Year 13 Science: Inductors, Faraday's law and transformers

Name: _____ Date: _____

Try these without your notes first, then check the answer key.

Practice

1. A 0.250 T field passes at right angles through a loop of area 0.0400 m². Find the flux.

2. That flux falls to zero in 0.100 s through a 500-turn coil. Find the average induced EMF.

3. The current in a 0.200 H inductor changes at 30.0 A s^{-1}. Find the size of the back EMF.

4. A transformer has 920 primary turns on a 230 V supply. How many secondary turns give 10.0 V, and what is the primary current when the secondary supplies 2.30 A, if it is ideal?

Exam-style question: a coil on a battery

A large coil has an inductance of 2.50 H and a resistance of 5.00 Ω. It is connected through a switch to a 10.0 V battery of negligible internal resistance.

5. Calculate the final current and the time constant.

6. Calculate the rate at which the current starts to increase, and explain why the current does not jump straight to its final value.

7. Calculate the EMF across the inductor 0.300 s after the switch is closed.

8. Calculate the energy stored once the current is steady, and explain why a large voltage appears across the switch when it is opened.

Fix the mistake

9. Correct this statement: "A strong magnet sitting still inside a coil induces a large EMF."

10. Correct this statement: "When the switch closes, the current jumps to ε ÷ R and the inductor's voltage is zero."

11. Correct this statement: "A step-up transformer gives you more power, because the voltage goes up."

12. Correct this statement: "A transformer connected to a car battery will step 12 V up to 230 V."

Answer key (for parents and tutors)

1. A 0.250 T field passes at right angles through a loop of area 0.0400 m². Find the flux.
   $\varphi = BA = 0.250 \times 0.0400 = 0.0100$ Wb.
2. That flux falls to zero in 0.100 s through a 500-turn coil. Find the average induced EMF.
   $\varepsilon = N\Delta\varphi \div \Delta t = 500 \times 0.0100 \div 0.100 = 50.0$ V.
3. The current in a 0.200 H inductor changes at 30.0 A s^{-1}. Find the size of the back EMF.
   $\varepsilon = L\Delta I \div \Delta t = 0.200 \times 30.0 = 6.00$ V.
4. A transformer has 920 primary turns on a 230 V supply. How many secondary turns give 10.0 V, and what is the primary current when the secondary supplies 2.30 A, if it is ideal?
   $N_s = N_p \times V_s \div V_p = 920 \times 10.0 \div 230 = 40$ turns; $I_p = V_sI_s \div V_p = 10.0 \times 2.30 \div 230 = 0.100$ A.
5. Calculate the final current and the time constant.
   $I = \varepsilon \div R = 10.0 \div 5.00 = 2.00$ A; $\tau = L \div R = 2.50 \div 5.00 = 0.500$ s (Achieved).
6. Calculate the rate at which the current starts to increase, and explain why the current does not jump straight to its final value.
   At the instant of closing $I = 0$, so there is no voltage across the resistance and the inductor has all 10.0 V: $\Delta I \div \Delta t = \varepsilon \div L = 10.0 \div 2.50 = 4.00$ A s^{-1}. The growing current makes a growing flux in the coil, which induces a back EMF opposing the increase (Lenz's law), so the current can only rise gradually (Merit).
7. Calculate the EMF across the inductor 0.300 s after the switch is closed.
   V_L = ε e^(−t ÷ τ) = 10.0 × e^(−0.300 ÷ 0.500) = 10.0 × 0.549 = 5.49 V (Excellence; 0.300 s is less than one τ, so more than 37% of 10.0 V is sensible).
8. Calculate the energy stored once the current is steady, and explain why a large voltage appears across the switch when it is opened.
   $E = \frac{1}{2}LI^2 = \frac{1}{2} \times 2.50 \times 2.00^2 = 5.00$ J. Opening the switch makes the current fall to zero in a very short time, so the flux through the coil collapses very quickly. The induced EMF, $L\Delta I \div \Delta t$, is very large and, by Lenz's law, acts to keep the current flowing; it appears across the opening switch contacts, and much of the 5.00 J stored in the magnetic field is released in the spark (Excellence links the rapid change, the size of the EMF and the stored energy).
9. Correct this statement: "A strong magnet sitting still inside a coil induces a large EMF."
   Only a changing flux induces an EMF; a stationary magnet in a stationary coil induces nothing.
10. Correct this statement: "When the switch closes, the current jumps to ε ÷ R and the inductor's voltage is zero."
    At the instant of closing the current is zero and the inductor has the full supply voltage; the current then rises with $\tau = L \div R$.
11. Correct this statement: "A step-up transformer gives you more power, because the voltage goes up."
    At best power out equals power in, so when the voltage steps up, the current steps down.
12. Correct this statement: "A transformer connected to a car battery will step 12 V up to 230 V."
    A steady DC current makes no changing flux, so a transformer gives no output from DC.