

Magnetic flux, Faraday's law and Lenz's law

AP Physics 2 (algebra-based) · Worksheet answers

Each answer gives the relationship, the substitution and the final result in bold. For direction questions, check that you identified the change in flux before choosing the induced field.

Level: AP Physics 2 (algebra-based) · **Curriculum:** AP P2 Unit 12

Problem 1 Flux through a loop

1. $\Phi = BA \cos 0^\circ = 0.50 \times 0.020 = \mathbf{1.0 \times 10^{-2} \text{ Wb}}$.
2. A perpendicular field is parallel to the normal, so $\theta = \mathbf{0^\circ}$.

Problem 2 Flux at different angles

$$BA = 0.30 \times 0.040 = 0.012 \text{ Wb}.$$

1. $\mathbf{1.2 \times 10^{-2} \text{ Wb}}$.
2. $0.012 \times \cos 60^\circ = \mathbf{6.0 \times 10^{-3} \text{ Wb}}$.
3. $0.012 \times \cos 90^\circ = \mathbf{0 \text{ Wb}}$.

Problem 3 Ways to change flux

Change **the field strength B**, change **the area A** of the loop in the field, or change **the angle θ** by rotating the loop (or the field).

Problem 4 Average emf

1. $\Delta\Phi = 0.060 - 0.020 = \mathbf{0.040 \text{ Wb}}$.
2. $\epsilon = \Delta\Phi/\Delta t = 0.040 / 0.40 = \mathbf{0.10 \text{ V}}$.

Problem 5 Approaching magnet

1. The flux through the loop **increases** as the field gets stronger.
2. The induced current is **counterclockwise** as seen from the magnet.
3. The loop must oppose the increase, so its face towards the magnet becomes a north pole and repels the incoming north pole.

Problem 6 Rod emf

$$\varepsilon = BLv = 0.50 \times 0.40 \times 3.0 = \mathbf{0.60 \text{ V}}.$$

Problem 7 Units of flux

1. $\Phi = BA$, so the unit is $\text{T} \cdot \text{m}^2$. By definition this is the weber: **1 Wb = 1 T·m²**.
2. $25 \text{ cm}^2 = 25 \times 10^{-4} \text{ m}^2 = \mathbf{2.5 \times 10^{-3} \text{ m}^2}$.
3. From $\varepsilon = \Delta\Phi/\Delta t$, Wb/s is the **volt**.

Problem 8 Coil in a rising field

$$\Delta\Phi = 0.60 \times 4.0 \times 10^{-3} = 2.4 \times 10^{-3} \text{ Wb}. \quad \varepsilon = N\Delta\Phi/\Delta t = 150 \times 2.4 \times 10^{-3} / 0.20 = \mathbf{1.8 \text{ V}}.$$

Problem 9 Flipping a coil

1. The flux changes from $+BA$ to $-BA$: $\Delta\Phi = 2BA = 2 \times 0.20 \times 0.010 = \mathbf{4.0 \times 10^{-3} \text{ Wb}}$.
2. $\varepsilon = N\Delta\Phi/\Delta t = 50 \times 4.0 \times 10^{-3} / 0.10 = \mathbf{2.0 \text{ V}}$.

Problem 10 Rod on rails

1. $\varepsilon = BLv = 0.40 \times 0.30 \times 5.0 = \mathbf{0.60 \text{ V}}$.
2. $I = \varepsilon/R = 0.60 / 3.0 = \mathbf{0.20 \text{ A}}$.
3. $F = BIL = 0.40 \times 0.20 \times 0.30 = \mathbf{0.024 \text{ N}}$.
4. $P = Fv = 0.024 \times 5.0 = \mathbf{0.12 \text{ W}}$, which equals $\varepsilon I = 0.12 \text{ W}$.

Problem 11 Reading a flux graph

1. The slope is $12 \text{ mWb} / 2 \text{ s} = 6.0 \text{ mWb/s}$. $\varepsilon = N\Delta\Phi/\Delta t = 20 \times 6.0 \times 10^{-3} = \mathbf{0.12 \text{ V}}$ in magnitude.
2. The flux is constant, so $\varepsilon = \mathbf{0}$.
3. The slope is $-12 \text{ mWb} / 2 \text{ s} = -6.0 \text{ mWb/s}$, so the magnitude is again **0.12 V**, but with the **opposite sign** (opposite current direction).

Problem 12 Direction of the current

1. Increasing flux into the page: the loop opposes it with a field out of the page, so the current is **counterclockwise**.
2. Decreasing flux into the page: the loop supports it with a field into the page, so the current is **clockwise**.

3. Lenz's law: the induced field always opposes the *change* in flux, not the field itself.

Problem 13 Falling magnet

1. $\Delta E = mgh = 0.050 \times 9.81 \times 0.80 = \mathbf{0.39 \text{ J}}$.

2. The moving magnet induces eddy currents in the copper. By Lenz's law these currents create a field that opposes the motion, so there is an upward force on the magnet. The lost gravitational energy becomes **thermal energy in the tube**.

Problem 14 Expanding loop

1. $A_1 = \pi(0.10)^2 = \mathbf{0.0314 \text{ m}^2}$. $A_2 = \pi(0.15)^2 = \mathbf{0.0707 \text{ m}^2}$.

2. $\Delta\Phi = B \Delta A = 0.20 \times 0.0393 = 7.85 \times 10^{-3} \text{ Wb}$. $\epsilon = \Delta\Phi/\Delta t = 7.85 \times 10^{-3} / 0.50 = \mathbf{1.6 \times 10^{-2} \text{ V}}$.

Problem 15 Aircraft wings

$\epsilon = BLv = (4.0 \times 10^{-5})(36)(250) = \mathbf{0.36 \text{ V}}$.

Problem 16 Quarter turn of a coil

1. $\Phi = BA \cos 0^\circ = 0.50 \times 0.020 = \mathbf{1.0 \times 10^{-2} \text{ Wb}}$.

2. $\Phi = BA \cos 90^\circ = \mathbf{0 \text{ Wb}}$.

3. A quarter turn takes $0.020 / 4 = 0.0050 \text{ s}$. $\epsilon = N\Delta\Phi/\Delta t = 100 \times 1.0 \times 10^{-2} / 0.0050 = \mathbf{2.0 \times 10^2 \text{ V}}$.

Problem 17 Pulling a bar

1. $\epsilon = BLv$, so $I = BLv/R$. The force is $F = BIL = BL(BLv/R) = \mathbf{B^2 L^2 v/R}$.

2. $v = FR / (B^2 L^2) = 0.45 \times 0.80 / (0.36 \times 0.25) = 0.36 / 0.090 = \mathbf{4.0 \text{ m/s}}$.

3. $\epsilon = BLv = 0.60 \times 0.50 \times 4.0 = \mathbf{1.2 \text{ V}}$. $P = \epsilon^2/R = 1.44 / 0.80 = \mathbf{1.8 \text{ W}}$, which equals $Fv = 0.45 \times 4.0$.

Problem 18 Loop entering a field

1. $\epsilon = BLv = 0.50 \times 0.20 \times 2.0 = \mathbf{0.20 \text{ V}}$.

2. $I = 0.20 / 0.040 = \mathbf{5.0 \text{ A}}$. $F = BIL = 0.50 \times 5.0 \times 0.20 = \mathbf{0.50 \text{ N}}$.

3. The flux no longer changes, so $\epsilon = \mathbf{0}$.

Problem 19 Magnet through a coil

1. The flux changes by 2.0 mWb every 10 ms, so $\varepsilon = N\Delta\Phi/\Delta t = 40 \times 2.0 \times 10^{-3} / 0.010 =$ **8.0 V** (constant).
2. The rate of change doubles, so the emf doubles to **16 V**.
3. Total $\Delta\Phi = 8.0$ mWb. $Q = N\Delta\Phi/R = 40 \times 8.0 \times 10^{-3} / 16 =$ **0.020 C**.

Problem 20 Spot the errors

1. The induced field opposes the *change* in flux. If the flux is decreasing, the induced field points in the **same** direction as the original one.
2. A magnet at rest gives a constant flux, so $\Delta\Phi/\Delta t = 0$ and the emf is **zero**. Strength alone does not induce an emf.