**Chapter 28: Electromagnetic Induction**

***Please remember to photocopy 4 pages onto one sheet by going A3→A4 and using back to back on the photocopier.***

Changing flux ⇒ induced emf ⇒ induced current ⇒ magnetic field

**Electromagnetic Induction** occurs when an emf is induced in a coil due to a changing magnetic flux.

We have seen from the last two chapters that **Electricity** and **Magnetism** are inter-linked.

The English scientist Michael Faraday investigated this relationship.

He found that if you moved a magnet in or out of a coil of wire, a voltage was generated (more properly called an emf (electromotive force).

He also realised that the quicker you moved the magnet (or the coil), the greater was the emf generated.

****This is now known as Faraday’s Law of Electromagnetic Induction.

**Demonstrating Faraday’s law**

1. Move the magnet in and out of the coil slowly and note a slight deflection.
2. Move the magnet quickly and note a greater deflection.

Later on it was found that the direction of the emf could also be predicted.

This is known as Lenz’s Law.

The two laws together are known as the laws of Electromagnetic Induction

**The laws of electromagnetic induction.**

1. **Faraday’s law** states that ***the size of the induced emf*** is proportional to the rate of change of magnetic flux.
2. **Lenz’s law** states that the ***direction of the induced emf*** is always such as to oppose the change producing it.\*

**Magnetic Flux**

To calculate the size of the induced emf we need one more concept; *magnetic flux*.

The symbol for magnetic flux is Φ (pronounced “phi”).

**The unit of magnetic flux is the *weber* (Wb)\***

To introduce the idea of magnetic flux consider an area, *A* in a uniform magnetic field.

When the magnetic force lines are perpendicular to this area (see diagram) the total magnetic flux (*Φ*) through the area is defined as the product of *B* and *A*.



Φ = ***BA***

The magnetic flux can now be visualised as the number of magnetic field lines passing through a given area.

We already introduced the concept of *magnetic flux density* (B) in the last chapter, but didn’t really explain it. Again, in relation to the diagrams, we could now refer to B as *the* *number of magnetic field lines per unit area* or *the* *density of the magnetic flux* or, as we actually call it, *the* *magnetic flux density*.

Now we are in a position to *calculate* the induced emf.

Remember Faraday’s law: The size of the induced emf is proportional to the *rate of change of flux.*

In this case the proportional constant turns out to be 1 (remember where we came across this before? Hint: F = ma)

Induced emf = - $\frac{final flux – initial flux}{time taken}$

So

(the minus sign is a reference to *Lenz’s Law*)

$$E= \frac{dΦ}{dt}$$

In symbols (this is the version that you’ll see in the log tables:

Finally, this formula assumes the coil has only one turn. If there are *N* turns, then the formula becomes

Induced emf = - $\left(N\right)[\frac{final flux – initial flux}{time taken}]$

**Lenz’s Law**

**Lenz’s Law** states that the direction of the induced emf is always such as to oppose the change producing it.

**Explanation**

We know that when a magnet and coil move relative to each other, an emf is induced.

Now if the coil is a conductor the induced emf will drive a current around the coil.

This current has a magnetic field associated with it.

The direction of this magnetic field will always be such as to oppose the change which caused it.

**Demonstrating Lenz’s Law (i): Magnet, Plastic and Copper Tubes\***

**Apparatus**

Plastic pipe

Magnet

Copper pipe

Magnet

Copper pipe, plastic pipe, stopwatch, strong neodymium magnet, piece of neodymium, or iron, (same size as magnet).

**Procedure**

Drop the neodymium magnet down both tubes and compare the time taken for each for each.

**Observation**

The time taken for the magnet to fall down through the copper tube is much longer than the time taken for the magnet to fall down the plastic tube.

**Explanation**

The falling magnet creates a changing magnetic flux in both tubes.
An emf is therefore induced in both tubes.
But current flows in only the copper tube because this is the only material that is a conductor.

This induced current generates a magnetic field which oppose the motion of the falling magnet.

**Demonstrating Lenz’s Law (ii): Magnet and Aluminium Ring**

**Apparatus**

Aluminium ring, magnet, thread, retort stand.

**Procedure**

1. Move one end of the bar magnet towards and into the ring. The ring moves away from the magnet.
2. Hold the magnet in the ring and quickly pull it away. The ring follows the magnet.

**Observation**

When the magnet moves, the ring responds by moving in the same direction.

**Explanation**

The moving magnet causes a changing magnetic flux in the ring.
An emf is therefore induced in the ring and this emf in turn generates a current.

This current creates a magnetic field that exerts a force to oppose the motion of the magnet. The magnet exerts an equal and opposite force on the ring and so the ring moves foward.

**Now have a go at the exam questions on this section**

**Electric Generators**

****

Let’s take a look at that very first diagram again:

Here mechanical energy is being converted to electrical energy.

This is the action which is responsible for almost all our electricity generation (solar energy being the main exception).

If you follow the electric wires in your house back to their source you will find at the other end a generating station which has either a magnet moving in and out of a coil of wire, or more likely, a coil of wire rotating in a magnetic field.

**An Electric Generator is a device that converts mechanical energy to electrical energy.**



Note that in the diagrams on the right the voltage is changing direction in a sine-wave fashion.

The generators in power plants are designed to change direction 50 times a second (frequency = 50 Hertz).

Because the voltage drives the current it follows that the current also changes direction 50 times a second.

**Alternating Current (A.C.)\***

Alternating current is current which continually changes direction.
Mains electricity consists of current which changes direction between 40 and 50 times a second.

***{To demonstrate alternating current****: Connect a (very) low voltage school power supply to two light emitting diodes and view through a slo’mo app on your phone.}*

**Comparing alternating voltage and current to direct voltage and current**

We have a problem.

If the current (or voltage) is constantly changing, how can we say what its value is?

We can’t take the average value because it’s zero.

We could take the height of the wave – but this keeps changing with time.

We could take the maximum height – but if the maximum height is say 3 Amps, it still won’t have the same heating effect as a direct current of 3 Amps.

To solve the problem we use a little mathematical trickery:

We use what’s known as the root mean square value (Vr.m.s.)

This is obtained by dividing the maximum value (Vmax ) by √2.

**Vrms =** $\frac{V\_{max}}{\sqrt{2}}$

**Irms =** $\frac{I\_{max}}{\sqrt{2}}$

We do this because the magnitude of the *r.m.s. alternating current* will have the same power output as a *direct current* of the same magnitude.

e.g. If the r.m.s. value of an *alternating current* is 2 Amps, it will the same heating effect as 2 Amps *direct current.*

**[2016]
Explain why it is necessary to use rms values when comparing a.c. and d.c. electricity.**So as to make the power output equivalent between a.c. and d.c.

**Mutual Induction**

When the emf field in one coil changes, an emf is induced in the other.

Changing emf (in first coil) ⇒ changing current (in first coil) ⇒ changing magnetic flux (in first coil)

⇒ induced emf (in second coil). This in turn can induce a current if the second circuit is complete.

**To Demonstrate Mutual Induction**

**Procedure**

* Set up two coils side by side as shown.
* Close the switch – a deflection is seen on the galvanometer.
* Open the switch – a larger deflection is observed.

**Observation**

Each time the circuit is completed or broken, a deflection is obtained on the galvanometer. The deflection at the break is greater than at the make.

**Explanation**

At the make and break of the circuit there is a change in the magnetic flux linking the coils and so an emf is induced in the secondary coil.

The deflection is greater at the break because the current drops more quickly than it increases.

**Mutual Induction and the Transformer**

Constantly changing emf (in first coil) ⇒ constantly changing current (in first coil) ⇒ constantly changing magnetic field (in first coil) ⇒ constantly changing induced emf (in second coil) ⇒ constantly changing current (in second coil if it’s a complete circuit).

**Apparatus**

6 V a.c. power supply, coils of wire – 400 turns and 800 turns, soft iron core, two a.c. voltmeters.

**Procedure**

1. Set up the apparatus as shown.
2. Switch on the a.c. supply (left hand side)..

**Observation** A continuous reading is obtained on the voltmeter at the right hand side.

**The size of the induced emf may be increased by**

1. Having the coils nearer each other
2. Winding the coils on the same soft iron core

*This is the principle behind how a transformer works*

**The relationship between Voltage out and Voltage in for a Transformer**

The relationship between voltage across the secondary coil (*Vs*) and voltage across the primary coil (*Vp*) is determined by the ratio of the number of turns on the secondary coil (*Ns*) to the number of turns on the primary coil (*Np*)



*Vs* = voltage across the secondary coil, *Vp* = voltage across the primary coil

*Ns* = Number of turns in secondary, *Np* = Number of turns in primary coil

**Note**

If the voltage is increased, the transformer is called a ‘Step-Up Transformer’

If the voltage is decreased, the transformer is called a ‘Step-Down Transformer’

**Uses of transformers**

Transformers are used in generating stations to step up the voltage from about 20 kV to anything up to 400 kV (can you remember why? Hint: Joules’ Law)

This has then to be dropped down to 230 Volts before it enters the home.

Many household appliances run on lower voltages again, and so a second transformer is required. This is usually inside the appliance (e.g. a radio).

**Question to make you think (otherwise known as WTF?)**

According to this, if the voltage out is 100 times greater than the voltage in, then the current out is 100 times *less* than the current in.

But from Ohm’s Law (V = IR) if the voltage increases then so also does the current.

What gives??

**Self-Induction**

A changing emf in a coil induces a changing magnetic field in the coil itself. This changing magnetic field in turn induces a second emf (in the coil itself) which is opposite in direction to the driving emf.

This induced emf is known as back-emf (because it is acting ‘backwards’)

Changing emf ⇒ changing current ⇒ changing magnetic field ⇒ induced changing emf (in opposite direction to original) ⇒ induced changing current (in opposite direction to original) {all in the same coil}

**To Demonstrate Self-Induction (Back Emf)**

**Apparatus**

6 V a.c. power supply, coil of wire with 1200 turns, soft iron core, 6 V filament lamp.



**Procedure**

1. Connect the bulb, coil and a.c. supply in series.
2. Switch on the power supply. The lamp lights.
3. Insert the iron core into the coil. The lamp becomes dimmer.

**Explanation**

The a.c. produces a changing magnetic field in the coil.

This induces an emf and hence a current that opposes the applied current.

The iron core increases the magnetic flux and hence the induced opposing current is increased.

The resultant current in the circuit is reduced and the bulb becomes dimmer.

**Note**

If this circuit is set up using a d.c. power supply, no dimming occurs with the core in the coil as there is no changing magnetic field.

It should now be apparent that a coil of wire can be used to reduce alternating current in the same way that a normal resistor is used to reduce Direct Current.

The coil, when used in this fashion, is known as an inductor.

**An inductor is** an electrical component used to reduce the flow of alternating current.

An example of an inductor is the dimmer switch used in stage lighting.

**Leaving Cert Physics syllabus**

|  |  |  |  |
| --- | --- | --- | --- |
| **Content** | **Depth of Treatment** | **Activities** | **STS** |
|  |  |  |  |
| **4. Electromagnetic****induction** | Magnetic flux Φ = *BA*Faraday’s law. | Demonstration of the principleand laws of electromagnetic induction.**Appropriate calculations.** | Application in generators. |
|  | Lenz’s law.Change of mechanical energy to electrical energy. |  |  |
|  |  |  |  |
| **5. Alternating current** | Variation of voltage and currentwith time, i.e. alternating voltages and currents.**Peak and rms values of alternating currents and voltages.** | Use oscilloscope to show a.c. **Compare peak and rms values.** | National grid and a.c. |
|  |  |  |  |
| **6. Concepts of mutual****induction and****self-induction** | **Mutual induction (two adjacent****coils): when the magnetic field in****one coil changes an emf is****induced in the other, e.g. transformers.****Self-induction: a changing magnetic****field in a coil induces an emf in the coil itself, e.g. inductor.** | **Demonstration**.**Demonstration**. |  |
|  |  |  |  |
|  | Structure and principle of operation of a transformer. | Demonstration.Appropriate calculations (voltage). | Uses of transformers. |
|  |  |  |  |
|  | Effects of inductors on a.c. (no mathematics or phase relations). |  | Dimmer switches in stage lighting – uses of inductors. |

**Extra Credit**

**Lenz’s Law** states that the ***direction of the induced emf*** is always such as to oppose the change producing it.\*

An alternative (less formal) definition is to say that the direction *of the induced magnetic field* will always be such as to oppose the change producing it. We don’t specify magnetic field, because there will only be an inducted magnetic field if there is an induced current, which will only happen if there is a complete circuit, whereas there will *always* be an induced emf.

This is a consequence of the conservation of energy – if the induced magnetic field attracted the magnet, then the magnet would move faster, resulting in a greater induced emf and magnetic field, resulting in magnet moving faster still, and eventually would break the speed of light!

**The unit of magnetic flux is the Weber (Wb)\***

Named after Professor Weber – he was a professor who lectured Albert Einstein. Einstein held him in contempt because Weber refused to give any time to recent developments in Physics, developments which contradicted – or at the very least questioned – the traditional teachings.

Einstein refused to address Weber by his proper title Herr Professor Weber, instead he addressed him as Herr Weber.

Weber in turn refused to write a reference for Einstein (mind you the fact that Einstein couldn’t be bothered going to Weber’s lectures probably didn’t help).

End result?

Einstein could only get a job as a lowly clerk in a patent office. This did have the advantage of providing Einstein with a lot of free time to think, time which he appears to have put to good use.

**\*Demonstrating Lenz’s Law (i): Magnet, Plastic and Copper Tubes**

A practical use of this in the real world is in the design of elevators.

They have strong magnets attached to their outer walls, and the lift shafts have copper linings, so even if the elevator becomes detached from its cable, it cannot fall faster than the eddy currents and Lenz's Law will allow.

There is a model of this in the *Science in Action* video: "Electricity and Magnetism", where Howie investigates the Trocadero Centre in London.

*The* S*heer Drop* amusement rides use permanent magnets to bring the ride to rest at the end of the fall.

**\*Alternating Current**

“Trust you will avoid the gigantic mistake of alternating current”.

Lord Kelvin (1824-1907)

Tesla (remember him) was generating electricity in the form of alternating current, but his great rival at the time was Edison, who favoured direct current. Edison roped in Kelvin to back him (Kelvin was recognised as the greatest living scientist at the time), but even with the backing of Kelvin he still lost out to Tesla (this one time).

A good analogy to help you understand the flow of the electrons caused by potential difference is to imagine *pushing* a stiff bicycle chain around and around.

Each link is an electron, and they all move at the same speed.

Alternating Current is therefore analogous to pushing *and pulling* the chain, switching directions 50 times a second (alternating current alternates at a frequency of 50 hertz).

Why aren’t Laptops allowed to be used on airplanes?

The rate of change of flux generated by the new generation of computer chips can be very significant- not because the strength of the magnetic field is significant, but because the frequency is so high (2 GHz plus).

The airline world isn't absolutely sure what does, or doesn't, constitute a threat to safety.

And the evidence of problems is largely anecdotal.

Their best policy is to ban ALL electronic devices other than their own built in systems which have, of course, been subject to flight testing.

A source of High Voltage but Low current is the Van de Graff generator

A source of High Current but Low Voltage is the Transformer used to melt nails.

**Can your teeth act as a radio antenna?**

Some people who have two or more different kinds of fillings in their teeth claim to be able to hear high-power AM broadcast stations when located within a few hundred feet of the stations. It may be that the radio waves act upon the teeth fillings in such a way that the electromagnetic oscillations get transformed to mechanical vibrations in the person's head, and these are heard as sound. But nobody seems to be quite sure if this

**Activities**

Take a battery with a wire on each terminal; Attach one end to a metal file.

Scrape the end of the other wire along the file beside an AM radio and listen to the crackles... furthermore; radio the old-fashioned way began with sparks.

Make radio waves by switching off an electric circuit, and detecting them as "crackle" on a long-wave radio.

**Self-induction**

If you have no friends so can’t join any clubs so have to invent your own club, self-induction is the process of inducting yourself into this club.

Thank you Sean Harper for this answer on a class test.

 **Exam Questions**

1. [2003]Explain the term *emf*
2. [2008][2004][2002][2002 OL][2004 OL][2007 OL][2008 OL]What is electromagnetic induction?
3. [2008 OL]

A magnet and a coil can be used to produce electricity.

How would you demonstrate this?

1. [2005 OL]
2. A coil of wire is connected to a sensitive galvanometer as shown in the diagram.

What is observed when the magnet is moved towards the coil?

1. Explain why this occurs.
2. Describe what happens when the speed of the magnet is increased.
3. [2010 OL]
4. Draw a sketch of the apparatus Michael Faraday used to generate electricity.
5. What name is given to the generation of electricity discovered by Michael Faraday?
6. What energy conversions takes place in Faraday’s experiment
7. How does Faraday’s experiment show that a changing magnetic field is required to generate electricity?
8. [2007][2005][2010]State Faraday’s law of electromagnetic induction.
9. [2002]State Lenz’s law of electromagnetic induction.
10. [2008][2003]

State the laws of electromagnetic induction.

1. [2004][2002 OL]Describe an experiment to demonstrate electromagnetic induction*.*



1. [2007]Describe an experiment to demonstrate Faraday’s law.

**Lenz Law**

1. [2004]
2. A light aluminium ring is suspended from a long thread as shown in the diagram.

When a strong magnet is moved away from it, the ring follows the magnet.

Explain why.

1. What would happen if the magnet were moved towards the ring?
2. [2008]
3. A bar magnet is attached to a string and allowed to swing as shown in the diagram.
A copper sheet is then placed underneath the magnet. Explain why the amplitude of the swings decreases rapidly.
4. What is the main energy conversion that takes place as the magnet slows down?



1. [2003]
2. A small magnet is attached to a spring as shown in the diagram.
The magnet is set oscillating up and down. Describe the current flowing in the circuit.
3. If the switch at A is open, the magnet will take longer to come to rest. Explain why.

**Magnetic flux and Faraday’s Law**

1. [2006][2005]

Define magnetic flux.

1. [2006]

A coil has 5000 turns.

What is the emf induced in the coil when the magnetic flux cutting the coil changes by 8 × 10–4 Wb in 0.1 s?

1. [2009]

What is the average emf induced in a coil of 20 turns when the magnetic flux cutting it decreases from 2.3 Wb to 1.4 Wb in 0.4 s?

1. [2008]
2. A metal loop of wire in the shape of a square of side 5 cm enters a magnetic field of flux density 8 T.

The loop is perpendicular to the field and is travelling at a speed of 5 m s–1.

How long does it take the loop to completely enter the field?

1. What is the magnetic flux cutting the loop when it is completely in the magnetic field?
2. What is the average emf induced in the loop as it enters the magnetic field?

{the diagram wasn’t in the original question but it may be useful here to help picture the situation}



1. [2005]
2. A square coil of side 5 cm lies perpendicular to a magnetic field of flux density 4.0 T.

The coil consists of 200 turns of wire. What is the magnetic flux cutting the coil?

1. The coil is rotated through an angle of 90o in 0.2 seconds. Calculate the magnitude of the average e.m.f. induced in the coil while it is being rotated.

{the diagram wasn’t in the original question but it may be useful here to help picture the situation}

1. [2006]

Read the following passage and answer the accompanying questions.

The growth of rock music in the 1960s was accompanied by a switch from acoustic guitars to electric guitars. The operation of each of these guitars is radically different.

The frequency of oscillation of the strings in both guitars can be adjusted by changing their tension. In the acoustic guitar the sound depends on the resonance produced in the hollow body of the instrument by the vibrations of the string. The electric guitar is a solid instrument and resonance does not occur.

Small bar magnets are placed under the steel strings of an electric guitar, as shown. Each magnet is placed inside a coil and it magnetises the steel guitar string immediately above it. When the string vibrates the magnetic flux cutting the coil changes, an emf is induced causing a varying current to flow in the coil. The signal is amplified and sent to a set of speakers.

Jimi Hendrix refined the electric guitar as an electronic instrument. He showed that further control over the music could be achieved by having coils of different turns.

(Adapted from Europhysics News (2001) Vol. 32 No. 4)

* 1. Why must the strings in the electric guitar be made of steel?
	2. Why does the current produced in a coil of the electric guitar vary?
	3. What is the effect on the sound produced when the number of turns in a coil is increased?
1. [2006][2010] The peak voltage of the mains electricity is 325 V. Calculate the rms voltage of the mains.
2. [2004] Sketch a voltage-time graph of the 230 V supply.
3. [2008 OL] Electricity produced in a generating station is a.c. What is meant by a.c.?
4. [2006]

Sketch a graph to show the relationship between current and time for

1. alternating current
2. direct current.
3. [2003 OL] What is a diode?
4. [2003 OL] Give an example of a device that contains a rectifier.
5. [2004 OL][2005 OL] Name a device that is based on electromagnetic induction.

**Transformers**

1. [2003 OL]

What is a transformer used for?

1. [2002 OL][2007 OL]

The transformer is a device based on the principle of electromagnetic induction.

Name two devices that use transformers.

1. [2007 OL][2004 OL] [2002 OL]

Name the parts of the transformer labelled A, B and C in the diagram.

1. [2002 OL]

How is the iron core in a transformer designed to make the transformer more efficient?

1. [2002 OL]

The efficiency of a transformer is 90%. What does this mean?

1. [2003 OL]

State one energy conversion that takes place in an electrical generator.

1. [2002 OL]

The mains electricity supply (230 V) is connected to the input coil of a transformer which has 400 turns. The output coil has 100 turns. What is the reading on the voltmeter?

1. [2004 OL]

The input coil of a transformer has 400 turns of wire and is connected to a 230 V a.c. supply while the output coil as 1200 turns. What is the voltage across the output coil?

1. [2007 OL]

The input voltage is 230 V. The input coil has 4600 turns and the output coil has 120 turns.

Calculate the output voltage.

**Self-Induction**

1. [2007]
2. A resistor is connected in series with an ammeter and an ac power supply. A current flows in the circuit. The resistor is then replaced with a coil. The resistance of the circuit does not change.

What is the effect on the current flowing in the circuit?

1. Justify your answer
2. [2002]
3. In an experiment, a coil was connected in series with an ammeter and an a.c. power supply as shown in the diagram. Explain why the current was reduced when an iron core was inserted in the coil.
4. Give an application of the principle shown by this experiment.

**Exam Solutions**

1. emf stands for electromotive force. It is a potential difference applied to a full circuit.
2. Electromagnetic Induction occurs when an emf is induced in a coil due to a changing magnetic flux.
3. *Apparatus*: coil, magnet and galvanometer.

*Procedure*: Set up as shown.

Move the magnet in and out of the coil.

*Observation*: the needle deflects.

1. The needle in the galvanometer deflects.
2. An emf is induced in the coil of wire, which in turn produces a current which moves the needle.
3. There is a greater deflection of the needle.
4. Correct diagram to include magnet, coil and meter
5. Electromagnetic induction
6. Kinetic to electric
7. Current stopped whenever the magnet was motionless // electricity is only generatedwhen the magnet or coil is moving.
8. Faraday’s Law states that the size of the induced emf is proportional to the rate of change of flux.
9. Lenz’s Law states that the direction of the induced emf is always such as to oppose the change producing it.
10. Faraday’s Law states that the size of the induced emf is proportional to the rate of change of flux.

Lenz’s Law states that the direction of the induced emf is always such as to oppose the change producing it.

1. Set up as shown.

Move the magnet in and out of the coil and note the deflection in the galvanometer.

1. Move the magnet in and out of the coil slowly and note a slight deflection.

Move the magnet quickly and note a greater deflection.

1. Current flows in the ring in such a direction as to oppose the change which caused it. Therefore the ring follows the magnet.
2. The ring would be repelled.
3. An emf is induced in the copper because is its experiencing a changing magnetic field.

This produces a current.

This current has a magnetic field associated with it which opposes the motion of the magnet.

1. Kinetic (or potential) to electrical (or heat).
2. Alternating current.
3. There is no longer a full circuit, so even though there is an induced potential difference there is no (induced) current, therefore no induced magnetic field in the coil therefore no opposing force.
4. Magnetic flux is defined as the product of magnetic flux density and area.
5. *E=*−N(Final Flux –Initial Flux) / time taken

*E* = 5000(8 × 10-4 /0.1) = 40 V

1. E= N [(Final Flux –Initial Flux) / time taken] = (20)[(2.3 – 1.4)/0.4]

E = 45 V

1. t = dist/velocity = 5 cm / 500 cm s-1 = 0.01 s
2. Φ = BA = (8)(.05 × .05) = 0.02 webers.
3. Induced emf = (Final Flux –Initial Flux) / Time Taken

 = (0 - 0.02)/0.01

 = 2 Volts

1. A = (0.05)2 = 0.0025

φ (= BA ) = (4)(0.0025)

φ = 0.01 Wb

1. E = N(Δφ/Δt)

Δφ /Δt = (0.01 – 0 )/0.2 = 0.05

E= 200(0.05)  E = 10 V

1. Because only metal strings can be magnitised.
2. Because the induced emf varies due to the amplitude of the vibrating string.
3. A louder sound is produced.
4. V max = (√2)(Vrms)  Vrms= 325/√2 = 230 V
5. Labelled axes: time on the horizontal and voltage on the vertical.
6. Alternating current
7. (i) axes labelled (*I* and *t*),sinusoidal curve (at least one full wave)

(ii) (axes labelled) correct curve

1. A diode is a device that allows current to flow in one direction only.
2. Radio, television, computer, battery charger, mobile phone charger.
3. Dynamo, generator, induction motor, transformer, dynamo
4. To increase or decrease voltage.
5. Computer, radio, TV, doorbell, washing machine, mobile phone chargers, power supply, etc.
6. A = primary / input coil, B = secondary / output coil, C = iron core
7. It has a laminated core.
8. 10% of the power in is lost.
9. Kinetic to electric.
10. Vin/Vout = Ninput/Noutput

230/Vout = 400/100

Vout = 230 × (100/400) = 57.5 Volts

1. Vin/Vout = Ninput/Noutput

230/Vout = 400/1200

Vout = 230 × (400/1200) = 690 Volts

1. Vin/Vout = Ninput/Noutput

230/Vout = 4600/120

Vout = 230 × (120/4600) = 6 Volts

1. Current is reduced
2. An emf is induced in the coil which induces a current which opposes the initial current.
3. There would normally be a back emf in the coil due to the alternating current being supplied.

When the core was inserted it increased the magnetic flux which in turn increased the self-induction (back emf) and this reduced the overall voltage and therefore the overall current.

1. Dimmer switch, smooth d.c., tuning radios, braking trains, damping in balances, induction coil

**Demonstrations**

Lenz’s law

Cut the bottom off an aluminium drinks can. Punch a small hole in the centre so that the small indent made will allow the disc to rotate easily. Place the disc on an electric hotplate that has an internal magnetic stirrer.

Turn on the stirrer (not the heating element) and note that the disc rotates. The stirrer consists of a magnet housed in the hotplate with its rotation speed controlled by the dial. When the magnet rotates there is a change in the magnetic flux around the aluminium disc. This causes an emf to be induced in the disc. The direction of the induced current is such as to oppose the change that caused it; hence the disc rotates.