of these current loops is exposed to a magnet field? moving charges; our current loop will, in general, experience a force from a magn

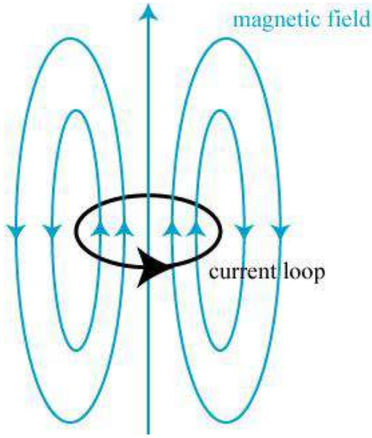
Let's look at a special case of this and imagine a current loop that is perfectly alig clarity, I'm going to draw our loop as square instead of round; the results describ



So what happens? Using the right-hand rule, we find that the forces on each "leg pull within the plane of the loop itself. Furthermore, because of the symmetry of right leg of the loop is equal and opposite to that of the left leg — they cancel com the front and back legs of the loop also cancel. The only action of the forces is to loop does not move or rotate.

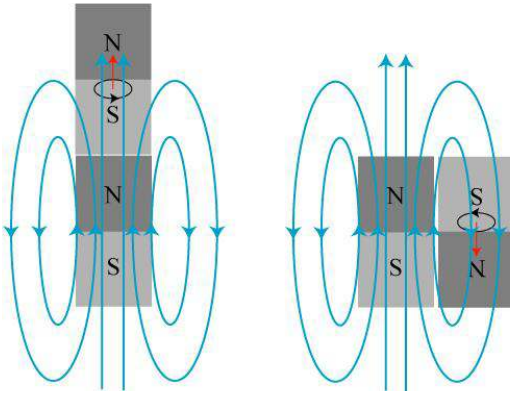
What happens when a loop is not aligned with the field? We could do lots of mat me just state the conclusion, which is plausible in light of our previous discussion rotate it until it reaches a point where it is stable. In other words, the loop exper the magnetic field.

To make the final connection between our statement that "magnetic forces act on magnets we know and love, we note that the magnetic field produced by a loop o a bar magnet — looks something like the picture illustrated below.



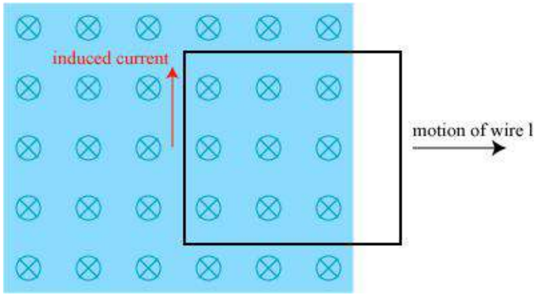
The magnetic field lines pass through the loop of current and then take a wide pa
to eventually come back through the bottom again.

What happens when we put two bar magnets together? The magnets will attemp
their magnetization (red lines) align with the magnetic field lines of the other. T
illustrated below: either the magnets line up such that their North and South pol
side-by-side with North and South next to each other. To phrase it in terms of ou
line up such that the red lines are parallel to the blue lines.



All of this description is somewhat beside the point, as it really just demonstrate
"magnetic fields act on moving charges" is consistent with our everyday picture o
our new impression of magnetism to understand how the Faraday disk operates.

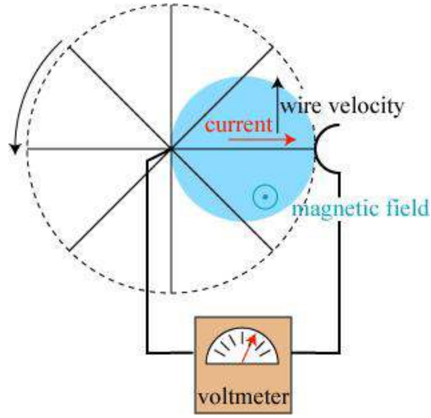
Let's consider a simple system that consists of a wire loop that is being pulled th
below. The magnetic field extends throughout the blue region and points into th
pulled to the right at a constant velocity.



The circles with crosses are the magnetic field lines, pointing into the screen (the
arrow). At first, it would seem that nothing much should happen when we pull t
neutral wire consists of positive ions and loosely-bound electrons; when the wire
electrons are moved as well. The electrons therefore have a right-going velocity a
suggests that the negatively-charged electrons move downward. This is the sam
upwards! In the two horizontal legs of the wire, the electrons are pressed upwar
to go, the magnetic force has no effect.

The electrons moving upward in the left side of the loop, however, push other ele
in a complete current flow around the entire circumference! This pushing of ele
referred to as an *electromotive force*, or emf for short. There are many ways to p
though, and the force produced by a moving loop in a magnetic field is referred t
force.

With this simple example, we can now explain the Faraday disk. We envision th
emanating radially from the central axis, as we illustrate in the picture below.



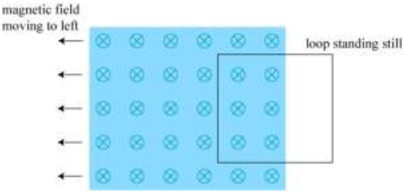
Now I've drawn the picture with the magnetic field pointing out of the screen; th
"arrow." Using the right-hand rule, we can see that the wire currently passing th
experience a magnetic force that pushes a current from the axis to the outer rim
wire disk with a solid metal disk, the basic idea remains the same, although the c
larger area of the disk as it travels from the center to the rim. This is, in fact a m
Faraday disk: current can "spill out" around the region where the magnetic field
the axis. It's kind of analogous to trying to push a volume of water uphill with yc
some water to go up, but you'll lose a lot spilling out on either side.

The Faraday disk is, in fact, the earliest example of an electrical generator, and is
generator. Like all generators, it converts mechanical work — in this case the eff
electrical energy through the use of magnetism.

I noted that the Faraday disk tends to be inefficient, but on a large scale they wo
large amount of mechanical energy and dump it very quickly, on demand, into el
large, heavy, spinning metal disk, switching on a strong magnetic field will make
rotation into a massive pulse of current. Such a device was built in the 1950s by
National University where it was used in synchrotron experiments until 1962. T
pictured below.

Remains of the homopolar generator at ANU, via [Wikipedia](#).

Practical uses aside, there is still more we can learn from homopolar generators
our simple model earlier, involving a wire loop being pulled through a magnetic
happens across our experiment and walks by it at the same speed and in the sam
moving. From his perspective, then, he sees a different experiment.



This may not seem like a significant change, but it turns out to be a very big deal
moving from the visitor's perspective, there are no moving charges and therefore
the electrons in the loop at all! It seems, from our simple argument, that the visi
while the experimenter would see a current flow.

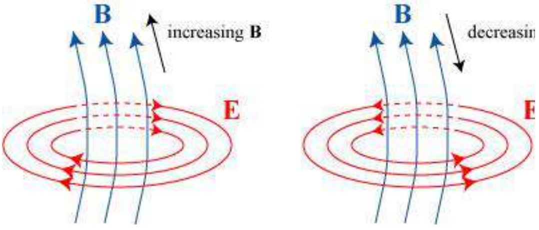
This obviously cannot be the case; an electron moving from the bottom of the wi
is a definite event that everyone should agree either happened or did not happen
to reconcile what appears to be a paradox: (1) The laws of physics, as we know th
observers, namely the experimenter. He, and anyone who is standing still like hi
physical law. (2) There is some additional physical law that we have not address
observers agree on the experimental result.

At the beginning of the 19th century, most scientists would have argued in favor
many times on this blog**, throughout most of the 19th century it was believed t
motion of a mysterious, intangible substance permeating all of space, the "aether
water and sound waves travel in air, it was reasoned that light waves must travel

Motion of the Earth with respect to the aether was in principle measurable, and physics would only have a universal form for a person at rest with the aether. Th light, electricity and magnetism would not be discovered until James Clerk Maxv scientists would not be terribly bothered in assuming that electricity and magnet of operation.

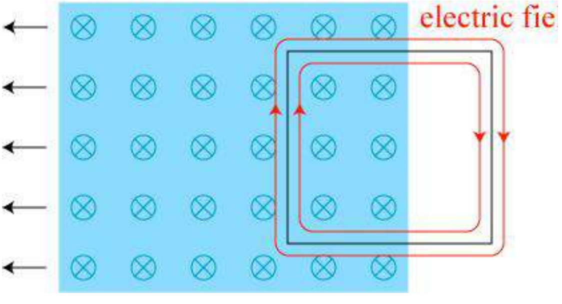
We know now, however, thanks to Einstein's theory of special relativity, that the independent of the constant motion of those observing them. This means that tl experiment must also see a current generated in the loop; but where does this cu

The answer was provided by Michael Faraday in 1831, when he discovered the pl [induction](). In short, Faraday discovered that a time-varying magnetic field induc illustrated below.

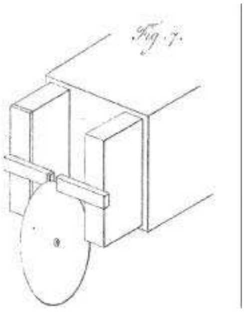


A magnetic field that is constant in time does not produce any electric field. If w flowing through a region, either by changing the power of the magnet or *by mov* circulating magnetic field.

Let's look at the experiment from the point of view of our walking visitor again. total effect of the magnetic field in the loop (what we call the flux) decreasing as left. By Faraday's law, we know that this changing magnetic field creates an elec the loop in a clockwise sense. This electric field drives the current around the lo and visitor agree that a current is moving; they would just disagree on the origin



Curiously, Faraday discovered both electromagnetic induction and motional emf
discussed in his 1831 paper**** and he introduced what we now call the Faraday



Faraday treated motional emf and induction as being two aspects of the same ph
that they are evidently produced by different forces: motional emf comes from tl
comes from an induced electric field. So Faraday was somewhat wrong in his an
accidentally right: in Einstein's special theory of relativity, electric and magnetic
electromagnetic phenomenon. The magnetic field seen by our stationary experi
visitor as an electric field. Einstein's first paper on special relativity in fact discu
electric fields transform into one another when one changes to a different movin
Faraday was also right in thinking of motional emf and induction as the same thi

Looking back, our discussion has taken us from a really crappy electrical generat
of electricity and magnetism. The Faraday disk is a nice example that shows us t
demonstrations can often take us into quite deep and profound aspects of nature

****

* For a discussion of how to interpret diagrams of fields, see my old "optics basic

** See, for instance, here and here.

*** I've taken some liberties in showing the electric field running all the way arou
electric field would only appear in those regions where the magnetic field is chan
boundary of where the field cuts off. My simple picture does not allow us to draw
however.

**** *Philosophical Transactions of the Royal Society of London*, vol. 122 (1832),

This entry was posted in Physics, Physics demos. Bookmark the permalink.

22 Responses to *Physics demonstrations: Faraday disk*

Mark Hanna *says:*
August 27, 2014 at 5:32 pm

“that leaves two possible directions; the correct one is specified by the “right-hand rul

I understand this question is probably either a massive can of worms or a rather stupi the right-hand rule the correct one? Why isn’t the “left-hand rule” a thing here?

I understand that this is the sort of thing that can be verified experimentally, but I’m r rule is. My intuition (which is obviously wrong here) tells me that physical laws shoul see it picking what seems like an arbitrary direction. Do we have any idea why this is t not the opposite direction?

Reply

skullsinthestars *says:*
August 28, 2014 at 11:37 am

Hadn’t really thought about it in detail before, but I think the answer is: the charged particles! The “right-hand rule” is based on the assumption that th historically, we had labeled the + and – charges opposite to what Benjamin about the “left-hand rule.”

Reply

Mark Hanna *says:*
August 28, 2014 at 4:27 pm

That certainly feels much more satisfying to my intuition 😜

I recently watched a bunch of videos on gyroscopic precession on You' gyroscope to play around with it, amazing stuff) and had the same init asymmetry seemed jarring to my intuition.

In that case, I actually found this video most informing as it seemed to that particular direction: https://www.youtube.com/watch?v=TUgwa

Uncle Al *says:*
August 28, 2014 at 10:02 am

Physical laws can be mirror-asymmetric (beta-decay) . 3-D coordinates are chiral (pai foot) lift chiral degeneracy (shoes fit with different energies). Handed rules for angula pseudotensors.

Massless boson photons detect no vacuum refraction, dispersion, dissipation, dichrois
true for fermionic matter (quarks). Parity violations, symmetry breakings, chiral anon
repair of Einstein-Hilbert action suggest vacuum trace chiral anisotropy acting only u
couple *exact* vacuum isotropy to angular momentum conservation. If fermionic matte
matter disappears .

Test spacetime geometry geometrically, not with composition or field. Six classes of *cl*
Cartography showed Euclid was incomplete. Look for a black swan.

Reply

Pete Olsen *says:*
November 27, 2014 at 4:37 am

Fleming's right-hand rule applies to generators (as here). The left-hand rule applies tc
movement as an output; electric bell, loudspeaker etc. I note that the name "Fleming"
this only used in UK?

Reply

Esam A SERHAN *says:*
January 7, 2015 at 3:34 pm

I want to know as well about the velocity(speed) of motion at the armature how it coul
EMF and the induction and also i need to know how we can have a constant velocity ir
connect the windings in parallel,series or compound connection.
Also when the movement is parallel or anti-parallel with the magnetic field does the n
the movement always leading the affect by put it on or take it of on the magnetic field
movement affect with a reaction by inducing EMF or not.

Reply

Ian Cable *says:*
February 1, 2015 at 10:05 pm

Can you please give more detailed instructions on building a homopolar generator? A
bought your faraday disk? Thank you!

Reply

skullsinthestars *says:*
February 5, 2015 at 2:14 pm

A simple version of a homopolar motor is described in this post of mine: https://skullsinthestars.com/2014/12/12/the-mystery-of-the-magnetic-tra

Also, my Faraday disc I got from Sargent Welch: https://sargentwelch.com catalog_number=WLS1815-43

Reply

ESAM A. SERHAN *says:*

February 7, 2015 at 2:42 pm

Hi LAN
Thanks for asking and as there is too many interests with my idea so i
myself and i faced many hard difficulties because i,m not an engineer
ideas maker so for this purpose i starts studying by myself and i need
scholarship as an independent researcher and the best think i can do i
with scholarship fund raise either a person or organisation .
By the way the principle is correct by i came into the designing field a
part and it need more refining and i need to do further study on the re
Finally i will be very appreciate if i receive an offer for scholarship .
Best regards
Yours
Esam

11mms *says:*

February 3, 2017 at 9:41 am

Can you make this page downloadable?

Reply

Esam Serhan *says:*

June 15, 2017 at 9:01 am

Yes the page is dowmnloadable

Reply

Esam Serhan *says:*

August 28, 2017 at 9:16 pm

Hi Ian
Electrically and mathematically for example if we have a motor running by DC on 24
And Reducing in minimum a 40 AMP DC with 0.5 AMP AC
How much you think you can improve this Motor?

What level of producing Energy you can reach?
Hopefully i can get an explanation from you
Thank you in advance

Reply

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ronchinnery *says:*
May 3, 2018 at 7:32 am

The "Faraday Paradox" remains… why does this generator still work if there is no rela the copper disc? The two can, in fact, be glued together, and there will still be power g rotating disc/magnet… just as described above. I'm honestly seeking a proper explana It also works of the magnet/disc are completely stationary, and just the contact point

Reply

ronchinnery *says:*
May 3, 2018 at 7:34 am

I forgot to state that in my above question, the magnet and copper disc are the is uniform across the entirety of the copper disc.

Reply

11mms *says:*
May 3, 2018 at 10:03 am

The answer is thought to be that the magnetic field does not change, or move, the field. So the disk is still moving through the magnetic field. It also works i rotates.

Reply

ronchinnery *says:*
May 3, 2018 at 7:33 pm

I've heard that explanation before… and my thoughts as to "why" are t alignment with other predominant fields around… like the earth.
The final question is… if the magnet/disc (or nickel plated magnet) ar relative to the magnet/disc, it still works… why? Is it just because the through the field? I've seen that it still generates voltage, but I've not s generates the massive current as the "normal" mode of operation.

11mms *says:*
May 3, 2018 at 9:27 pm

ronchinnery … I'd like to talk to you. You obviously know the details. I Unipolar Dynamo. … I just reviewed a Paper I downloaded at some tir FIMechE. He states that the magnetic field is not fixed, like everyone t

field lines move with the magnet. He claims the voltage is in relation t
PDF. I'll need to find the link to it for you, or search "Faraday's Final I
Magnet".
I assume that the voltage, from two contacts only, is a weak one from t
before. ... Bob

11mms *says:*
May 3, 2018 at 9:34 pm

Here's a link. http://distinti.com/docs/papersFromOthers/KellyFa3.p
Then again, he may be wrong. Just saw a magnet rotating under a disk

11mms *says:*
May 3, 2018 at 9:57 pm

I just found a video by another scientist that shows Kelly is wrong.
Rotating the magnet fixed with the disk proves that the field does not

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Ago *says:*
March 15, 2021 at 2:32 am

I thought I understood these devices, but this write-up has confused me to no end.

1. Regarding the magnet / electron current loops illustration… the first paragraph desc
this magnet. The second paragraph suggests subjecting these "loops" to a magnetic fie
They are already subjected to a magnetic field, as described in p1. Furthermore, consic
misleading to describe them as current loops?

2. The right hand rule, which is described as the index finger pointing forward represe
representing a Force, and the middle finger curved inwards representing the magnetic
picture with the magnetic field pointing out of the screen … Using the right-hand rule,
passing through the magnetic field will experience a magnetic force that pushes a curr
wheel."

This sentence needs to decide if it's talking about the direction of the current, previous
force, previously undefined but described as perpendicular to V. Therefore, up/thumb
swaps the velocity of the "wire" to the thumb/pressure direction and the velocity (desc
velocity vector.

3. In a field pointing into the page, " an electrically neutral wire consists of positive ior
the wire is moved to the right, those electrons are moved as well. The electrons therefo
using the rright-hand rule, it suggests that the negatively echarged electrons move dov

So they have a right going velocity because we are moving them to the right, but also b
charged" electrons move downwards? Why downwards, when the right hand rule very

of the “inwards” field, and the “pulling a coil example” rule very clearly says they are n

I went from a “fairly comfortable” to “frustrated and confused” after reading this, and disks yet.

Reply

Ionascu D. P. *says:*

July 4, 2023 at 2:50 pm

Click on right and print to pdf printing. Or click on page and save to …
What the author of this article does not say is why no current is produced when we rot and why current is produced when we simultaneously we rotating the magnet and the direction, i.e. we do not move them in the opposite direction. But the curent is induce

Reply

R. Boen *says:*

April 1, 2024 at 3:17 pm

I am wondering if, this many years after 2014, the author is interested in a possible Fa 1880s. I have an early polyphon disc music player different than other photos I have f belt that drives 4 glass discs (14-15″ diameter) w tape that I think keeps copper or alu Copper? wire ends are used in about 4 places, collecting electrical energy? Difficult to & repairing, but still trying to figure out where some loose parts go. Let me know if yo thing work again to play large metal music discs.

Reply

Skulls in the Stars

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