GCSE Physics Coursework

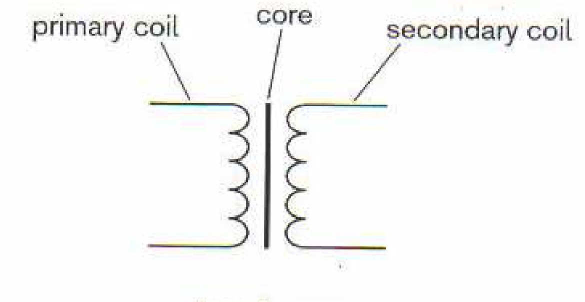
Plan

Introduction

I shall be investigating a factor affecting the voltage output of a transformer.
In order to do this I shall be measuring the range of voltages that are induced across the secondary coil of the transformer when one factor is varied. To do this as accurately as possible and to obtain a fair test I shall ensure that every other variable factor in the practical remains constant.

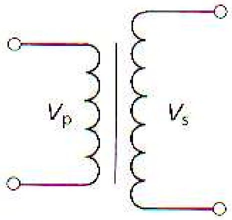
Background Theory

Transformers are used industrially to increase the low voltages produced in electricity generation (25 kV) to higher voltages to be transported in the grid electricity supply's cables (250 kV), and then to decrease these voltages for use in domestic appliances (230 V).
A transformer is a device for changing the voltage of alternating current (a.c.) signals and power supplies. Two coils are wound around an iron core, which is preferably laminated so as to reduce energy loss via eddy currents. Iron is a magnetically soft metal, which thus allows it to easily be magnetised and demagnetised (i.e. it doesn't retain a permanent magnetic field). Transformers utilise the effect of Electromagnetic Induction. The alternating voltage in the primary coil creates an alternating current, leading to an alternating magnetic field in the primary coil. The magnetic field lines move back and forth and are cut by the secondary coils, inducing a voltage in them; thus a current flows in the secondary coil.

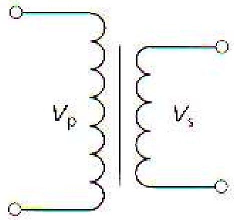


transformer

In a step-up transformer there are more turns on the secondary coil than on the primary; there is a larger voltage in the secondary coil than in the primary (i.e. larger secondary voltage).



a Step-up: $V_s > V_p$



b Step-down: $V_p > V_s$

In a step-down transformer the primary coil has more turns than the secondary, and so there is a smaller voltage in the secondary coil than in the primary (i.e. smaller secondary voltage).

Variables

In my experiment the secondary voltage is the dependent variable.

The independent variables are:

- Number of turns on the primary coil

Increasing number of primary coil turns decreases secondary voltage

- Number of turns on the secondary coil

Increasing number of secondary coil turns increases the number of times the magnetic field lines are cut, increasing the secondary voltage

- Primary voltage

Increasing primary voltage increases the current, increasing the speed at which the magnetic field alternates, increasing the number of times the magnetic field lines are cut by the secondary coil in a given time, increasing the secondary voltage

- Cross-sectional area of secondary coils

Increasing cross-sectional area of secondary coils increases the number of magnetic field lines cut in a given time, increasing secondary voltage

- Distance of separation between primary and secondary coils

Increasing the distance leads to the attenuation of magnetic field lines, decreasing secondary voltage

- Material of wire

Different metal wires have different resistances; increasing the resistance of the coil's wire decreases the current, decreasing rate at which the magnetic field lines alternate, so less magnetic field lines are cut by secondary coil in given time, decreasing the secondary voltage

- Softness of iron core

Core must be soft so as to be magnetised and demagnetised easily resulting in each reading of the secondary voltage being unaffected by a previous one via the prior build up of an electromagnetic field on the core (i.e. so each reading is reliable)

- Spacing between coils

Increasing the space between coils increases the distance the magnetic field lines have to travel, decreasing their strength, decreasing the secondary voltage

The equation relating the number of coil turns and size of voltages is;

$V_1/V_2=N_1/N_2$

Where V=voltage, N=number of turns on coil
And $_1$ and $_2$ denote primary and secondary coils respectively.

This can be rearranged to give the secondary voltage;

$V_1/V_2=N_1/N_2$

$\rightarrow \quad V_1=N_1*V_2/N_2$
$\rightarrow \quad V_1*N_2=N_1*V_2$
$\rightarrow \quad V_1*N_2/N_1=V_2$

$V_1*N_2/N_1=V_2$

The variable I have decided to use is the primary voltage (V_1). I intend to keep N_1 and N_2 constant so that V_2 is only varied by V_1. I shall also wind the same number of turns for the primary and secondary coils, with the result that whatever number of coils I decide upon for both N_1 and N_2 after the investigations of my preliminary experiments, N_2 divided by N_1 will be equal to one;

e.g. if $N_1=50$ and $N_2=50$;

$V_1 * 50/50=V_2$

$\rightarrow V_1*1=V_2$

$\rightarrow V_1=V_2$

Therefore when the primary voltage is equal to 20 V, the secondary voltage should also equal 20 V.

However, I believe that there will be some energy losses in the experiment I shall undertake. For this reason, I think that by ensuring N_2/N_1 is the constant '1', effectively it follows that according to my transformer equation V_1 should equal V_2. In this way it will be easier to see how much energy is lost in the experiment by merely subtracting each secondary voltage from its relative primary voltage. With this information I will be able to describe in my analysis and evaluation where the energy losses may have occurred and how to prevent this in any further transformer experiments I undertake.

Nevertheless if it were possible for me to carry out a 100% efficient experiment, according to the equation $V_1=V_2$, the primary and secondary voltages should be directly proportional when the number of turns on the primary and secondary coils are constant.

$V_1 \alpha V_2$

e.g.

when $V_1=20$, V_2 should =20 (when N_1 and N_2 are equal)
20V*1=20V

when $V_1=20$, V_2 should=40 (when N_2 is double N_1 [step-up transformer])
20V* 2/1=40V

when $V_1=20$, V_2 should=10 (when N_2 is half N_1 [step-down transformer])
20V* 1/2=10V

If we double V_1, V_2 should also double;

when V_1=40, V_2 should =40 (when N_1 and N_2 are equal)
40V*1=40V

when V_1=40, V_2 should=80 (when N_2 is double N_1 [step-up transformer])
40V* 2/1=80V

when V_1=40, V_2 should=20 (when N_2 is half N_1 [step-down transformer])
20V* 1/2=10V

If we half V_1, V_2 should also half;

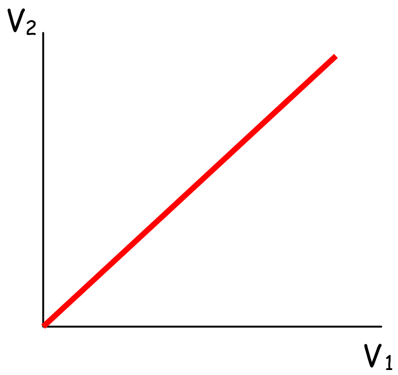
when V_1=10, V_2 should =10 (when N_1 and N_2 are equal)
10V*1=10V

when V_1=10, V_2 should=20 (when N_2 is double N_1 [step-up transformer])
10V* 2/1=20V

when V_1=10, V_2 should=5 (when N_2 is half N_1 [step-down transformer])
10V* 1/2=5V

This shows that;
The primary voltage is directly proportional to the secondary voltage

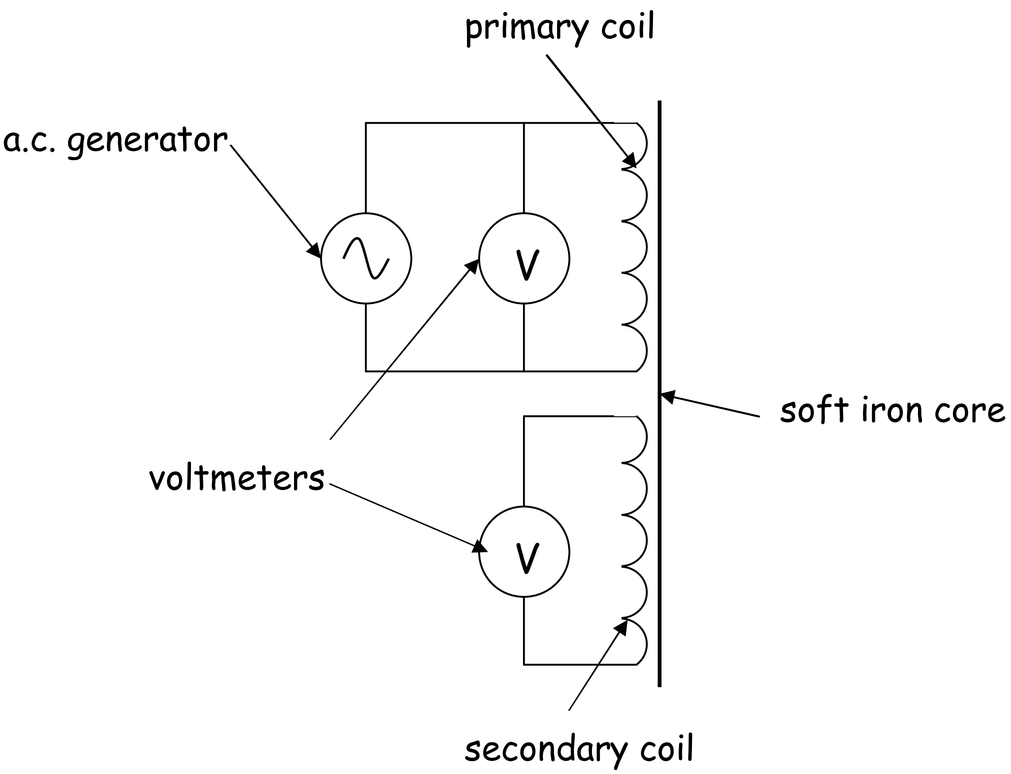
$V_1 \alpha V_2$



Apparatus

3 metres of wire for two coils of length 10cm and number of turns 50
2 voltmeters
An a.c. power supply
An iron core
Connecting wires with crocodile clips

I intend to set up my apparatus as shown below:



Method

When I have set up the apparatus as shown above, I will take voltage readings across the primary and secondary coils for nominal voltages from one to twenty volts. I shall repeat this procedure three times and average the results for each nominal voltage. Then I shall tabulate my results and plot primary voltage against secondary voltage on a graph so that I can then analyse my results.

Safety

There are a number of safety aspects I must bear in mind whilst carrying out my practical;

- The power supply mustn't be on whilst I change the nominal voltage.
- The power supply mustn't be switched on until the circuits are fully connected.
- I will limit the size of the nominal voltage.
- I will carry out the experiment on clear work surfaces, away from bench edges, and away from any water.

Standardisation/Fair Test

As well as keeping all the variables listed under 'Variables' constant (except for primary voltage of course), in particular the number of turns on the primary and secondary coils, I will also aim to standardise each repetition of the procedure to obtain a fair test. To achieve this I shall use the same core, lengths of same wire for coils, voltmeters, connective wires, a.c. supply, etc. All conditions other than primary voltage should be kept constant to obtain a fair test.

Preliminary work

Firstly I wanted to determine what distance between the primary and secondary coils gives the optimum conversion of primary voltage to secondary voltage. As shown in the table below, this distance is 0cm.

Secondly I wished to know what the best range of nominal voltages is. I found that with nominal voltages greater than 4Vm, the power supply trips after about five seconds, and so I shall take all my readings after ten seconds, and while this may not give accurate results, it should obtain ones reliable relative to each other. For nominal voltages greater than 12V the power supply trips almost instantly, with no time to take readings. Thus I have decided not to carry out the experiment for voltages over 12V.

Preliminary Results:

Distance between coils (cm)	Nominal Voltage (V)	Primary Voltage (V) (to 2 d.p.)	Secondary Voltage (V) (to 2 d.p.)
0	2	1.71	0.25
3	2	1.68	0.15
6	2	1.68	0.09
9	2	1.69	0.06
12	2	1.63	0.05
15	2	1.65	0.02
0	1	0.75	0.14
0	2	1.68	0.25
0	3	2.33	0.36
0	4	3.20	0.42
0	5	3.75	0.48
0	6	4.42	0.49
0	7	4.90	0.52
0	8	5.50	0.53
0	9	5.90	0.54
0	10	6.10	0.54
0	11	6.34	0.55
0	12	6.70	0.54

Conditions used in preliminary;

Each coil length 1.5m, and 50 turns
Coils range of distances apart
Readings for nominal voltages 1-20V

Conditions for actual experiment;

Each coil length 3m, and 100 turns
Coils 0cm apart
Readings for nominal voltages 1-12V

Prediction

I predict that as I increase the primary voltage, the secondary voltage will also increase, and that the primary and secondary voltages should be directly proportional.

This is because as the primary voltage is increased, so the alternating current in the primary coil also increases. This results in the magnetic field lines changing direction more frequently, and so are cut more times in a given time period by the turns on the secondary coil, increasing the voltage induced, via electromagnetic induction, in a given time. Thus increasing primary voltage increases the secondary voltage.

Yet I can be even more specific. As I will have the same number of turns on the primary and secondary coils, and they will be made with the same wire (i.e. will have same resistance), in these conditions the primary voltage should always equal the secondary voltage (in the circumstances of the transformer being 100% efficient). However due to my preliminary results I know that this is not true; the secondary voltage is less than the primary voltage in the experiment I will undertake due to losses in power, the causes of which I will discuss in my Evaluation and Analysis.

Results

V_1=Primary Voltage
V_2=Secondary Voltage

Nominal Voltage (V)	V_1 (V)			V_2 (V)			Mean V_1 (V)	Mean V_2 (V)	Difference between V_1 and V_2 (V)
1	0.58	0.58	0.59	0.13	0.13	0.13	0.58	0.13	0.45
2	1.43	1.43	1.41	0.32	0.33	0.32	1.42	0.32	1.10
3	1.96	1.95	1.97	0.42	0.41	0.42	1.95	0.42	1.53
4	2.83	2.82	2.83	0.52	0.51	0.51	2.83	0.51	2.32
5	3.16	3.09	3.22	0.54	0.54	0.54	3.16	0.54	2.62
6	3.96	3.97	3.99	0.60	0.60	0.60	3.97	0.60	3.37
7	4.29	4.32	4.38	0.62	0.61	0.61	4.33	0.61	3.72
8	5.18	5.13	5.17	0.64	0.65	0.64	5.16	0.64	4.52
9	5.35	5.42	5.46	0.65	0.65	0.65	5.41	0.65	4.76
10	5.90	5.86	5.94	0.67	0.66	0.66	5.90	0.66	5.24
11	6.09	6.23	6.21	0.67	0.67	0.67	6.18	0.67	5.51
12	6.44	6.62	6.48	0.67	0.67	0.67	6.51	0.67	5.84

Conditions on day for experiment;

Each coil length 2m, and 70 turns
Coils 0cm apart
Readings for nominal voltages 1-12V

As I predicted, the power supply tripped out very quickly towards the upper end of my nominal voltage range; particularly from around 9V onwards. While my results are therefore unlikely to be accurate, I believe they are reliable as I read every voltage after the power supply had been turned on for three seconds.

Suitability

I believe that some aspects of my procedure were suitable to gain good results, whilst others were not.

Analysis

As can be seen in my results table, increasing the primary voltage increases the secondary voltage. In this way my results support my prediction.

I plotted these results on a graph so that this relationship can be seen more clearly. I then constructed lines to see whether the secondary voltage is directly proportional to the primary voltage, as I predicted.

Primary Voltage (V)	Secondary Voltage (V)
0.50	0.11
1.00	0.22
2.00	0.43
4.00	0.6
0.75	0.16
1.50	0.33
3.00	0.53
6.00	0.67

As can be seen from this table, it at first seems that V_2 is directly proportional to V_1 (i.e. doubling V_1 doubles V_2). This is certainly true for primary voltages up to about 2.0V (see graph), but after this point, increasing V_1 increases V_2 at a decreasing rate. From this point onwards, while increasing the primary voltage will increase the secondary voltage, the two are not directly proportional.

The graph is straight up until V_1=2.0V, showing direct proportionality, but after this point the graph curves until it levels off at around V_1=6.3V, where increasing V_1 doesn't appear to increase V_2.

My results are without any anomalies, and show a trend that was anticipated. All replicates were very consistent, showing that my results are reliable. As there is a large discrepancy between the values in my predicted calculations, and the data I have obtained, and as there are many flaws in the experiment, I don't, however, believe they are accurate. Nevertheless my results demonstrate that increasing the primary voltage increases the secondary voltage.

This is because as the primary voltage is increased, so the alternating current in the primary coil also increases. This creates an alternating magnetic field in the primary coil, resulting in the magnetic field lines changing direction more frequently. They are cut more times in a given time period by the turns on the secondary coil, increasing the voltage induced, via electromagnetic induction, in a given time. Thus increasing primary voltage increases the secondary voltage.

There are a number of reasons why V_2 doesn't equal V_1:

- Not all the magnetic field lines pass from the primary to the secondary coil.
- When a current is induced in the secondary coil, a heating effect occurs due to the coil's electrical resistance. This is wasted energy.
- As the magnetic field lines alternate back and forth, unwanted eddy currents are produced in the iron core (iron is a metal and thus a conductor), creating a heating effect (during the experiment I noticed that the core got hot and the coil's insulation began to melt at higher nominal voltages).
- The wires used are metals. Therefore they contain delocalised electrons, which are free to move and collide with atoms, generating heat. This too is a source of energy loss.
- At the higher voltages a humming sound was heard. This was caused by the rotation of domains in the iron core.

I shall now account for V_1 and V_2 not being directly proportional as the transformer equation tells us:
At larger nominal voltages, e.g. when nominal voltage=10V, the primary coil gets hot. This is because a high constant voltage leads to a high current. This high current increases the number of collisions between electrons moving round the circuit, increasing the resistance of the primary coil.

$$V=IR$$

When there is a constant voltage;

$$k=IR$$

→ $k/R=I$

→ Increasing resistance decreases current (they are inversely proportional)

A high resistance leads to a low current, so the electrons can't move passed a given point in the circuit as quickly. The weakened alternating current leads to a weakened alternating magnetic field. Therefore not as many magnetic field lines are cut by the turns on the secondary coil in a given time, and consequently a smaller voltage is induced.

I predicted via my good scientific knowledge and calculations that V_1 should be directly proportional to V_2. Moreover that when N_1 and N_2 are equal V_1 and V_2 should also be equal. I found from my results that while the V_1 and V_2 are directly proportional up until a certain point (V_1=2V) they are certainly not equal due to the inefficiency of the transformer. Also, after V_1=2V, there is no direct proportionality between V_1 and V_2. This is as the higher the voltage the higher the resistance. Yet increasing V_1 does increase V_2 up until a point where my graph appears to level off at V_1=6.3V. While the results aren't the same as my predictive calculations, I did expect there to be some discrepancy between them in view of my preliminary work. Therefore I believe that I have obtained good results as the curve I obtained is smooth and there is direct proportionality up to a certain point, and as the experiment carried out was undertaken in a restrictive school laboratory.

Evaluation

I found that the procedure was fairly easy to carry out, and worked well, as I have obtained evidence that has shown a definite trend. The only slight difficulty was the measuring of voltages within three seconds of turning the power supply on. I have no anomalous points, as they all lie on the line of best fit, which suggests my results are reliable.
There are a number of reasons why I don't believe the procedure was entirely suitable. The problems I found are outlined below, along with possible solutions I might employ in future extension work.

- The power supply tripped out too soon after being turned on, with the result that my readings are probably not as accurate as they would have been if I had waited until any fluctuation subsided to take the readings. Nevertheless I don't think this affected reliability, as I took the readings at the same time (3 seconds) after turning on the power supply. A power supply with a higher tolerance should be used in future work.
- By looking at my graph it is possible to see that there are large gaps between points. I should like to repeat the experiment taking readings at intervals of 0.5V instead of 1.0V to be more certain of my line of best fit and its trend.
- Taking more replicates would increase reliability and my faith in the results.
- It is evident that there is some problem in the experiment as the primary voltage is so much less than the nominal voltage.
- I used a fairly narrow iron core. Using a thicker one in future work may strengthen the magnetic field in the primary resulting in a greater secondary voltage being induced.
- Using a different number or ration of coils may result in a greater conversion of primary voltage to secondary voltage.
- I stated that the separation of the coils would be 0cm. Perhaps it is necessary to be more specific. What I meant was that the two coils would be side by side, with their edges just touching. However no gap could be construed as meaning that there was an overlap between the two coils. I don't believe this would give a favourable conversion of V_1 into V_2 as the magnetic field lines would not be cut by the maximum number of secondary coils turns. However I would like to carry out work varying the distances and overlaps between the coils to find out if this statement is correct.

I have described the reasons why I don't believe my results are accurate in the Analysis section. By looking at my results graph it is possible to see that V_1 is certainly not always directly proportional to V_2, as the graph curves instead of being straight. Nevertheless I do believe my results to be reliable on account of the smooth trend their averages have produced, and as no anomalies were obtained. Furthermore the ranges, in which replicates from the same nominal voltage lie, are very small. This is illustrated in the table below:

Nominal Voltage (V)	V_1 (V)			Range between V_1 s (V)	V_2 (V)			Range between V_2 s (V)
1	0.58	0.58	0.59	0.01	0.13	0.13	0.13	0.00
2	1.43	1.43	1.41	0.02	0.32	0.33	0.32	0.01
3	1.96	1.95	1.97	0.02	0.42	0.41	0.42	0.01
4	2.83	2.82	2.83	0.01	0.52	0.51	0.51	0.01
5	3.16	3.09	3.22	0.13	0.54	0.54	0.54	0.00
6	3.96	3.97	3.99	0.03	0.60	0.60	0.60	0.00
7	4.29	4.32	4.38	0.09	0.62	0.61	0.61	0.01
8	5.18	5.13	5.17	0.05	0.64	0.65	0.64	0.01
9	5.35	5.42	5.46	0.11	0.65	0.65	0.65	0.00
10	5.90	5.86	5.94	0.08	0.67	0.66	0.66	0.01
11	6.09	6.23	6.21	0.14	0.67	0.67	0.67	0.00
12	6.44	6.62	6.48	0.18	0.67	0.67	0.67	0.00

While the method gave reliable results I do believe it would be possible to improve their accuracy. I have stated earlier in the Evaluation what improvements could be made.

I think that I do have enough evidence to draw a conclusion, yet carrying out more replicates and performing the experimental procedure for a greater number of nominal voltages (e.g. every 0.5V) would improve the reliability of my results and the accuracy of their graph's best-fit line. I would like to perform the experiment for nominal voltages over 10V to find out whether the graph truly levels off, as my results suggest. The more data I collect the more faith I can have in any conclusions drawn.

To further investigate factors affecting the voltage output of a transformer I should like to experiment by varying the number of coils on the primary, the number of coils on the secondary, the ratio of N_1 to N_2, the size of the iron core, the metal used for the coil wire and the gap between the primary and secondary coils. With this information I would be able to understand better how a transformer works and is affected by different variable factors. Overall I think the experiment worked well.