- *For an **IDEAL** transformer :*

electrical power input to the primary coil = electrical power output from the secondary coil

Primary current x primary voltage = secondary current x secondary voltage

$$I_p \times V_p = I_s \times V_s$$

$$\frac{I_p}{I_s} = \frac{V_s}{V_p} = \frac{N_s}{N_p}$$

- In a **STEP-UP** transformer, the **VOLTAGE** is **INCREASED** and the **CURRENT** is **DECREASED**.
- In a **STEP-DOWN** transformer, the **VOLTAGE** is **DECREASED** and the **CURRENT** is **INCREASED**.

- ***Transmission of electricity over long distances is much more efficient at <u>HIGH VOLTAGE</u> than it is at <u>LOW VOLTAGE</u>.***

This is because for a given amount of electrical power being transmitted :

POWER (P) = VOLTAGE (V) x CURRENT (I)

So, THE HIGHER THE VOLTAGE, THE LOWER THE CURRENT.

And since : POWER LOSS = CURRENT ^{2} x RESISTANCE of Transmission cable

HIGH VOLTAGE = LOW CURRENT = LOW POWER LOSS.

- *Transformers are needed to **step-up** the alternating voltage of the electricity generated in power stations so that it can be transmitted over long distances with the **minimum power loss.***

__Step-down__ transformers are then used to decrease the voltage of the electricity supplied to consumers.

- *Since electromagnetic induction requires a varying magnetic flux linkage, **transformers only work with alternating current** and that is why the electricity generated in power stations is alternating and not direct.*

WHY ELECTRICAL POWER HAS TO BE TRANSMITTED AT HIGH VOLTAGE

Consider a power station generating **1 MW** of electricity which is then going to undergo long distance transmission.

Calculate the power lost in the transmission cables if these have an electrical resistance of **400 Ω** and the electricity is transmitted at :

(a) **25 kV,** **(b) 400kV.**

(a) current in cables, $I_1 = \frac{P}{V_1} = \frac{1 \times 10^6}{2.5 \times 10^4} = 40\text{ A}$

Power loss = $I_1^2 \times R = 40^2 \times 400 = 640\,000\text{ W}$ = **0.64 MW**

(b) current in cables, $I_2 = \frac{P}{V_2} = \frac{1 \times 10^6}{4 \times 10^5} = 2.5\text{ A}$

Power loss = $I_2^2 \times R = 2.5^2 \times 400 = 2500\text{ W}$ = **2.5 kW**

These calculations show that when the transmission voltage is **HIGH,** the power lost as heat in the cables is very **LOW** and when the voltage is **LOW,** more than half of the electrical power is lost in transmission.

- **PRACTICE QUESTIONS (3)**

1 A step-up transformer has a primary coil with **200 turns**. It is used to increase the mains voltage of **230 V** to **5.5 KV a.c.**

(a) Calculate the **number of turns in the secondary coil.**

(b) When the current in the secondary coil is **0.15 A,** what is the **current in the primary coil?** What assumption have you made to work this out?

2 A transformer having a primary coil of **1000 turns** is used to step down an alternating voltage of **230 V** to **12 V.**

(a) calculate the **number of turns on the secondary coil.**

(b) The transformer is used to supply power to a **12 V, 60 W** lamp. Calculate the **current** in :

(i) the **secondary coil,**
(ii) the **primary coil** when the lamp is on.

(c) The lamp is connected to the transformer by means of a cable of resistance **0.4 Ω.**

(i) Estimate the **power wasted** due to the heating effect of the current in the cable.

(ii) Discuss whether or not it would be better to replace the lamp and transformer with a **230 V, 60 W** lamp connected to the mains using the same cable.

- **HOMEWORK QUESTIONS**

1 (a) An aircraft is flying horizontally at a constant speed **(v)** close to the North Pole. **Fig 1.** shows the aircraft viewed from above. The vertical component **(B)** of the Earth's magnetic field is indicated by crosses.

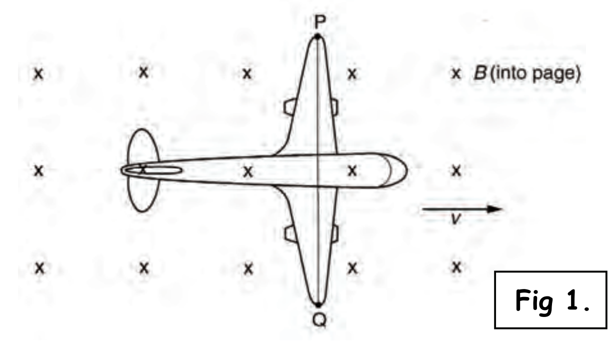


Fig 1.

(i) A wire stretches from wing tip **P** to wing tip **Q.** Each free electron, charge **–e,** in the wire experiences a force along the wire. Write down **an expression for this force.**

(ii) On **Fig 1.** mark with an arrow, the **direction of this force.**

(iii) **Explain** why a steady voltage is induced between the wing tips.

(b) The vertical component **(B)** of the Earth's magnetic field is **5.0×10^{-5} T.** The aircraft is flying at **200 m s^{-1}.** The distance **PQ** between the wing tips is **40 m.**

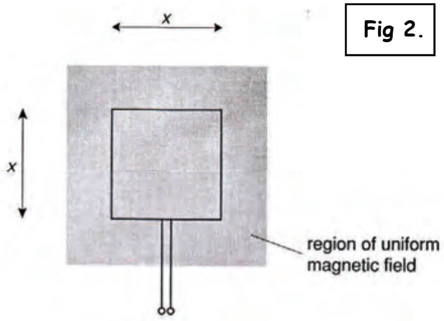
(i) Calculate the **force** exerted by the magnetic field on each electron in the wire.

(ii) Hence, or otherwise, calculate the **voltage induced** between the wing tips.

(OCR A2 Physics - Module 2824 - January 2002)

2 **Fig 2.** shows a square flat coil of insulated wire placed in a region of uniform magnetic field of flux density **(B).** The direction of the field is **vertically out of the paper.** The coil of side **(x)** has **(N)** turns.

Fig 2.

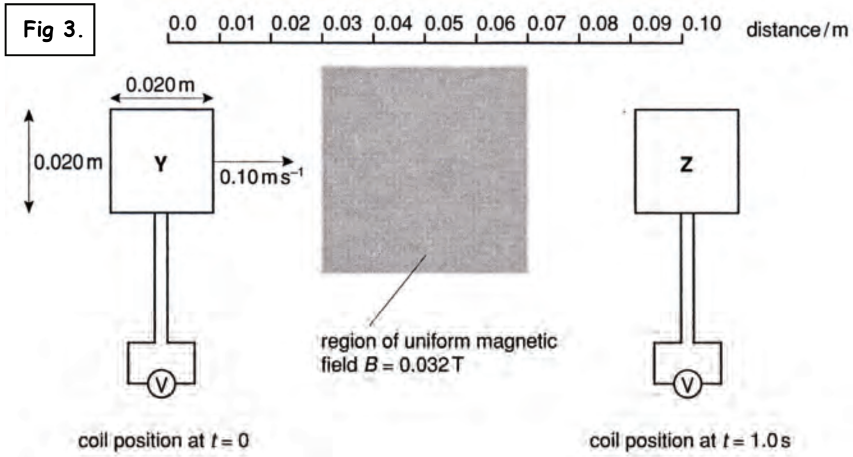


(a) (i) Define the term **magnetic flux.**

(ii) Show that the **magnetic flux linkage** of the coil in **Fig 2.** is **NBx²**.

(iii) The coil of side **x = 0.020 m** is placed at position **Y** in **Fig 3.** The ends of the **1250 turn** coil are connected to a voltmeter. The coil moves sideways steadily through the region of magnetic field of flux density **0.032 T** at a speed of **0.10 m s⁻¹**

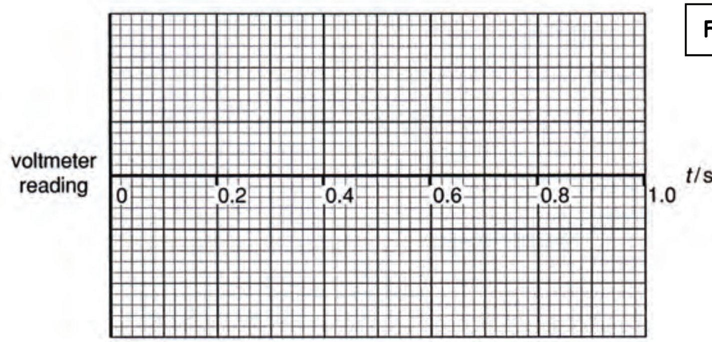
Fig 3.



(i) Show that the voltmeter reading as the coil enters the field region, after t = **0.2 s**, is **80 mV.** Explain your reasoning fully.

(ii) On **Fig 4.** shown below, draw a graph of the **voltmeter reading** against **time** for the motion of the coil from **Y** to **Z.** Label the y-axis with a suitable scale.

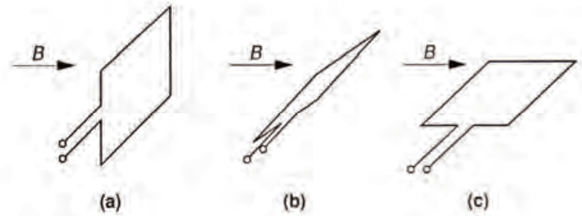
Fig 4.



3 A single-turn square coil of side **0.050 m** is placed in a magnetic field of flux density (B) of magnitude **0.026 T.**

(a) The coil is placed in three different orientations to the field as shown in **Fig 5 (a), (b) & (c).** In **(a)** the plane of the coil is **perpendicular** to the field. In **(b),** it is at **45°** to the field and in (c), it is **parallel** to the field.

Fig 5.

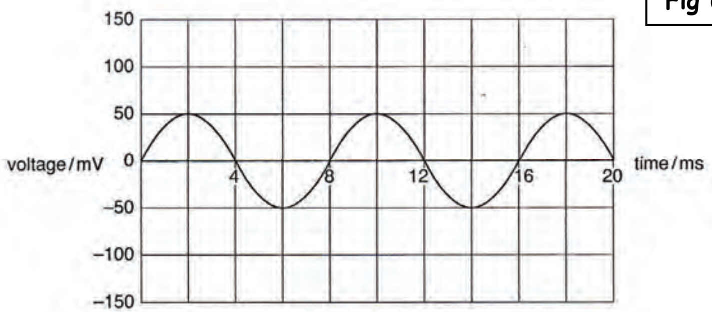


Calculate the value, giving a **suitable unit,** of the **magnetic flux** linking the coil for the position shown in :

(i) **Fig 5 (a),** (ii) **Fig 5 (b),** (iii) **Fig 5 (c).**

(b) The coil is rotated in the magnetic field to generate an e.m.f. across its ends. The graph of the variation of **e.m.f.** with **time** is shown in **Fig 6**.

Fig 6



(i) On **Fig 6** mark, with an **X,** a point on the graph at a time when the flux linking the coil is a **maximum.**

(ii) Give your reasoning for your choice of position **X.**

(iii) The rate of rotation of the coil is doubled. On **Fig 6.** draw a graph showing at least **two cycles** of the **e.m.f.** now generated across the ends of the coil.

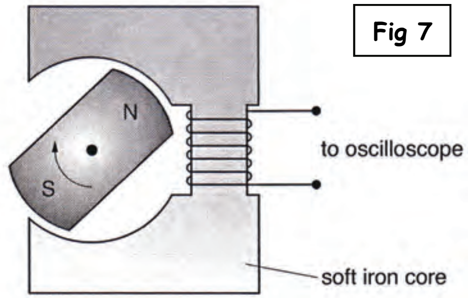
(OCR A2 Physics - Module 2824 - January 2005)

4 This question is about electromagnetic induction.

(a) State **Faraday's law of electromagnetic induction.** Explain the terms **magnetic flux** and **magnetic flux linkage,** which you may have used in your statement of the law.

(b) **Fig 7.** shows a simple a.c. generator used for demonstrations in the laboratory. It consists of a magnet being rotated inside a cavity in a soft iron core. The output from the coil, wound on the iron core, is connected to an oscilloscope.

Fig 7

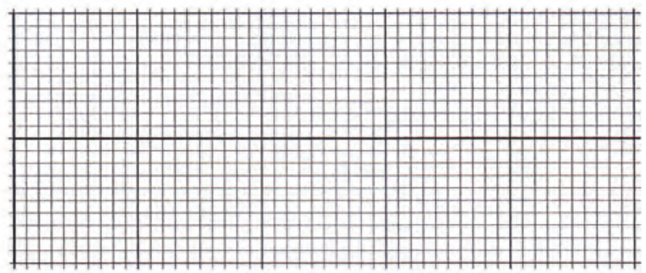


Sketch on the grid of **Fig 8.** a **typical output voltage** which would be seen on the oscilloscope screen.
State and **explain,** using Faraday's law and/or the terms given in **(a),** how **doubling** each of the following factors will alter this output voltage :

- The **speed of rotation** of the magnet.
- The **number of turns** of the coil.

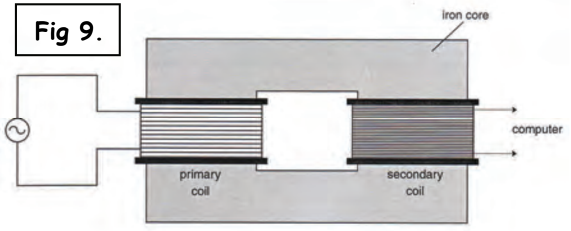
Finally, **explain** how the output voltage would be different if the iron core were removed, leaving the magnet and core in the same positions.

Fig 8



5 **Fig 9.** shows a simple transformer used for demonstrations in the laboratory. It consists of two coils linked by a laminated soft iron core. The primary coil is connected to a signal generator and the secondary coil to a voltage sensor, interface and computer. The number of turns on the secondary coil is **double** that on the primary coil.

Fig 9.



(a) (i) Draw on **Fig 9.** the complete paths of **two** lines of magnetic flux linked with the current in the primary coil.

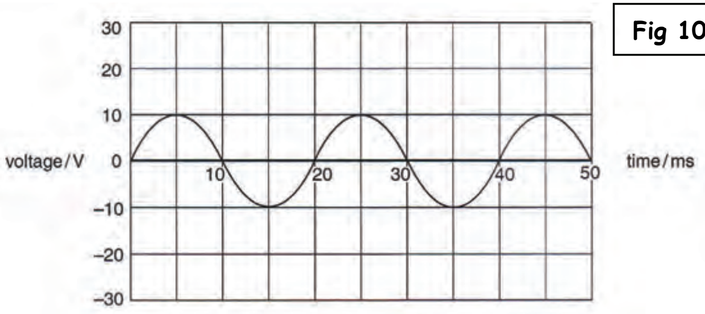
(ii) Define the term **magnetic flux.**

(iii) Explain how **magnetic flux linkage** differs from **magnetic flux.**

(iv) Use **Faraday's law** of electromagnetic induction to explain why an **alternating current** is necessary in the primary coil for a voltage to be detected across the secondary coil.

(b) **Fig 10** shows the computer screen in the demonstration where the number of turns on the secondary coil is double that on the primary coil.

Fig 10.



(i) Show that the frequency of the supply is **50 Hz.**

(ii) Calculate the amplitude of the supply **voltage.**

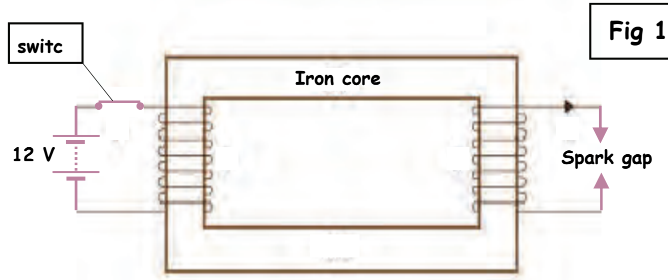
(OCR A2 Physics - Module 2824 - January 2003)

6 A spark plug is the device in a petrol engine which ignites the fuel-air mixture, causing an explosion in the cylinder.

(a) A potential difference of **40 kV** is needed across a gap of **0.60 mm** to produce the spark which ignites the fuel vapour. Calculate the magnitude of the **electric field strength** in the spark gap just before the spark.

(b) The electrical supply in a motor car is **12 V.** To achieve **40 kV,** two coils are wound on the same iron core, shown schematically in **Fig 11.** The **secondary** coil is in series with the spark gap. The **primary** coil is in series with the battery and a switch.

Fig 11.



(i) Draw on **Fig 11.** the complete paths of **two** lines of magnetic flux linked with the current in the primary coil.

(ii) The **magnetic flux** through both coils is **the same,** but the **magnetic flux linkage is not. Explain** why.

(iii) **Explain** why a **potential difference** is produced across the spark gap as the switch is opened.

(iv) **Explain** how each of the following factors influences the **size** of the **potential difference** across the spark gap :

1. The **rate of collapse of the magnetic flux.**
2. The **ratio of the number of turns between the primary and secondary coils.**

(OCR A2 Physics - Module 2824 - June 2008)