Basic Electric Transformers

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Lesson Focus

This lesson focuses on transformers as one of the most important components in any electrical system. Students engage in a hands-on activity where they build and test a simple but working transformer, using inexpensive materials.

Lesson Synopsis

The lesson begins by outlining the work of some of the early experimenters and the sequence which eventually led to the realization of how a changeable electro-magnetic field could be harnessed to do real work. From there the lesson goes on to outline the advantages offered by alternating current (AC) power systems over the direct current (DC) systems. A hands-on activity in which the students can build and test a simple but working transformer, using inexpensive materials obtainable in any hardware store, at a cost of only a few dollars and are re-usable.

The lesson ends with a section in which the students are invited to discuss with the teacher, various ways in which they think their demonstration transformer could be improved. A glimpse of a very large "real world" transformer is also provided.

Age Levels

14 to 18

Objectives

Students will:

- Learn about what transformers are.
- Learn about what transformers do.
- Learn about how transformers are made.
- Make small demonstration transformers.

Anticipated Learner Outcomes

Students will gain:

- Ability to understand and articulate what transformers are, what they do and where they can be found.
- The importance of disciplined team work.
- Problem solving.

Lesson Activities

- It is suggested that the first (45-minute) session be devoted to the teacher explaining to the class the text material and diagrams contained in this lesson. Teams of students then build and test their transformers in subsequent sessions.
- Desirably the class should have enough sets of components to provide an activity for all students working in groups of, say, four or five to a team. The students can

decide for themselves whether they help assemble the transformer “core” or to help wind the two coils. (Note that all these components can be re-used many times over, so there is no wastage). See Figs 8 – 13. Depending on the age and manual dexterity of the students, one or maybe two further sessions should be allowed for them to build their demonstration transformers.

- The core is made from 24 small (2” x 2”) steel corner brackets, available in any hardware store. These can, of course, be re-used over and over again.
- The formers on which the coils are wound are short pieces of 1-1/8” inside diameter plastic water pipe, cut to a length of 1” as accurately as possible. To save time, it is suggested the teacher prepares these pieces ahead of time. The wire used should be “magnet wire”, meaning that it is insulated with varnish. It is suggested that #30 AWG be used (or a wire of about 0.25 mm diameter). (AWG stands for “American Wire Gage). Anything smaller is difficult to handle, and anything larger takes up too much room on the former. (A 1lb. spool of #30 magnet wire contains about 2,000 ft of wire, sufficient for at least 10 pairs of coils). Two students are required to wind the coils; one to hold the spool of wire, while the other winds the wire onto the short lengths of plastic pipe. One coil should have 150 turns and the other 300 turns. This should be done slowly and deliberately, with both students counting, to avoid errors! Wrap each coil with green masking tape and mark each with the number of turns.

Resources/Materials

- Teacher Resource Documents (attached).
- Student Resource Sheets (attached)
- A list of items required for the hands-on exercise, plus some helpful photographs showing the assembly process, are included at the end of this lesson

Alignment to Curriculum Frameworks

- See attached curriculum alignment sheet.

Internet Connections

- TryEngineering (www.tryengineering.org)
- ITEA Standards for Technological Literacy: Content for the Study of Technology (www.iteaconnect.org/TAA)
- NSTA National Science Education Standards (www.nsta.org/publications/nses.aspx)

Recommended Reading

- Wikipedia “How transformers are made”.

Optional Writing Activity

- Having discussed the obvious limitations of this very simple demonstration unit, students should be asked to set out ways in which they think it could be improved.

For Teachers:
Teacher Resources

◆ Lesson Goal
Students will learn that transformers are one of the most important components in any electrical system. Students engage in a hands-on activity where they build and test a simple but working transformer, using inexpensive materials.

◆ Lesson Objectives
Students will:
- Learn about what transformers are.
- Learn about what transformers do.
- Learn about how transformers are made.
- Teams of two or three make small demonstration transformers

◆ Materials and costs
See the Transformer Parts List at the end of this lesson. In most instances, if the hardware store understands that the materials are for a school project, they will give a substantial discount.

◆Additional Safety Note:
Students should be clearly warned that on no account should they attempt to connect this simple apparatus to the 120 volt ac domestic supply.

◆ Time Needed
- Two to three 45-minute sessions

◆ Related Lessons
This lesson forms part of an interrelated set of four lessons, the others being "Basic Electricity and Magnetism", "Basic Direct Current Generators and Motors", and "Basic Alternating Current Motors".

Let there be no misunderstanding!

If the electrical transformer had never been invented, life as we know it today would still be back where Thomas Edison left it in 1880. Without the transformer, we would still be using "direct current" (school boards) for all domestic and industrial purposes. There would be no long distance transmission of energy and no large scale power generating stations, either thermal, hydro or nuclear. In short, there would be no economies of scale and no major industries. Direct current is fine for sending relatively small amounts of electricity (say, 1,000 kW) relatively short distances, (say a mile or two). But beyond that, either the voltage required would have to be too high for safety (say 1,000 volts) or the transmission losses (I^2R) would become unacceptably high (say 30% or more).

And as if all that were not enough, transformers have two additional advantages:-

- They have no moving parts and are therefore robust, cheap and very long-lived. 50 years is normal and some go to 100 years.
- Similarly, because they have no moving parts, they are astonishingly efficient. Even the small grey cylindrical things you see on hydro poles outside your house, (Fig 1) have efficiencies of 97% or better, while the really big ones in major substations (see Figs 6 & 7) have efficiencies of 99.9% or better.

Fig. 1

Typical single phase distribution transformer which takes a supply voltage of 15-kV and steps it down to 120 Volts for household consumption. Power rating 10 kVA (10,000 volts x amps)

And yet today transformers are almost always taken for granted and therefore overlooked.

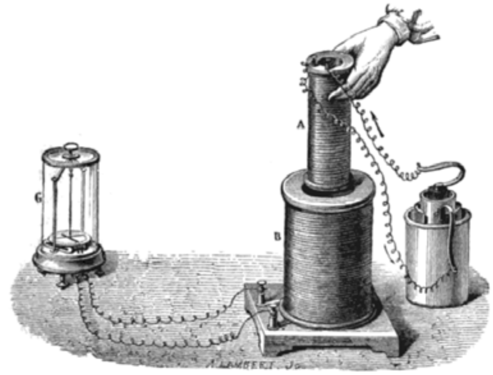
THE BASICS

FLUX-TURN LINKAGES, RATE OF CHANGE OF FLUX-TURN LINKAGES, AND INDUCED VOLTAGE.

This effect was first discovered in 1821 by the Danish scientist Hans Christian Oerstead, and further developed by Michael Faraday (1791-1867) in the period between 1821 and

Fig. 2

1835, and is illustrated here in Fig 2. As a matter of interest, this illustration comes from the notes of Faraday himself, and as you will see, his experiment comprised two quite large coils of wire, too large to reproduce in a classroom. The upper coil (the one held by a hand) was connected to an electric battery. The lower, slightly larger, coil was connected to what in those days was called a "mirror galvanometer"[1].



This instrument was very sensitive and comprised a small mirror suspended vertically by a fine thread. The upper end of the thread was attached to a very small coil of very fine wire. The lower end of the thread was anchored to the base of the apparatus. The purpose of the small mirror was to reflect a small beam of light onto a screen, and in doing so, significantly magnify the scale of reflection. The whole "Galvanometer" was enclosed in a glass cylinder for protection.

The sum and substance of this apparatus was as follows

- The d. c. current passing through the upper coil formed an "electro magnet". As Faraday lowered this coil into the larger coil, he noted that the mirror in the galvanometer deflected slightly.
- Then, when he withdrew the upper coil, he observed that the galvanometer deflected in the opposite direction.
- Faraday also observed that the faster he inserted and withdrew his electromagnet, the greater the deflection of the galvanometer.
- It was not long before Faraday realized that if he substituted a strong bar magnet for his electromagnet, he could get the same results with much less complication.

This exercise is intended to illustrate the fact "an induced voltage is proportional to the <u>rate of change</u> of flux-turn linkages". Note here also the use of the term "induced" voltage. The word induced is used here to distinguish between a voltage arising from some sort of magnetic interaction, and a steady voltage coming from a battery or other source. Double the number of magnetic lines and the voltage will double. If you double

[1] Luigi Galvani, 1737 – 1798. An Italian physician. He is most noted for the discovery that when a frog's leg was allowed to touch an source of electricity, the leg would twitch. In other words it was galvanized into action!

the number of turns in the coil, or double the speed at which the magnet is moved, and the voltage will similarly double.

As a matter of interest, if you could arrange a mechanism which could smoothly insert and withdraw the bar magnet, (a slow speed steam engine perhaps), you would have immediately made yourself an alternating current (AC) generator. As a matter of interest, some early experimenters did in fact attempt to make generators this way, but a rotating magnetic field was soon found to be better.

FLUX DENSITY, SATURATION, MAGNETIC PERMABILITY, HYSTERESIS AND EDDY CURRENTS

Permeability: By this point the concept that ferrous metals make good magnets should be relatively clear. (See related Lesson Plan “Basic Electricity and Magnetism”). By experiment over the years, metallurgists have found that different grades of iron make different (i.e. stronger or weaker) magnets. Similarly that some grades of iron can retain their magnetism over very long periods (years), while other will loose it almost as soon as the electromagnetic current is cut off. This can be measured and is calculated in terms of the number of (magnetic) lines per square inch of cross section of the iron used. By way of illustration, a common figure for a maximum flux density in ordinary soft iron or mild steel is about 15.000 lines per square inch. In other words the iron mentioned above would be said to have a permeability of 15,000. By contrast, and as a standard reference, the permeability of air is taken as 1.00. This is a very important concept to keep in mind, because it tells us that if you have a magnet which has only a coil of wire with air inside, you will need 15,000 times more effort to produce a magnet of the same strength. This is a huge difference. Or conversely, with a coil of wire having an iron core inside it, you can get the same strength using 1/15.000 (0.000066) the amount of effort! The student should appreciate here that the matter of “Lines of Magnetic force” is purely a concept, to facilitate calculations. They cannot be seen.

Saturation: Following on from the above, most steels exhibit a marked tendency resist additional flux density beyond a certain point. In other words, the steel simply does what the word implies – it saturates, and cannot be further magnetized.

Hysteresis: During their early investigations, the pioneers in this field made another interesting discovery. They plotted a graph of the flux density (lines/sq inch) versus current in the coil. This current, was of course d. c. from a battery. What they obtained was curve which increased smoothly until a certain point, beyond which it began to fall off due to saturation. But then, as they gradually reduced the magnetizing current again, the curve they obtained "on the way down" was slightly higher than it had been "on the way up". Furthermore, if they kept going "up" with the opposite direction of current, they got the same shape of curve as before, only of course "upside down". Finally, as they backed down again with current in the opposite direction, the got the same effect the remaining magnetism was slightly stronger than on the way "up". See Fig 3. This was a very significant finding, because what it means is that the area inside this loop represents the amount of energy required to magnetize, de-magnetize and then re-magnetize the sample in the opposite direction. Although very small, you should understand that if this is repeated many times per second, it can begin to represent a significant consumption of energy. This explains why, for example, many electrical appliances gradually become warm – or even hot, if carried to extremes. This characteristic is common to many materials. For example, it explains why motorcar tires become warm after a long trip. As the rubber is repeatedly flexed, the hysteresis of the rubber creates heat. So, you see that magnets are not the only things which exhibit hysteresis.

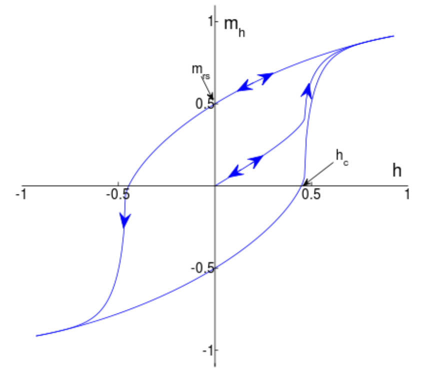


Fig. 3

Eddy Currents. The last major characteristic which affect almost all electrical equipment is what are known as "Eddy Currents". Supposing you had a really large diameter solid iron bar, say, 6" in diameter. And supposing you then wound a large coil of magnet wire around the outside. The exact number of turns doesn't matter for the moment. And then again suppose you applied even a small AC voltage to the coil. That voltage would immediately set up an alternating current in the coil, which in turn set up an alternating flux in the iron bar. Two things would immediately happen. (a) The ac flux would cause some (quite small) hysterisis losses. These would probably not be very large. But (b) the flux inside the iron bar would also induce a voltage inside the iron, just as it does in the secondary coil outside the bar. With nowhere else to go, this induced flux would set up an induced voltage in the iron. And these induced voltages would cause induced currents to flow in the iron. And here lies the main problem. Iron has a comparatively low resistance (more than copper, but much less than glass, for example). Thus these induced currents, with very little resistance to limit them, could reach very high values, with correspondingly very high heat losses. Even as late as the late 1880's Edison did not realize this in his early machines, and they soon ran very hot. The solution, however, was fairly easy. Instead of using solid iron components, he hit on the notion of building them from layers of very thin steel, (known as "laminations"). Each lamination was coated with a very thin layer of insulating varnish. This was a very satisfactory solution which is still used today. Because each lamination was very thin (about 0.015" thick) the resistance was correspondingly high and the loss was reduced to a small fraction of the solid material. (See the hands-on demonstration at the end of this lesson).

The results of Faraday's experiments, which were largely intuitive, were subsequently placed on a firm analytical basis by James Clark Maxwell (1831-1879)

HOW DOES A TRANSFORMER WORK?

The operation of a transformer is really quite simple, and is the reason why transformers are cheap, robust and efficient. Refer to Fig 5 below.

You will see that each time Faraday inserted and then withdrew the inner coil, the galvanometer deflected, first one way, and then the other. In effect this was a pulsating effect, although very slow. Now suppose, instead of the hand-operated inner coil, Faraday had used an inner coil permanently fixed in place, but which was supplied from an alternating voltage. He would have obtained the same effect. The only difference is that in Faraday's day he had to create the pulsing effect by hand because there were no AC generators with which to supply his "transformer". Indeed even the word "transformer" probably had not been invented. But 50 years or so later, when alternating current generators first became available (Siemens of Germany), it became apparent to experimenters that applying a comparatively low alternating voltage to one winding of a "step-up transformer", could produce significantly higher voltages in the other winding, which in turn were ideally suited to long-distance transmission of electrical energy. Some of the early experimenters in this field were Gaulard and Gibbs in Europe, Ferranti in

Britain, together with Stanley and Westinghouse in the United States, all in the period 1880 - 1885.

(As a historical note here, Edison, whose early experiments were all with direct current, was bitterly opposed to alternating current – for personal and commercial reasons – and fought it for many years, before more or less capitulating in the early 1900's.).

Fig 4 illustrates how a simple transformer works. Assume the primary winding has 100 turns and the secondary winding has 200 turns. Assume also that the primary winding is connected to a source of AC voltage. This voltage will send an AC current through that winding. The current then induces an alternating magnetic flux in the steel core. Assuming the core has no significant air gaps, this flux will permeate right round the closed loop of iron. In doing so, each time the flux alternates from "north" to "south" and back again, it will induce flux-turn linkages in the secondary winding. Assuming that the magnetic flux is uniformly distributed throughout the core, the flux-turn-linkages in both windings will be the same. In this example, if the primary winding has 100 turns and that 100 volts is applied to it, that will represent (100 Volts/100 turns) = 1 volt per turn. And then assuming all flux created in the primary winding links with the 200 turns in the secondary winding, this will produce (1 volt/turn x200 turns) = 200 Volts.

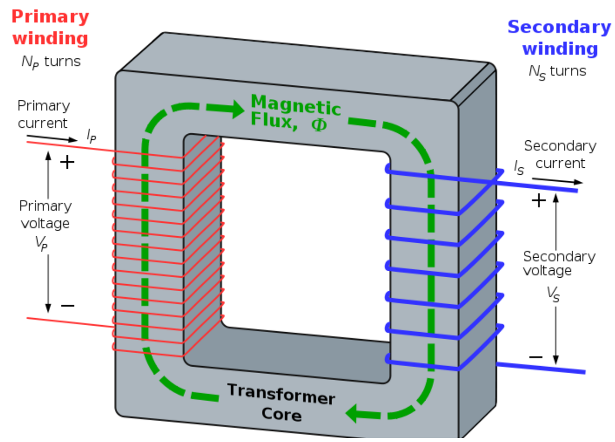


Fig. 4

Credit: http://en.wikipedia.org/wiki/File:Transformer3d_col3.svg

Flux Leakage

In actual fact not all the flux produced by the primary winding will link with the turns in the secondary coil. Some of it leaks away, as shown in Fig 5. This is known as flux leakage and is largely dependent on how closely the two coils can be situated together. Leakage flux results in a slight (maybe 3% - 5%) reduction in

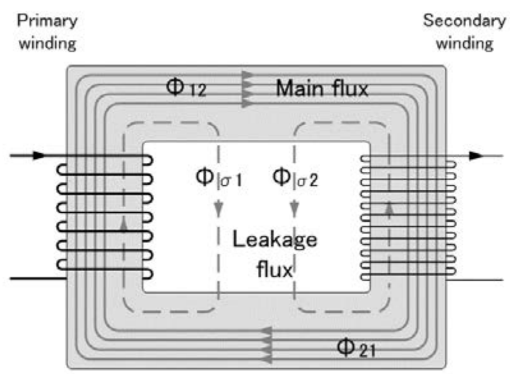


Fig. 5

Credit: http://en.wikipedia.org/wiki/File:Transformer_flux.gif the voltage ratio of the transformer. But it does not materially reduce the efficiency, because the voltage ratio can be adjusted upwards slightly by adding a few turns inn the secondary coil to compensate for this.

A "REAL" TRANSFORMER

- Real transformers come in a wide range of sizes, from those producing milliamps for use in electronic circuits, to huge units producing hundreds of Mega Volt-Amperes (MVA). The latter are known as "power transformers". Student Note: stands for Mega. K stands for Kilo). For a more complete listing of electrical symbols and abbreviations, see page 22 of related lesson plan "Basic Electricity and Magnetism".

- A really large "power" transformer would look something like that shown in Figs 6 and 7. There would a substantial steel "core", rectangular in shape and looking rather like a large picture frame. The whole of the upper part of the core would be removable, to permit placement of the coils.

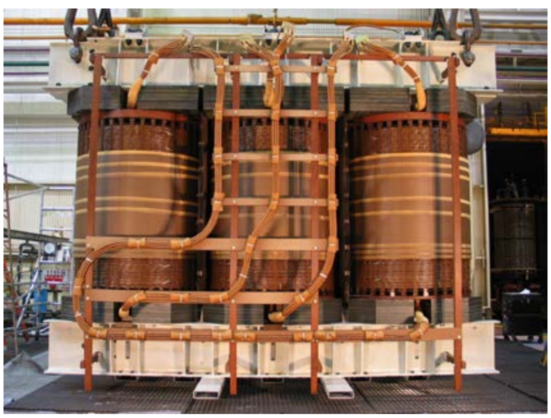


Fig. 6
Credit: Pennsylvania Transformer Company

Fig. 7
Credit: Pennsylvania Transformer Company

MOVING ON A BIT The above has been a very much simplified outline of what a transformer is and how it does it. For good measure, however, the following notes may serve to amplify the present day technology.

- Insulation of coils. For small transformers, the coils are usually wound with varnish insulated wire as used in the hands on demonstration below. But for larger transformers the copper is usually of rectangular cross-section and insulated with several layers of high quality brown paper. (See "Cooling below".

- Cooling: Liquid filled. Although the introduction to these notes emphasizes the almost amazingly high efficiency of a transformer, the fact remains that transformers do give off some heat. Therefore all but the very smallest require some form of cooling. There are now two basic types – Liquid cooled and dry type. By far the most common is the liquid cooled, with the liquid being oil. This is a special type of oil which looks a little like furnace oil. It has however been specially formulated to provide very high insulating properties. This oil offers several advantages.
- It is very effective in carrying off the surplus heat via external cooling fins.
- Long experience has shown that a combination of paper insulation (of the copper windings) soaked in oil is by far the most effective insulating material. Remember that transformers have no moving parts, so the softness of paper is not a problem
- To contain the oil, the whole ensemble has to be enclosed in an oil-tight tank. The oil also serves to muffle the electrical hum to some extent.
- The large transformer shown in Fig 7 shows these cooling fins or radiators. Note also the fans used for additional cooling on hot days.
- The principal disadvantage of oil is that it is highly flammable and can only be used out doors.
- For special application and at considerable extra expense a non-flammable liquid silicone can sometimes be used.
- For voltages higher than about 10,000 volts, and up to the highest in use today – 800,000 volts, oil filled transformers are almost universal because of the much superior insulating and cooling properties.
- A really large transformer can weigh 500 or 600 tons. Such a weight, of course, puts a severe limitation of transportation. Also, as noted above, the insulation of large transformers is mostly many layers of paper soaked in a specially formulated mineral oil. With time, the paper has a tendency to become brittle, which in turn would break if the transformer is jolted during a moving process. For these two reasons, most large transformers are almost never moved once they are installed in the intended location, and it is not uncommon to large transformers still in regular service after 75 or even 100

years." Remember also that transformers have no moving parts, so there is absolutely no "wear and tear" in the accepted sense.

- Cooling Dry Type. The cheapest and most basic is what is known as a “Dry-Type” or “Air cooled”. In this type the coils are dipped in a thermal setting varnish for protection against moisture. As a matter of interest the copper wire used in these transformers is simply a scaled up version of the varnished “Magnet Wire” mentioned above. The coils are made with large open spaces in them, to permit a generous flow of air through them. This flow is by what is known as “convection”. Fans to force the flow of air are almost never used. With this type of design all live terminals could be easily accessible and therefore dangerous. The whole assembly is therefore enclosed in a wire mesh cage for safety reasons. Dry type transformers also have a tendency to be a little noisy, emitting a pronounced hum. The main advantage of a dry-type transformer is that it is completely non-flammable, and therefore safe for use in doors.

HANDS-ON DEMONSTRATION

1. Before proceeding to the practical demonstration described below, the teacher should obtain a “Bell Transformer” from a local hardware. Bell transformers are used to power domestic front door bells or chimes. They step down the household voltage of 120 - 240 volts to 8 volts, which is a very safe voltage for students to handle.   In some instances school boards have an upper limit of 12 volts for classroom use. However, in this particular instance, although the transformer has a nominal step-up ratio of 2:1, which would in theory give an output voltage of 16 volts, the various imperfections of the demonstration transformer limit output voltage to about 13 or 14 volts, which is still perfectly safe for classroom use (Teachers may wish to check this with their local school board).

2. It is recommended that the teacher enclose the bell transformer into a steel or plastic receptacle box normally used for wall mounted light switches, as shown in Fig 8. (Safety note: Many bell transformers have

Fig. 8

additional screw-type terminals for output voltages of 12 or 16 volts. These should be deactivated by removing those screws. See Figure 8.

3. The teacher should also obtain several feet of 1-1/8" inside diameter plastic water pipe. See Transformer Parts List below. Cut off a number of short pieces, each 1" long. The ends should be as smooth and as accurately cut to length and as square as possible. Otherwise they will not fit into the demonstrator transformer – see Fig 9. Two such lengths are required for each transformer. The total number cut will depend on the size of the class.

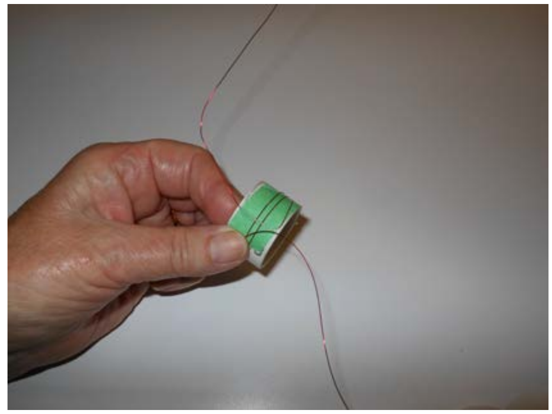


Fig. 9

4. The class should be provided with a spool of #30 AWG magnet wire. (A 1 lb. spool carries about 2,000 feet of this size of wire, which is enough for at least 10 pairs of coils).
5. Divide the class into teams of four or 5 as convenient. From each team give two students two of the pieces of pipe and tell them to wind two coils – one to hold the spool reasonably firmly, and the other to wind the wire onto the pieces of pipe. See Fig. 9.

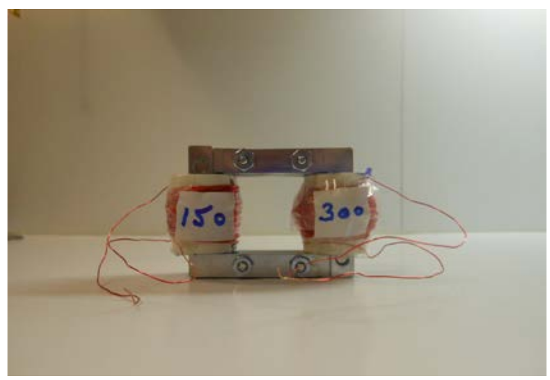


Fig. 10

6. They should wind 150 turns onto one piece of pipe and 300 turns onto the other. This should be done slowly and deliberately, with both students counting. It is easy to lose count! See Fig. 10.
7. Fix both ends of the wire with masking tape. Using a sharp knife, scrape the varnish from the last inch or so of the wire. This step can only be done after the coil winding process is completed. Note that these coils can be re-used for future classes if necessary).
8. Provide the third member of each team with

Fig. 11

24 of the small steel "corner brackets" shown in Fig.11, and 4 small nuts and bolts, size 1/8" x 1-1/2" long. (Note: These brackets should be size 2" x 2". See Transformer parts list).

9. Have these students assemble 12 of these pieces into a square "U" shape, with overlapping corners, and fix very loosely with two of the bolts as shown in Fig 11. (Easy enough when you get the hang of it!).
10. Place one of the coils on each of the two legs of the "U". See Fig. 12. Then gently interleave the remaining 12 brackets across the top of the "U" so that the whole forms a square. Insert two more of the bolts through the holes in the core and tighten all four bolts securely. You should then have your finished transformer as shown in Fig 10 above.

Fig. 12

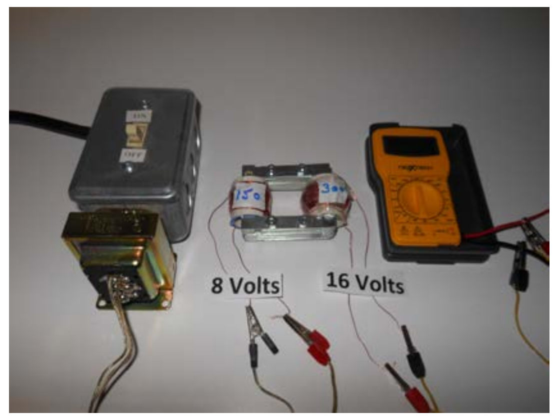


Fig. 13

11. Using small alligator clips, connect the 8 volt output of the bell transformer to the coil which has 150 turns, and connect a voltmeter to the coil with 300 turns, and turn the power on. See Fig. 13.
12. You should get a reading of approximately 13.5 or 14 volts or a little less. Why is this? It is because in the smaller coil, there will be (8 volts/150 turns) = (0.053 volts per turn). On the basis of what we have seen above, and assuming that all lines of magnetic flux link equally with the all the turns in both coils, (See Fig 4) then the voltage induced in the larger coil would be (300 turns x 0.053 volts per turn) = 16 volts. In actual fact you will probably only get about 13.5 or 14 volts. The first problem here is that not all the flux produced by the primary coil links with the turns of the secondary coil. See Fig. 5 and "leakage flux". Another problem is that our transformer has numerous air gaps and holes in it. As we have seen, it takes roughly 15,000 times as much "electromotive force" to produce a given flux in air as it does in good quality steel. A second and equally significant limitation is that we have absolutely no way of knowing the quality of the steel we have used in our core and how close it may be to its'

saturation point. “Real” transformers have specially formulated steel which produces the most flux density for the least amount of “ampere turns”.

However what we have assembled here should be enough to demonstrate the main principles of a transformer. Specifically, note that although there is no electrical connection between the two coils, both coils have an AC voltage induced in them. Students may also note that when switched “on”, the transformer will hum slightly and if left on for any length of time, may get slightly warm (but not hot!)

Safety Note:

1. Most school boards consider 12 volts to be the maximum which should permitted in a classroom. However the 13-14 volts which these very crude transformers can produce are considered equally safe.
2. However, the 16 volt screw tap on the Bell Transformer should be removed be removed as a precaution.
3. On no account should the device described above be plugged into a 120 volt receptacle.

SUMMARY

In the jargon of the industry, what we have just assembled would be known as a “Step-up” transformer. If we had reversed the connections, and applied the 8 volts to the 300 turn coil and measured the voltage on the 150 turn coil, we would have measured rather less than 4 volts, (because of its’ simplicity) and produced a “Step Down” transformer.

The above is a really basic example, put together to demonstrate the principle. In actual fact, the way in which the core is put together, especially around the corners, results in a good many lines of magnetic flux being lost to what is known as “Leakage”. Hence the voltage ratios illustrated above will be significantly less than 2:1 suggested.

But don’t forget, if it looks like a transformer and hums like a transformer, it must be a transformer.

The Electric Transformer

For Teachers:
Student Worksheet:

◆ **Reflection**

Complete the reflection questions below:

1. Supposing you had wound the transformer coil mentioned above, on a copper or aluminum tube, what difference would it make?

2. What is the meaning of the “turns ratio” of a transformer?

3. What is the base frequency of the hum emitted by a 60 Hz transformer?

4. Why did we use a plastic tube on which to wind the coils?

5. Supposing we had used 16 steel pieces for the core, instead of 24, what would be the result?

6. Are there any things that could be done to enhance the design of the transformer?

For Teachers:
Alignment to Curriculum Frameworks

Note: Lesson plans in this series are aligned to one or more of the following sets of standards:

- U.S. Science Education Standards (http://www.nap.edu/catalog.php?record_id=4962)
- U.S. Next Generation Science Standards (http://www.nextgenscience.org/)
- International Technology Education Association's Standards for Technological Literacy (http://www.iteea.org/TAA/PDFs/xstnd.pdf)
- U.S. National Council of Teachers of Mathematics' Principles and Standards for School Mathematics (http://www.nctm.org/standards/content.aspx?id=16909)
- U.S. Common Core State Standards for Mathematics (http://www.corestandards.org/Math)
- Computer Science Teachers Association K-12 Computer Science Standards (http://csta.acm.org/Curriculum/sub/K12Standards.html)

◆National Science Education Standards Grades 5-8 (ages 10 - 14)

CONTENT STANDARD A: Science as Inquiry

As a result of activities, all students should develop

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

CONTENT STANDARD B: Physical Science

As a result of their activities, all students should develop an understanding of

- Transfer of energy

◆National Science Education Standards Grades 9-12 (ages 14-18)

CONTENT STANDARD A: Science as Inquiry

As a result of activities, all students should develop

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

CONTENT STANDARD B: Physical Science

As a result of their activities, all students should develop understanding of

- Interactions of energy and matter

◆Next Generation Science Standards Grades 6-8 (Ages 11-14)

Motion and Stability: Forces and Interactions

- MS-PS2-3. Ask questions about data to determine the factors that affect the strength of electric and magnetic forces.

◆Next Generation Science Standards Grades 9-12 (Ages 14-18)

Motion and Stability: Forces and Interactions

- HS-PS2-5. Plan and conduct an investigation to provide evidence that an electric current can produce a magnetic field and that a changing magnetic field can produce an electric current.

◆Standards for Technological Literacy - All Ages

Design

- Standard 2: Students will develop an understanding of the core concepts technology.
- Standard 7: Students will develop an understanding of the influence of technology on history.

The Designed World

- Standard 16: Students will develop an understanding of and be able to select and use energy and power technologies.

TRANSFORMER PARTS LIST & COST ESTIMATE **12.Dec.2012**

Item	Source	Qty	Remarks	Unit Cost	Cost per set
Core					
Core steel	Home Hardware #2379-615	24	2" Flat corner braces ZP	$0.35	$8.40
Core bolts	1/8" x 32 tpi x 1-1/2" long	4		$0.15	$0.60
Coils					
1-1/8" id plastic pipe	Cut 1" long +/- 0"	2	Cut with pipe cutter	$5.00/8ft	$0.10
8 Volt winding	# 30 AWG 150 turns	52 ft	Insulated magnet wire	1lb = $55 = 2,000 ft	
16 Volt winding	# 30 AWG 325 turns	112 ft	Insulated magnet wire		$ 4.54
			Secure with masking tape.		
Small Robertson Screwdriver		1			n/a
Small sharp knife to scrape varnish off wire.		1			n/a
			Total per transformer		$13.64
Power Supply					
120/8 Volt Bell Transformer (or the nearest equivalent small transformer in your area)		1	Preferably mount with switch		$ 13.00
Rectangular steel or plastic receptacle box		1	in receptacle box with ground		$ 1.50
120 V light switch		1	in receptacle box with ground		$ 1.00
3 Cond flexible cable		6 ft	For power supply		$ 5.00
3-pin plug		1	Ditto		$ 6.50
Small, 12 Volt red light to indicate when power is on.		1	From "The Source" or Radio Shack.		$ 0.50
Small Crocodile clips		6	For jumpers		n/a
Speaker wire or similar		2 m	Ditto. For 16 Volt side ONLY		n/a
			NOT for use on 120 Volts		n/a
			Approximate Total. One only, reqd.		$ 30.00