So you're on this island…

There is a book on this island that contains the three words you need to know in order to escape. The book will snap open at midnight…but it's a completely moonless night. You have at your disposal a tiny lightbulb, a long length of wire, and a horseshoe magnet. How can you create the light you need to see those three words?

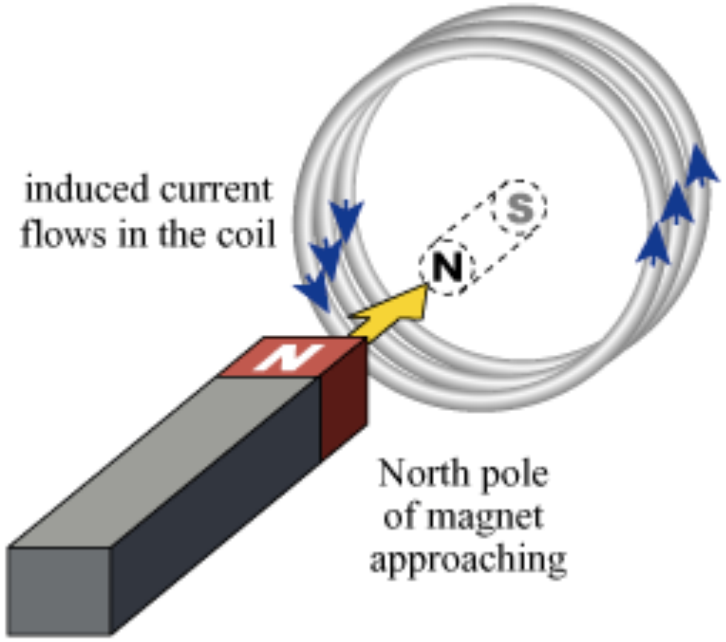
Wire + magnet - classical explanation

Given the set up below, when the magnet is moved through the coil of wire, why does this generate a current?

Based on what we've learned so far, we know that when a charged particle moves in a magnetic field, a force is exerted on it.

Moving the coil in the presence of the magnet means we are making the electrons in the wire move through a field - so a force is exerted on them!

Force causes acceleration, so the motion of those particles induces a current, with no battery required!



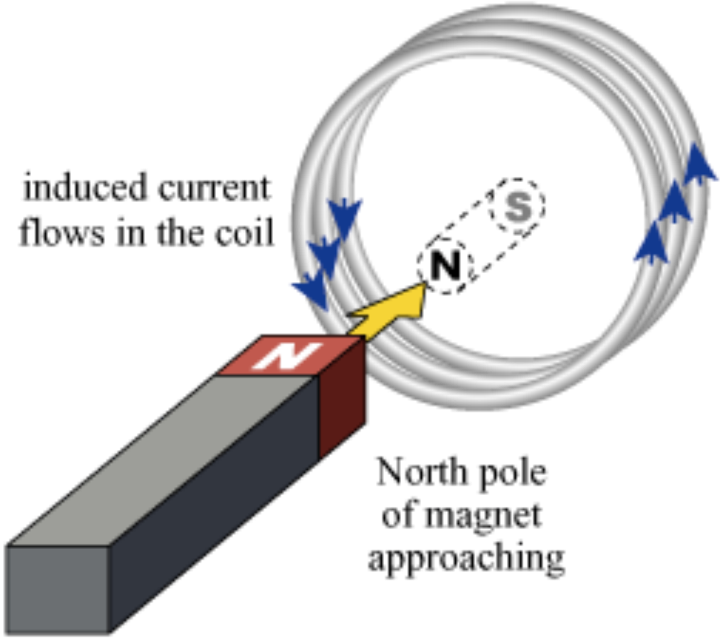
http://www.hk-phy.org/energy/domestic/cook_phy03_e.html

Wire + magnet - Faraday's explanation

Given the set up below, when the magnet is moved through the coil of wire, why does this generate a current?

Faraday looked at this an entirely different way. He thought about how the magnetic field could cause this to happen, and realized that a static magnetic field can't induce a current, but a **changing** one can.

The question is - how is the magnetic field changing here? In this picture shown, the magnet moves in/out of the coil; in class, the magnet held steady and the coil moved towards/away from it. In both cases, current was induced. So what factors affect this?



http://www.hk-phy.org/energy/domestic/cook_phy03_e.html

Solution to island problem …

Make a coil out of the wire, rotate it in the magnetic field (or make it move into and out of the field in some way) to produce an AC voltage and, hence, current which can power the lightbulb.

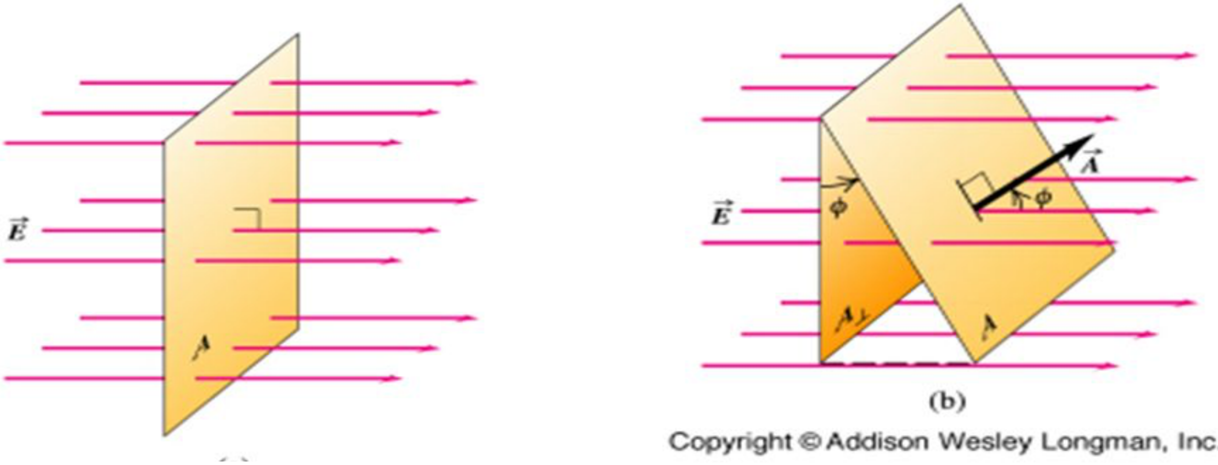
Electric flux revisited

- Remember electric flux? What is **flux**?

  Most generally, “flux” means something passing through a boundary, like an “influx” of people at a border, or water flowing (actually where the word comes from) through a cross-section of a pipe.

- How did we define electric flux through a Gaussian surface? (hint: we used a solar panels analogy - how could we increase the solar flux on a panel?)

  Electric flux is a way to measure how much of the electric field (e.g. the number of field lines) is passing through a surface of area A, defined by $\Phi_E = \vec{E} \cdot \vec{A} = EA\cos\theta$



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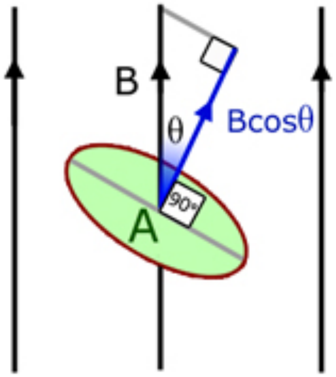
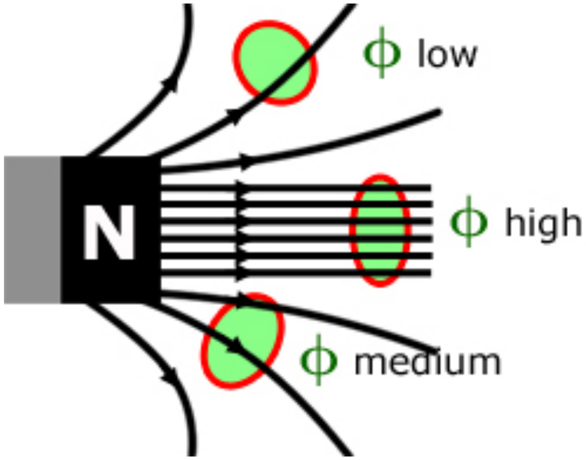
Magnetic flux

The concept of magnetic flux is very similar: how many magnetic field lines are passing through a surface, or:

$$\boldsymbol{\Phi_B = \vec{B} \cdot \vec{A} = BA\cos\theta}$$

- Remember that A is defined by a normal vector that points perpendicularly from the surface; $\boldsymbol{\theta}$ is defined as the angle between B and that normal vector to A.
- The units for magnetic flux are **Webers (Wb)**



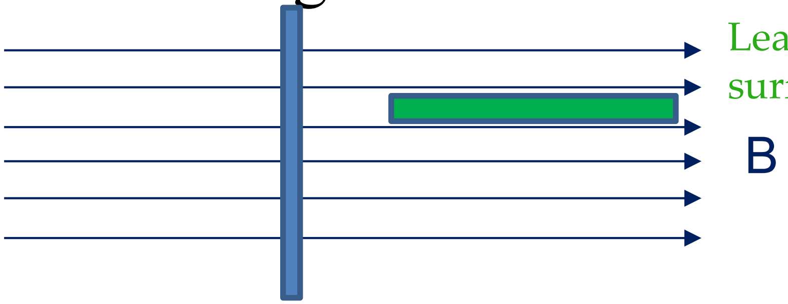


What three factors can affect magnetic flux, then?

http://www.a-levelphysicstutor.com/field-magnet-1.php

Magnetic flux concept check

A magnetic field is shown below. In what orientation would a surface have the greatest flux through it? The least flux?



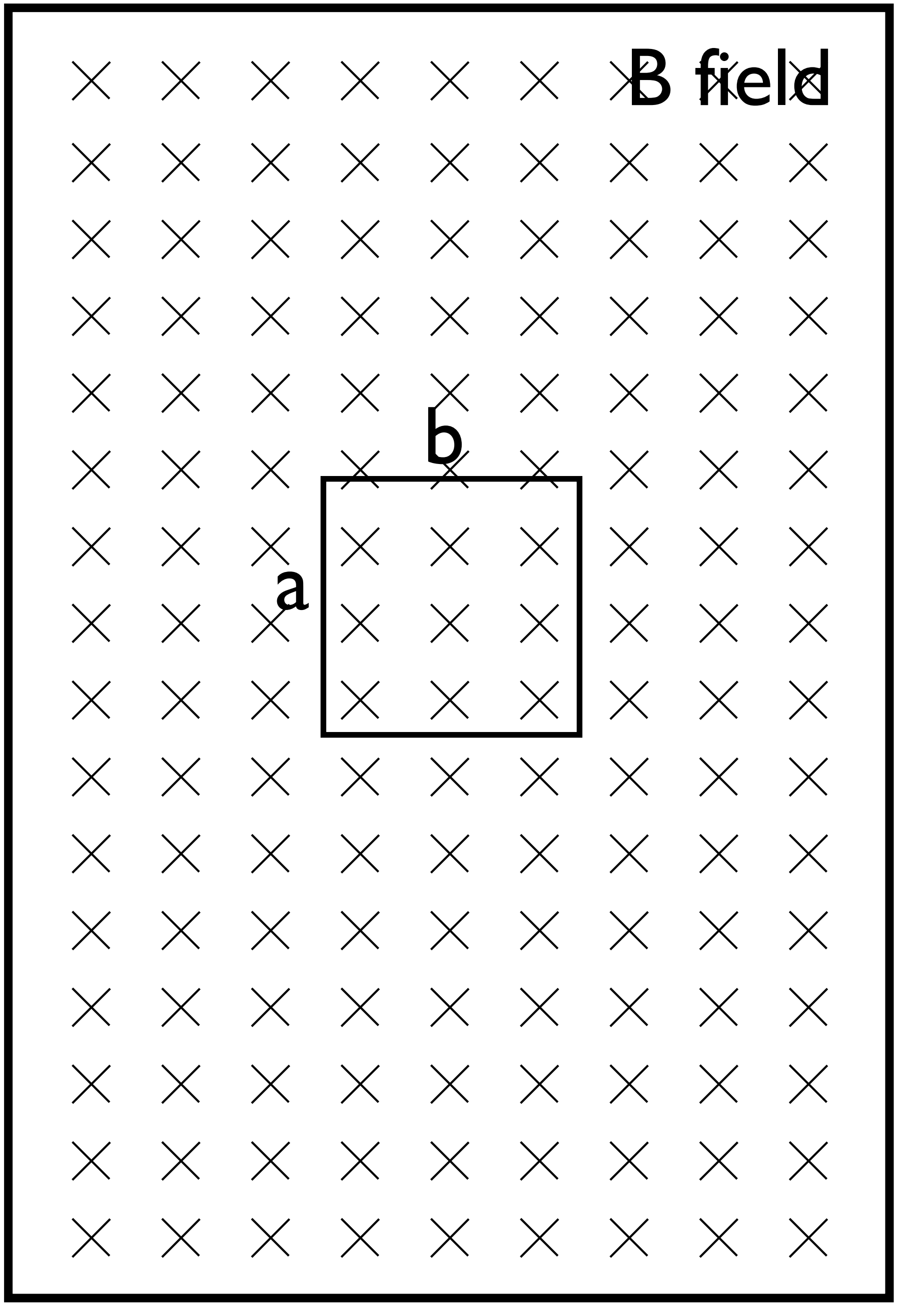
Least flux when plane of the surface is parallel to the field

Greatest flux when plane of the surface is perpendicular to the field

- ❑ Argentina has more land area than Greenland (by about 60,000 km^2). Why is the magnetic flux of the Earth's magnetic field larger through Greenland than through Argentina?

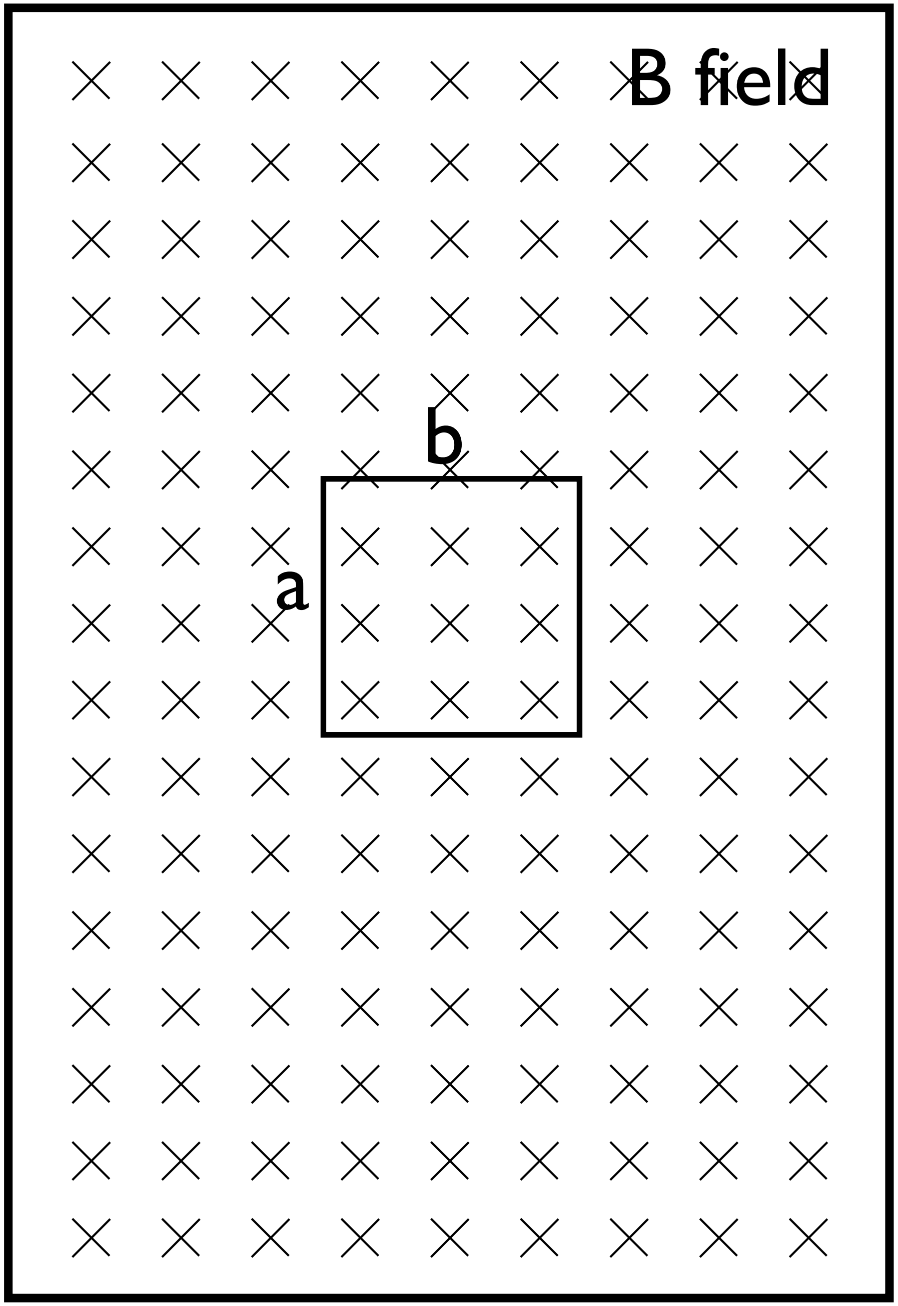
Greenland is closer to the magnetic pole, so the field lines are more perpendicular to the ground there - in Argentina, the angle between B and the normal to A is smaller so the net flux is less!

Assume you have a loop in the plane of the page that faces a magnetic field directed into the page. The dimensions of the loop are axb. Determine the magnetic flux through the coil.

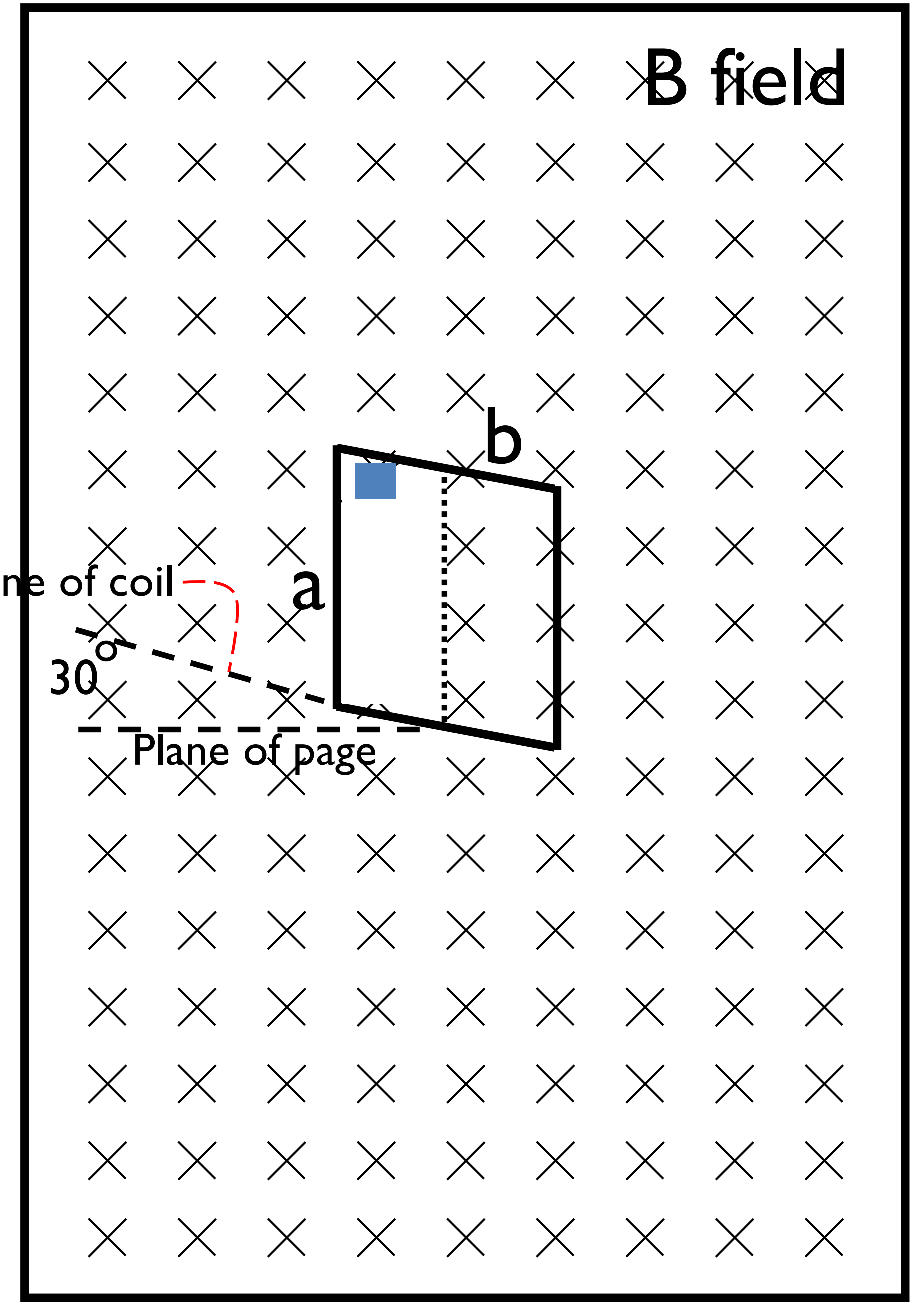


Assume you have a loop in the plane of the page that faces a magnetic field directed into the page. The dimensions of the loop are axb. Determine the magnetic flux through the coil.

$$(\phi_B = B(ab))$$



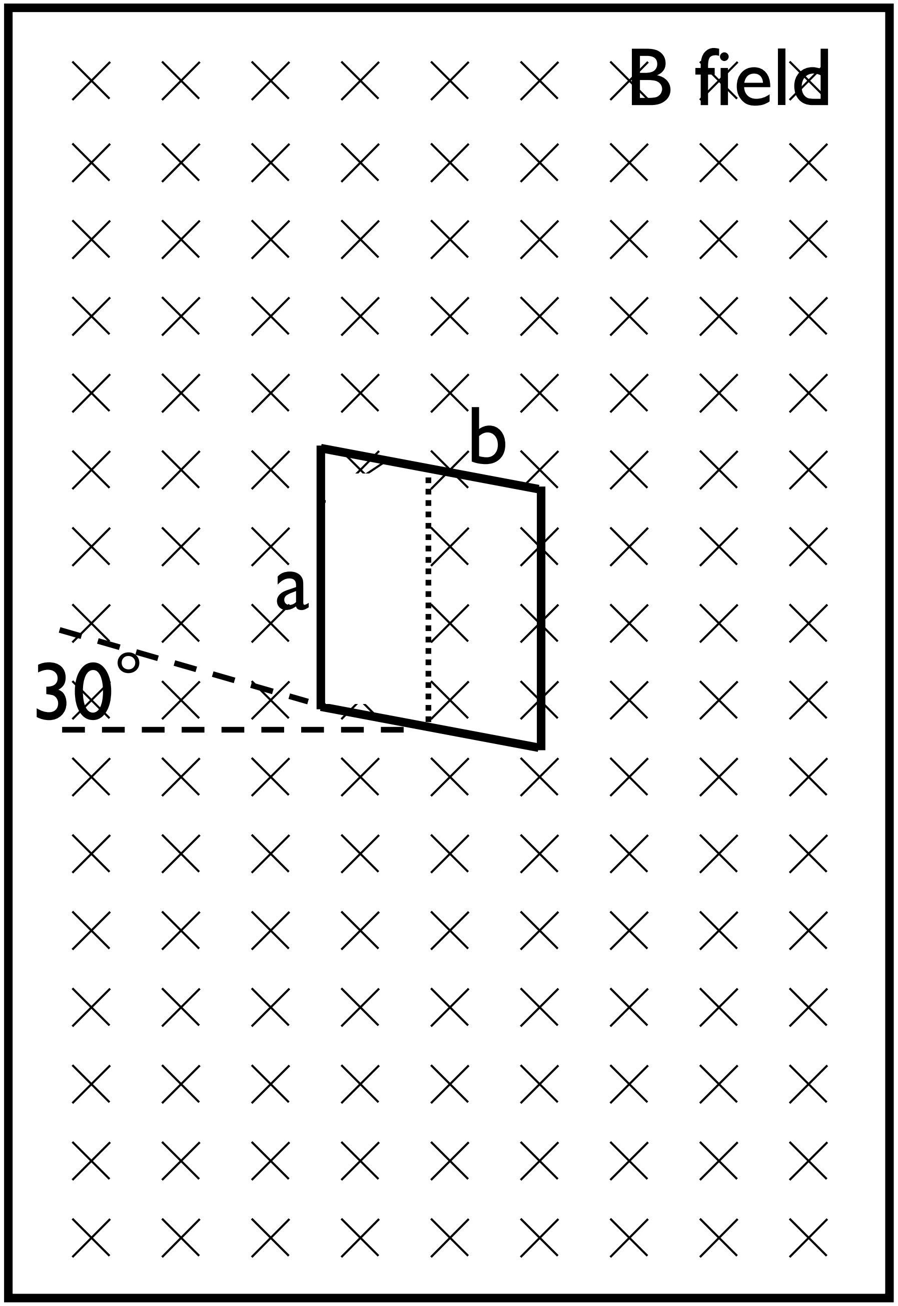
Same situation but with the coil rotated 30° into the page. What is the magnetic flux?



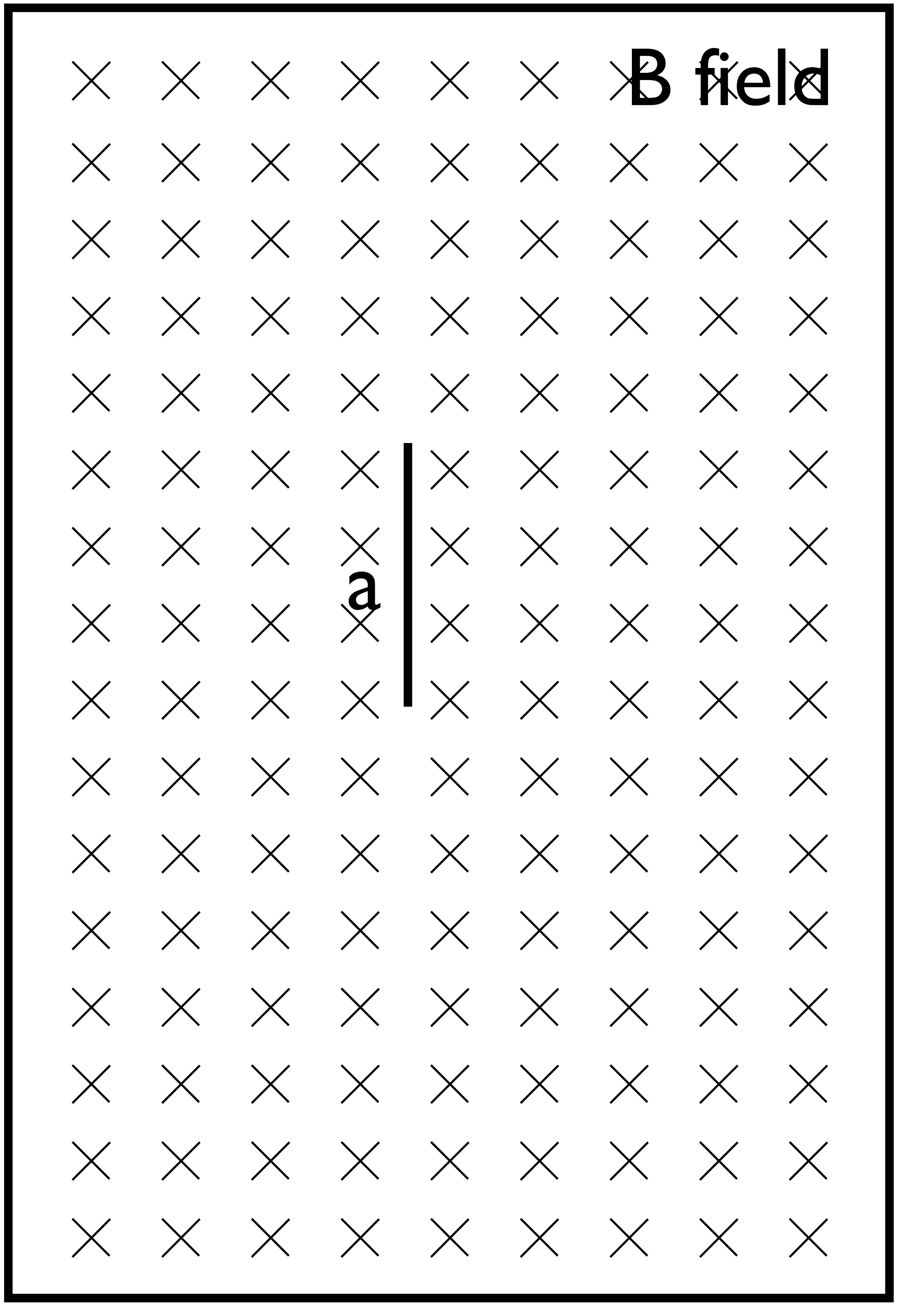
Same situation but with the coil rotated 30° into the page. What is the magnetic flux?

$$(\phi_B = B(ab)\ \cos 30^\circ)$$

Note: the angle between the line of B and the line of A, which is perpendicular to the coil, is sixty degrees.

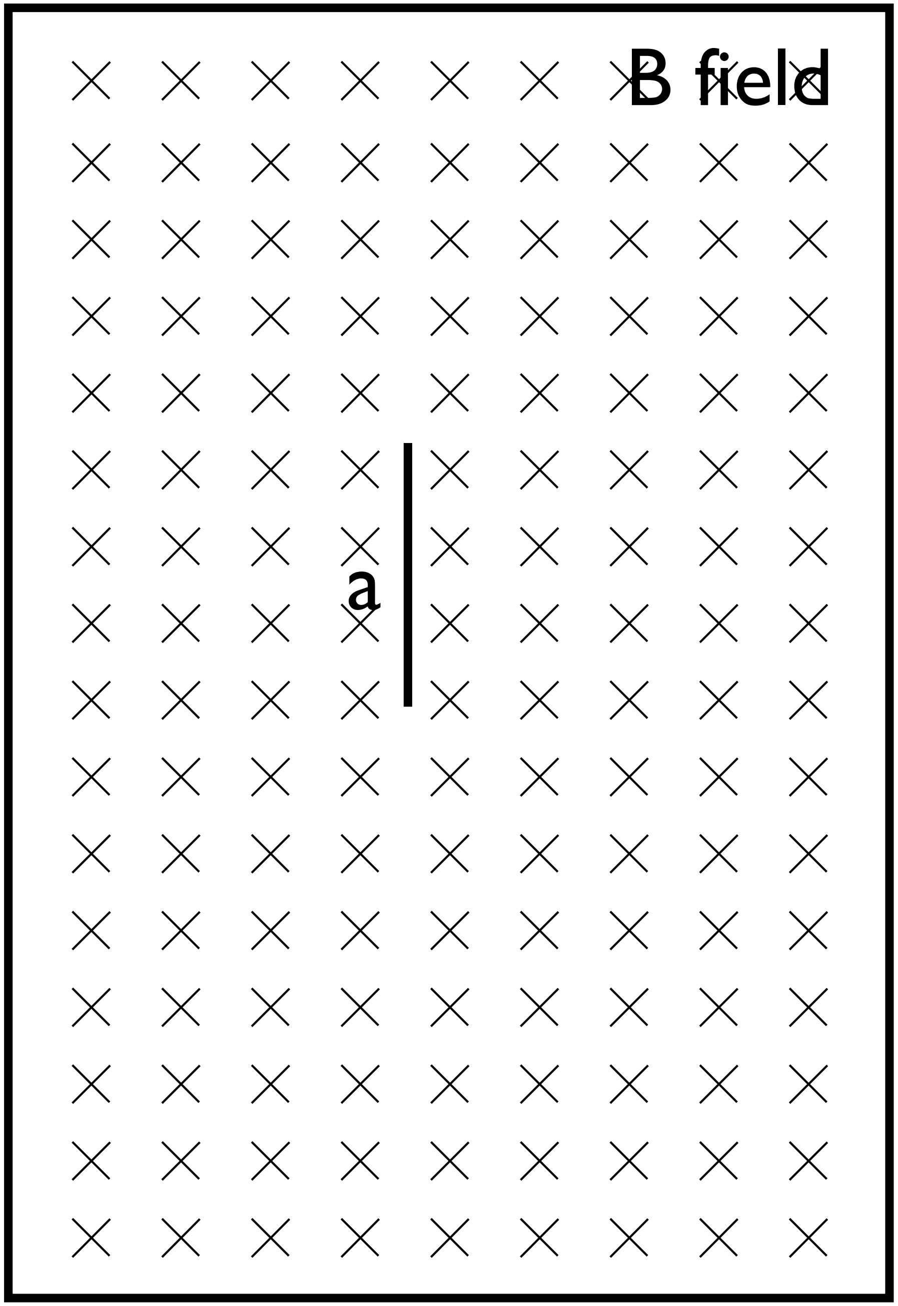


Same situation but with the coil rotated perpendicular to the page. What is the magnetic flux?



Same situation but with the coil rotated perpendicular to the page. What is the magnetic flux?

(Zero as the angle between B and A is ninety degrees so the cosine of the angle is zero.)



Magnetic flux and induced current

So you have a constant magnetic field passing through a stationary coil whose surface is perpendicular to the field.

- Is there magnetic flux through the coil?

  Yes! (Exactly like the previous slides' examples)

- Will this induce a current in the coil?

  No! If we try it, a stationary magnet and coil do absolutely nothing to an attached galvanometer.

- What (else?) will induce a current in the coil?

  To get a current, we need **relative motion** between the coil and magnet. We can hold the magnet steady and move the coil, or hold the coil and move the magnet. Either one produces a current.

Faraday's Law

Michael Faraday (1791-1867) discovered that the amount of induced EMF depends on:

- → The **rate of change of the magnetic field**
- → The **angle between the magnetic field and the loop**
- → The **area of the loop**

All of these observations indicate that induced current is related to the **change in magnetic flux**, or $\Delta\Phi_B$ through the loop. We know from before that current is produced by an emf. So:

$$\varepsilon = -\frac{\Delta\Phi_B}{\Delta t}$$

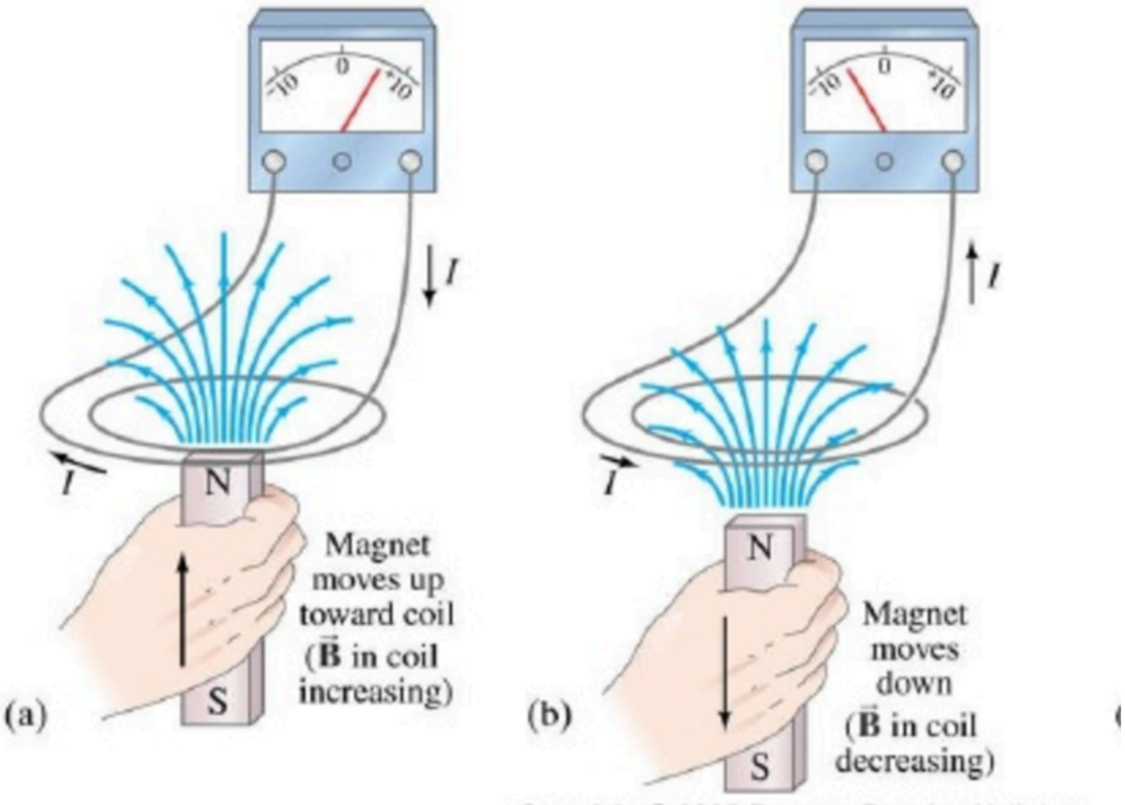
If there is more than one loop, then we multiple the right side by "N" (the number of loops).

- What does the negative sign mean?

Lenz's Law

A current produced by an induced EMF moves in a direction so that its magnetic field opposes the original change in flux.

- Hence, the negative sign in Lenz's law.
- Note that this means there are two magnetic fields we care about: the changing one that induces the current, and the one produced by the induced current (this is the opposite one)



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Knowing this, how do you think AC is produced in power plants?