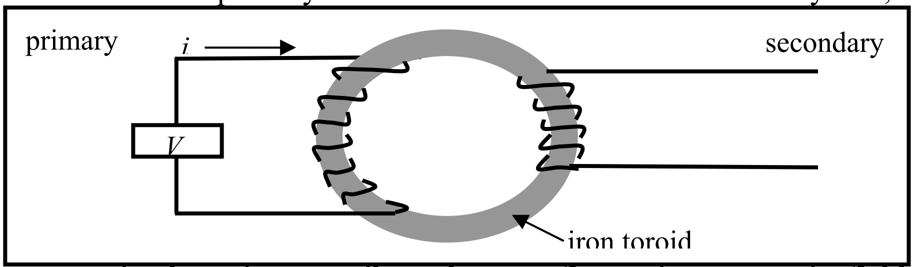
Workshop Tutorials for Physics

Solutions to ER9: **Applications of Electromagnetism**

A. Qualitative Questions:

1. A transformer uses a current in a primary coil to induce a current in a secondary coil, as shown in the diagram below.



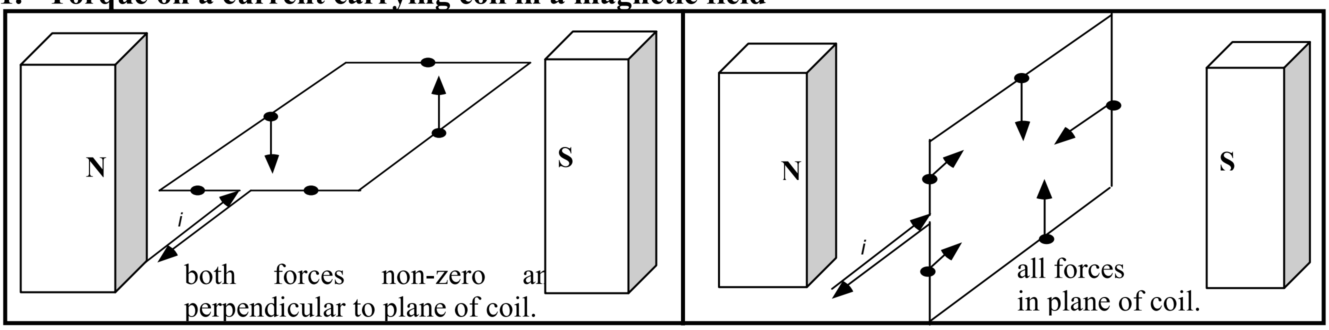
a. The alternating current in the primary coil produces a fluctuating magnetic field in the toroid. Although the magnetic field does not extend beyond the toroid, this changing magnetic field produces an electric field which does extend outside the toroid. The electric field provides a force on the charges in the secondary coil, which makes them move, hence producing a current in the secondary coil.
b. The ratio of the voltage across the primary coil to the voltage across the secondary coil is equal to the ratio of the number of turns on the primary coil to the number of turns on the secondary coil, i.e. $\frac{V_P}{V_S} = \frac{N_P}{N_S}$.

The magnetic field, B, throughout the toroid must be the same all throughout the toroid, hence the flux, Φ, through any loop of wire around the toroid is the same. (Assuming that the area of the loops is the same.) The change in flux, $d\Phi/dt$ must also be the same through any loop. The *emf* or voltage, V, across a coil wrapped about the toroid is $V = N \times d\Phi/dt$ where N is the number of turns. Hence $V_p = N_p \times d\Phi_p/dt$ and
$V_s = N_s \times d\Phi_s/dt$, or $V_s / N_s = d\Phi_s/dt$ Using the fact that $\Phi_s = \Phi_p$, we can now write
$V_p = N_p \times d\Phi_p/dt = N_p \times d\Phi_s/dt = N_p \times V_s / N_s$ which is the same as $\frac{V_P}{V_S} = \frac{N_P}{N_S}$.

2. An electric toothbrush with charger.
a. Inside the toothbrush there would have to be a battery and a motor to give the mechanical movement of the brush. A switch is also necessary to disconnect the battery when not in use.
b. There is a coil sealed in the base of the hand-piece and the peg that it sits on when being charged has an iron core. There is a second coil which is sealed in the charger. When the charger is plugged into the mains the current in the charger coil induces a current in the hand-piece coil. The peg with the iron core improves the magnetic flux linkage. This current would be alternating and would have to be rectified before charging the battery. Hence in our solution to part **a** we should add a coil and rectifier circuit to convert the AC induced *emf* into a DC *emf* to charge the battery.

B. Activity Questions:

1. Torque on a current carrying coil in a magnetic field



If held stationary prior to release, the loop on the left is more likely to start turning on its own.

2. Simple electric motor

The current experiences a force due to the external magnetic field from the magnets. On one side of the coil the force is upwards, on the other it is downwards, resulting in a torque on the coil (figure **a**). If the current continues to flow, as the coil begins to rotate the forces will change direction and point in the opposite direction and oppose the motion of the coil (figure **b**). Hence it is important that the current be stopped so that the force becomes zero. The coil will then continue to rotate, with no force other than friction opposing it, until it returns to its original position. It will then get another push to continue it spinning and, as long as the force due to the field on the current is greater than friction, it will continue to spin.

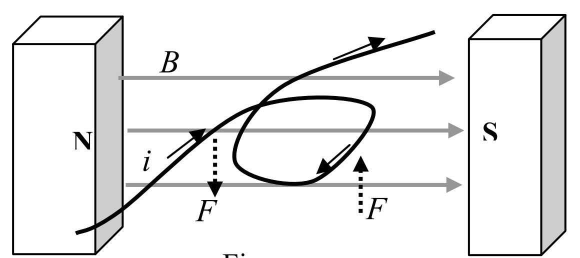


Figure **a**

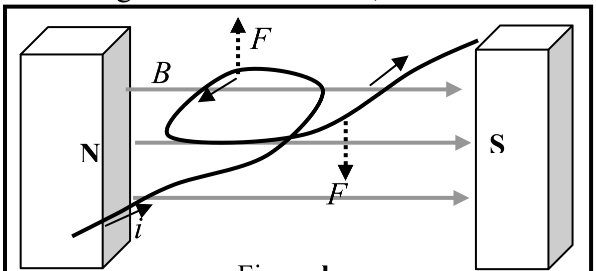


Figure **b**

3. Electric generator

The generator is really just a motor in reverse. Rather than using a current in a magnetic field to produce a torque on a coil, it uses the motion of a coil in a magnetic field to induce a current in the coil. The induced *emf* in the coil is proportional to the rate of change of magnetic flux through the coil. As the coil rotates the magnetic flux oscillates, increasing and decreasing as the angle between the plane of the coil and the field changes. This induces an alternating current in the coil, which lights up the LED as the current flows in one direction only.

4. Power plants

Virtually all commercial electricity production uses a generator. Usually water, either as liquid or as steam, is used to drive a turbine which spins a coil in a generator to produce an *emf*. Examples include wind power, coal and other fossil fuel power plants, geothermal power and nuclear power plants. Solar cells *do not* use a generator, they use the photoelectric effect to produce a current.

C. Quantitative Question:

1. A generator.

a. The length of a turn is 0.70m and the area, A, is 0.03 m^2. So N = 500 m / 0.7 m = 714.
240V RMS is obtained when the maximum value of the *emf* generated is 240√2 V.
The *emf* generated at ant time t is $\varepsilon = d\Phi/dt = d[NAB\cos(\omega t)] / dt = NAB\omega \sin\omega t$.
The max emf is when $\sin(\omega t) = 1$, which gives $\varepsilon_{max} = NAB\omega$. Setting the two maximum *emf* values equal: $emf_{max} = NAB\omega = 240\sqrt{2}$, and rearranging for B:

$$B = \frac{\varepsilon_{max}}{NA\omega} = \frac{240\sqrt{2}\text{ V}}{714 \times 0.03\text{ m}^2 \times 2\pi\, 50\text{ Hz}} = 0.05\text{ T}.$$

b. To reduce the *emf* by half we reduce the number of turns by half - 357 turns, should be removed.

2. Building a battery charger.

a. The relationship between the number of turns and the voltage output in a transformer is given by $\frac{N_p}{N_s} = \frac{V_p}{V_s}$. Therefore $N_s = N_p.V_s / V_p$ = 300 × 12V / 240 V = 15 turns.

b. Efficiency = $\frac{P_{out}}{P_{in}} = \frac{V_s I_s}{V_p I_p} = \frac{12\text{ V} \times 4.0\text{ A}}{240\text{ V} \times 2.5\text{ A}}$ = 0.08 or 8%.

c. If charge is to build up on the terminals over time then the battery needs to have DC current flowing through it in a direction opposite to that when it is supplying power.

d. They need 12 V + 3 V =15V from the secondary.
$N_s = N_p.V_s / V_p$= 300 × 15 V / 240V = 75/4 ~ 19 turns.