A Level Physics Online

# OCR B Physics – H557

## Module 6: Field and Particle Physics

| You should be able to demonstrate and show your understanding of: | Progress and understanding: | | | |
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| **6.1: Fields (Electromagnetism)** | | | | |
| Magnetic/B-Field: A region surrounding a permanent magnet or electromagnet in which a moving charge would experience a force | | | | |
| Magnetic Field Lines/Flux Lines: Lines forming continuous loops from magnetic north poles to magnetic south poles (They indicate the direction of the B-field) | | | | |
| Solenoid: Long, current carrying coils that act as electromagnets. Through the middle, the B-field is uniform shown by parallel, equally spaced lines of flux. The longer the solenoid, the more parallel the lines of flux in through the solenoid | | | | |
| Right Hand/Curl Rule: To work out the direction of field (and thus the location of north and south poles), curl the fingers of your right hand in the direction of the current. Your thumb then indicates the direction of the magnetic field lines | | | | |
| Magnetic Flux Density, B (Units: T or $Wbm^{-2}$): Measure of the magnetic field strength. It is a vector quantity, as shown by the presence of direction arrows on the lines of flux | | | | |
| When two magnets attract, the direction of the resultant forces can be deduced from the flux pattern. The lines of flux tend to shorten and straighten, this causes the magnets to pull together and rotate until they are head on | | | | |
| Flux, ϕ (Units: Wb): Magnetic flux is a 'measure of magnetism', or the strength of a magnetic field. | | | | |
| Note: $1Wb = 1Tm^2$ | | | | |
| Flux density and flux are related by; $$\phi = BA$$ Where B is the component of flux density perpendicular to the area | | | | |

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<tr><th rowspan="2">You should be able to demonstrate and show your understanding of:</th><th colspan="4">Progress and understanding:</th></tr>
<tr><th>1</th><th>2</th><th>3</th><th>4</th></tr>
<tr><td>For a B-field at an angle to the area concerned;<br><br>$$\phi = (B\cos\theta)A = BA\cos\theta$$<br>Where θ is the angle between the B-field lines and the normal to the area, A. For multiple, N, rings;<br>$$\phi = BAN\cos\theta$$</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Flux Linkage: In a coil with N turns, flux linkage = Nϕ, where ϕ is the flux through one coil. Flux linkage concerns the field lines (flux) flowing <u>through</u> a solenoid.</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Electromagnetic Induction: Any change in magnetic flux in a circuit results in the induction of an emf across that circuit. A faster flux change results in a greater emf induced</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Faraday's Law of Electromagnetic Induction: The rate of change of flux linkage in a circuit is proportional to the induced emf in that circuit<br><br>$$\varepsilon \propto \frac{\Delta\phi}{\Delta t}$$<br>If we now introduce flux linkage;<br>$$\varepsilon \propto \frac{\Delta(N\phi)}{\Delta t} \quad \rightarrow \quad \varepsilon \propto N\frac{\Delta\phi}{\Delta t} \; (N \textit{ is taken out as a constant})$$<br>Finally introduce Lenz's Law (see below);<br>$$\varepsilon = -\frac{d(N\phi)}{dt}$$</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Lenz's Law: The direction of an induced emf is always such to act against the change that causes the induced emf (Otherwise the conservation of energy is violated) e.g. An induced emf will produce a current that opposes the rate of change of flux responsible for the induction</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Weber: The amount of flux that needs to change per second in a circuit to induce an emf of 1V</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Components Comparison:<br><br>
<table>
<tr><td>Electrical Circuits</td><td>Magnetic Circuits:</td></tr>
<tr><td>Potential difference</td><td>Current turns (NI)</td></tr>
<tr><td>Current</td><td>Flux</td></tr>
<tr><td>Wire</td><td>Magnetic material</td></tr>
<tr><td>Conductivity (of the conductor)</td><td>Permeability (of the material)</td></tr>
<tr><td>Length of Wire</td><td>Length of Material</td></tr>
<tr><td>Conductance (of circuit)</td><td>Permeance (of circuit)</td></tr>
</table></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Permeance, Λ: In terms of magnetism, it is the property of allowing the passage of lines of magnetic flux (High permeance means that the magnetic circuit will give a large flux, analogous to large G lives large I)</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Permeability, μ: The measure of a material's ability to support the formation of a magnetic circuit within itself</td><td></td><td></td><td></td><td></td></tr>
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| Increasing Flux in a Transformer (for a given number of current turns):<br><br>-The material used should have a high permeability<br>-The material should have a small length and a large area (L is made small by making the circuit compact, A is made large by having two magnetic circuits in parallel<br>(Analogous to $G = \frac{\sigma A}{L}$ to get a large current for a given voltage, the conducting material must have a high conductivity, be as short as possible and have a large area) | | | | |
| Air Gaps in Magnetic Circuits:<br><br>Iron has a much greater permeability than air. In a completely closed magnetic circuit, little flux 'leaks' out. In a circuit with an air gap, the permeance of the circuit is reduced hence the flux in the circuit is drastically reduced. (Analogous to iron being an electrical resistor with a small resistance and air having a large electrical resistance) | | | | |
| Eddy Currents Forming in a Transformer:<br><br>1)Iron has a high magnetic permeance so is used as the core of the transformer<br>2)It is also a good electrical conductor. The changing flux in the primary coil induces currents in the secondary coil, but also in the iron core itself. These are known as eddy currents (circulating swirls of current)<br>3)According to Lenz's Law. The flux produced by the eddy currents opposes the flux created by the primary coil and hence reduces the efficiency of the transformer<br>4) The wasted energy is dissipated as heat within the core by heating caused by the eddy currents | | | | |
| Lamination: To reduce the energy lost due to eddy currents a transformer is made out of a stack of flat plates called laminations. Each lamination is separated from the next by thin, electrically insulating layers. Laminated transformers typically have an efficiency of > 98% | | | | |
| Alternating Flux in a Transformer:<br><br>Faraday's Law of electromagnetic induction states that $\varepsilon \propto$ rate of change of flux linkage. Across the primary coil an alternating potential difference is connected, resulting in an alternating current in that coil. The primary coil generates the flux, so a constantly changing flux is produced | | | | |
| Self-Inductance: The induction of an emf in the coil of the primary circuit of a transformer by the changing flux induced by the potential difference in that coil. According to Lenz's law, the self-induced emf opposes the current that created the changing flux that caused the induction | | | | |
| Voltage in the Primary Coil: Due to self-inductance, $V_{TOT} = V_P - \varepsilon = I_P R$, Since resistance is very small in the primary circuit so IR is negligible hence $V_P = \varepsilon$, hence $V_P$ is the rate of change of flux linkage | | | | |

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| Transformer Equation: $\frac{\Delta(N\phi)}{\Delta t} = N_P \times \frac{d\phi}{dt}$ where $N_P$ = No. of turns on primary coil. If we ignore the small loss of ϕ to the air, then ϕ is the same in the primary and secondary coils (like current in a series circuit). Using the self-inductance relationship above, $V_P = \varepsilon$, we can say $V_P = N_P \times \frac{d\phi}{dt}$ and hence;<br>$\frac{d\phi}{dt} = \frac{V_P}{N_P}$ $(Precursor\ to\ Transformer\ Equation)$<br>Emf is induced in the secondary coil given by $V_S = -N_S \times \frac{d\phi}{dt}$. As discussed above, $\frac{d\phi}{dt}$ is the same for both coils hence by rearrangement;<br>$\frac{V_p}{V_S} = -\frac{N_P}{N_S}$ $(Transformer\ Equation)$<br>The minus sign shows that the alternating p.d. across the secondary coil is 180 degrees out of phase with the alternating p.d. across the primary coil. If $N_P > N_S$ then the transformer is a step down and vice versa | | | | |
| Currents in a Transformer: For an ideal transformer, all energy losses are ignored and all power delivered to the primary coil is transferred to the secondary coil, hence;<br>$P_P = P_S \quad \rightarrow \quad I_P V_P = I_S V_S \quad \rightarrow \quad \frac{I_P}{I_S} = \frac{V_S}{V_P} = \frac{N_S}{N_P}$ | | | | |
| Flux and Current in a Transformer: Flux is created by current turns in a transformer, where the current loops encircle the flux. Current is created by a changing flux, where the flux loops encircle the induced current. The changing primary current $I_P$ creates the changing flux ϕ, the changing flux ϕ induces the secondary current $I_S$ | | | | |
| Generator: Use motion (often produced by a turbine) to produce the flux changes needed to induce an emf. The output of the generator may be a.c. or d.c. (As opposed to a transformer which induces an emf without physical movement, a.c. current produces the necessary flux) | | | | |
| Dynamo: An older term for a generator, a bar magnet rotates within a fixed coil. As the north pole passes one side of the coil, the current flows one way; then the south pole passes and the current reverses | | | | |
| The induced emf when a coil is passed through a magnetic field is given by;<br>$\varepsilon = vLB$<br>Where v is the velocity of the coil, L is the length of the coil perpendicular to the direction of travel and B is the flux density | | | | |
| Faraday's Interpretation: An alternative way of describing Faraday's Law is 'induced emf equals the rate at which the lines of flux are being 'cut' by the moving coil'. | | | | |

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| Rotating Coil: Generators have a coil rotating in a magnetic field (or a magnet rotating in a stator coil). As the coil rotates, ϕ through the coil changes from 0 (when the plane of the coil is parallel to the B-field) to a maximum value of ϕ = BA when the area is perpendicular to the B-field.<br><br>If the coil is rotating at an angular velocity, ω, then θ = ωt ($\omega = \frac{\Delta\theta}{\Delta t}$) where θ is the angle between the normal to the plane of the coil and the B-field. This means that the flux through the coil is given by $N\phi = NBAcos(\omega t)$, so for one coil, just cancel the N on both sides. | | | | |
| Emf vs Time and Nϕ vs Time Graphs:<br><br>-The negative gradient of the Nϕ-t graph gives ε<br>-ε has its largest value when the Nϕ-t graph is steepest, as Nϕ is changing fastest<br>-ε is zero when the Nϕ-t graph is a maximum or minimum, as the gradient is zero at these points<br>-Increasing Nϕ produces a negative ε (and vice versa) due to the negative sign present in Faraday's Law, which is in turn due to Lenz's Law | | | | |
| Field Around a Wire: A wire carrying a current generates its own field. The B-field becomes weaker further away from the wire, it does not follow a linear relationship. | | | | |
| Wire in a Uniform Magnetic Field: If the current carrying wire is placed in a uniform magnetic field, the field of the wire adds to the uniform field (like a vector). Lines of flux tend to shorten and straighten, so a 'catapult force' acts on the wire | | | | |
| Motor: A device that transfers energy into kinetic energy. It consists of an armature, a multi turn coil with an iron core (to increase the permeance of the magnetic circuit). Instead of a commutator to switch the direction of the field; an alternating B-field can be used that continually moves ahead of the armature, stretching the lines of flux. The shortening and straightening of the lines pulls the armature round in a circle | | | | |
| Catapult force: Let F be the catapult force, the force felt by a wire in a magnetic field of strength B, is proportional to the strength of the field, the current through the wire (which creates a stronger field around the wire), and the length of the wire perpendicular to the motion of the wire. Hence;<br><br>$F = BIL$ | | | | |
| Tesla, T: Unit of the B-field strength, defined as the force per unit current per unit length of conductor perpendicular to the B-field | | | | |

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| Motors as Generators:<br><br>Every motor is a generator is every generator is a motor. If a generator is rotated, as soon as the generator is used to deliver a current to a load, a resistance is felt. This is the generator acting as a motor, it pushes against you, hence is converting energy into kinetic energy.<br><br>Inversely, once a motor starts spinning, it generates an emf, called a back emf. By Lenz's Law, this opposes the p.d. driving the motor, hence limiting the speed of the motor. For a low angular velocity, there is little back emf generated so the armature accelerates. For a high angular velocity, there is a large back emf which balanced the applied p.d. so the armature stops accelerating and rotates with a constant angular velocity. | | | | |