Transformer Lab Preparation.

Explain the working of a transformer.

Start off with the demo that I placed in the front in the class-room. First demonstrate that when inserting a permanent magnetic in a coil a current is generated in the coil (i.e. amp meter deflects). Refresh on Faraday's law. Ask the students if somebody does remember Faraday's law from last week's lab.

Now replace the permanent magnet by the other coil that is connected to the DC power supply. Please make sure to use the coil with the thick wires for this one. Put the current through the coil at 5 ampere, please not more as you will burn out the coil. Now move this coil toward the coil that is connected to the ampmeter. A deflection should be possible. Make sure you move it fast enough. So instead of using a permanent magnet we could use an electromagnet to generate the flux change necessary to generate an induction current. Maybe ask one of the students to explain this using Faraday's law. Make sure to switch of the power supply after you are done with the demonstration, otherwise the coil might burn out.

Now place the coils on top of each other and vary the current through the coil with the knob on the poser supply. You might need to rotate the knob quickly. Observe the ampmeter. Ask the students why an induction current is also generated in this way. Make sure to lower the current after the demonstration and to switch off the power supply.

A transformer uses this same mechanism. In order to create a varying magnetic flux through the secondary coil, a current is sourced through the primary coil. This is not a constant current, but an alternating current. As a consequence the generated magnetic field is also not constant but varying as a function of the time. And then of course Faraday's law will do the job.

In order to make sure that all flux lines generated by the primary coil will go through the secondary coil one couples both coils with a magnetic material. Magnetic iron is used for that. The magnetic moments in the iron line up easily along the magnetic field generated by the primary coil. Now it might be good to one more time to summarize the working of the transformer:

1. A current is sourced through the primary coil.
2. Ampere's law tells us that this will result in a magnetic field in the coil.
3. The magnetic field generated by the current will align the magnetic dipoles in the iron guiding the magnetic field lines toward the secondary coil. So the magnetic flux generated by the primary coil will also go through the secondary coil.
4. As the current through the primary coil is not constant but alternating also the generated magnetic field is not constant but alternating, and also the flux through the secondary coil is not constant but alternating.
5. A varying flux will create an electric field twister in the windings of the secondary coil creating an induction current.

   Now introduce coupled flux and derive the transformer equation.

Why are transformers so important for our electricity net?

Transformers are used to convert voltages. Our electric distribution net uses high voltages when transporting electricity over large distances. This is done to minimize resistivity losses. Consider for example that a windmill near Abilene generates electricity that is used all the way in Austin Texas.
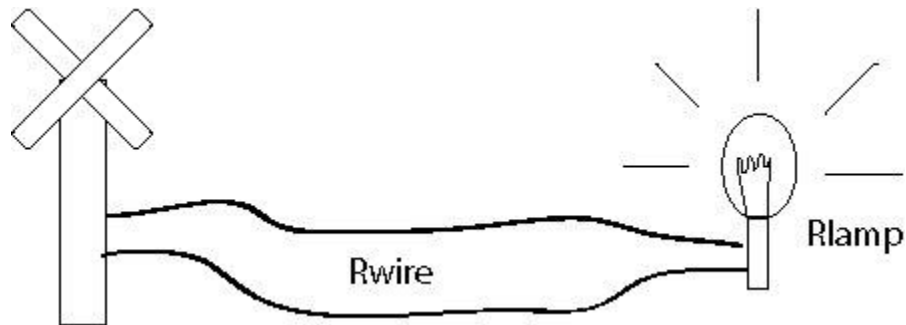
Part of the energy is transported from Abilene to Texas will be lost as the aluminum wires have a resistance. The electricity lost in the transmission wires is proportional to the current THROUGH the wires and the voltage across the wires:

$$P=i*V \qquad\qquad [1]$$

We could rewrite this equation by using Ohm's law to:

$$P=i*i/R=i^2/Rwire \qquad\qquad [2]$$

So one can see that the power loss in the transmission lines from the windmills in west-Texas to Austin is proportional to the current square. So the larger the current through the wires the larger the Ohmic losses. A certain amount of electric power (P=i*V) can be transported different ways. One can use a high voltage and a small current, or one can use a low voltage and a high current, i.e.

$$P=i_{small}V_{large} \qquad P=i_{large}V_{small} \qquad\qquad [3]$$

The total amount of energy transported per second of course is given by P and can be equal to each other. According to the loss equation above, the loss is proportional to the current square. So the smaller the current the lower the losses. So for this reason one uses transformers in Abilene to step up the voltage, and of course transformers in Austin to step down the voltages, as you do not want 15 kVolt to come out of the socket in Austin.

Transformer Losses?

Transformers are used everywhere to step down or step up the voltage. Think of: cell phone chargers, for powering computer chips, for toys, etc. Electric current will pass through numerous transformers between generation in the electricity plant and the use in by the consumer. In the USA we use 4E12 kWatt.hour a year which corresponds to 400 billion dollars. So if one can come up with better transformers that are maybe only 0.1% more energy efficient one can still save a lot of money and make a difference (0.4 billion dollar/year). Discuss the losses. Remember you like to refer back to what we learned earlier in the semester.

1. Ohmic losses in the copper wires. The copper wires have a resistance. So part of the energy that goes into the primary coil will result in heating of the transformer. To reduce copper losses , the copper wires are made with a larger cross sectional area, so their resistance is reduced.
2. Eddy Current losses in the magnetic iron core of the transformer. The varying flux will not only create an electric field twister around the copper wires, but also an electric field twister in the magnetic core of the transformer. As the magnetic core of the transformer is of iron, these electric field twisters will cause eddy current in the magnetic iron of the transformer. As the iron has a resistance, these eddy currents will result in heat. We refer to those losses as eddy current losses. Eddy current losses can be minimized by not using a block of iron for the core, but to laminate the core and electrically insulate each plate of the core. Ask the students to observe the core of their magnet in close-up. The plates of iron are glued together by insulating paint. So the core has a high resistance and the eddy current losses are strongly reduced.
3. The last type of loss has to do with the magnetic material. During one cycle the magnetic flux through the iron is cycled between two directions. To change the magnetic moment from one direction to the other direction requires an amount of work to be done. This results in an energy loss. These losses are referred to as hysteresis losses. The amount of loss depends on the magnetic hysteresis of the material. In the Physics department we have several pieces of equipment that can measure the magnetic hysteresis.