

Faraday's law, inductors and LR circuits

AP Physics C (Mechanics and E&M, calculus-based) · Worksheet

Name: _____ Date: _____ Class: _____

These 20 problems train the calculus-based side of electromagnetic induction: flux, emf, inductance, energy and the exponential behaviour of LR and LC circuits.

They run from one-step calculations to multi-part derivations in the style of AP Physics C: Electricity and Magnetism free-response questions. Use $g = 9.81 \text{ m/s}^2$ where needed and show every step.

Level: AP Physics C (Mechanics and E&M, calculus-based) · **Curriculum:** AP PC:E&M Unit 13

Problem 1 Flux through a loop (easy)

A circular loop of area 0.020 m^2 sits in a uniform field of 0.30 T .

1. Calculate the flux when the field is perpendicular to the loop.
2. Calculate the flux when the normal to the loop makes 60° with the field.
3. State the unit of flux in terms of tesla.

Problem 2 Emf from a changing flux (easy)

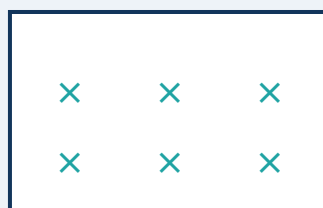
A coil of 50 turns links a flux that falls uniformly from 2.0 mWb to 0.5 mWb in 0.10 s .

1. Calculate the change in flux in webers.
2. Calculate the magnitude of the induced emf.
3. Show that 1 Wb/s equals 1 V .

Problem 3 Direction of the induced current (easy)

The loop in the figure lies in a field directed into the page that is increasing.

1. State the direction of the induced magnetic field inside the loop.
2. State whether the induced current is clockwise or anticlockwise.
3. Explain what would change if the field were decreasing.



A loop in an increasing field pointing into the page.

Problem 4 Motional emf of a rod (easy)

A conducting rod of length 0.30 m moves at 4.0 m/s perpendicular to a field of 0.25 T.

1. Calculate the emf across the rod.
2. The rod forms part of a circuit of total resistance 0.50 Ω . Calculate the current.

Problem 5 Inductance of a coil (easy)

A coil has 400 turns. A current of 0.50 A produces a flux of 2.5×10^{-5} Wb through each turn.

1. Calculate the flux linkage $N\Phi$.
2. Calculate the inductance in mH.

Problem 6 Self-induced emf (easy)

An inductor of 40 mH carries a current that rises uniformly from 0 to 2.0 A in 0.050 s.

1. Calculate dl/dt .
2. Calculate the magnitude of the self-induced emf.

Problem 7 Time constant (easy)

An inductor of 0.30 H is in series with a 60 Ω resistor.

1. Calculate the time constant in milliseconds.
2. Estimate the time needed for the current to reach about 99 % of its final value, using 5τ .

Problem 8 Energy in an inductor (medium)

An inductor of 0.25 H carries a steady current of 3.0 A.

1. Calculate the stored energy.
2. The current is doubled. State the factor by which the energy changes and explain why.

Problem 9 Inductance of a solenoid (medium)

A solenoid has 1200 turns, length 0.60 m and radius 1.5 cm, with air inside.

1. Calculate its cross-sectional area.
2. Calculate its inductance in mH.
3. State what happens to L if the number of turns doubles at fixed length.

Problem 10 Alternating emf from a changing field (medium)

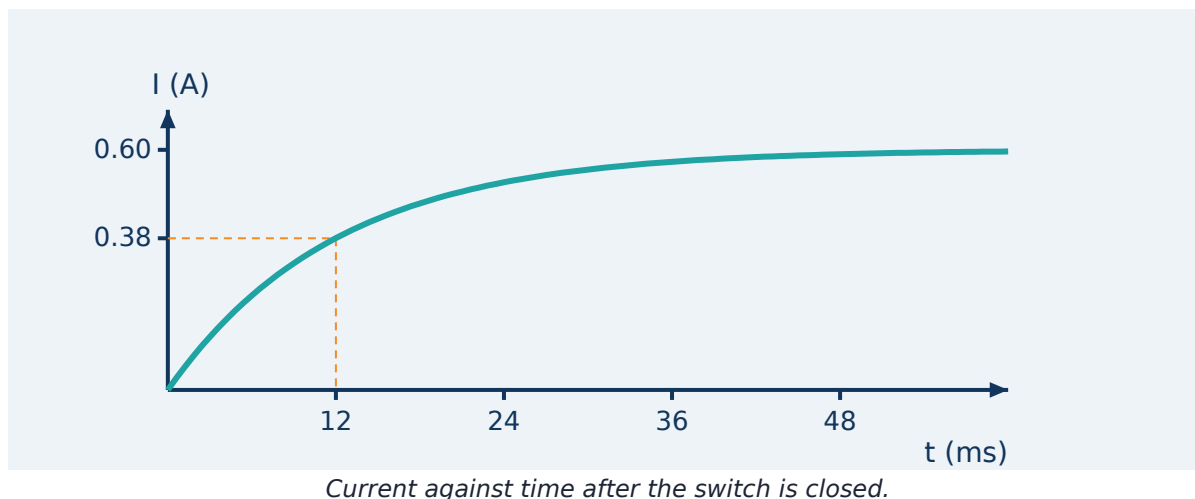
A coil of 100 turns and area 0.010 m² sits in a field $B = 0.40 \sin(100\pi t)$ tesla, with B perpendicular to the coil (t in seconds).

1. Write the flux as a function of time.
2. Differentiate to find the emf as a function of time.
3. Calculate the peak emf.

Problem 11 Reading a current graph (medium)

The graph shows the current in an LR circuit connected to a 12 V battery after the switch is closed.

1. Read the final current.
2. Read the time constant from the time at which the current reaches 63 % of its final value.
3. Calculate R and then L.



Problem 12 Growth of current (medium)

A circuit has $L = 0.80 \text{ H}$, $R = 40 \, \Omega$ and $\mathcal{E} = 24 \text{ V}$. The switch closes at $t = 0$.

1. Calculate τ .
2. Calculate the current at $t = 40 \text{ ms}$.

Problem 13 Decay of current (medium)

The circuit in the previous problem carries its final current. The battery is then replaced by a wire so that the current decays through the same L and R.

1. State the initial current.
2. Calculate the current 30 ms later.

Problem 14 Initial rate of change (medium)

For the same circuit ($L = 0.80 \text{ H}$, $R = 40 \, \Omega$, $\mathcal{E} = 24 \text{ V}$):

1. State the voltage across the resistor just after the switch is closed.
2. Calculate di/dt at that instant.
3. Explain why the final current does not depend on L.

Problem 15 Frequency of an LC circuit (medium)

An inductor of 2.0 mH is connected to a capacitor of $50 \, \mu\text{F}$.

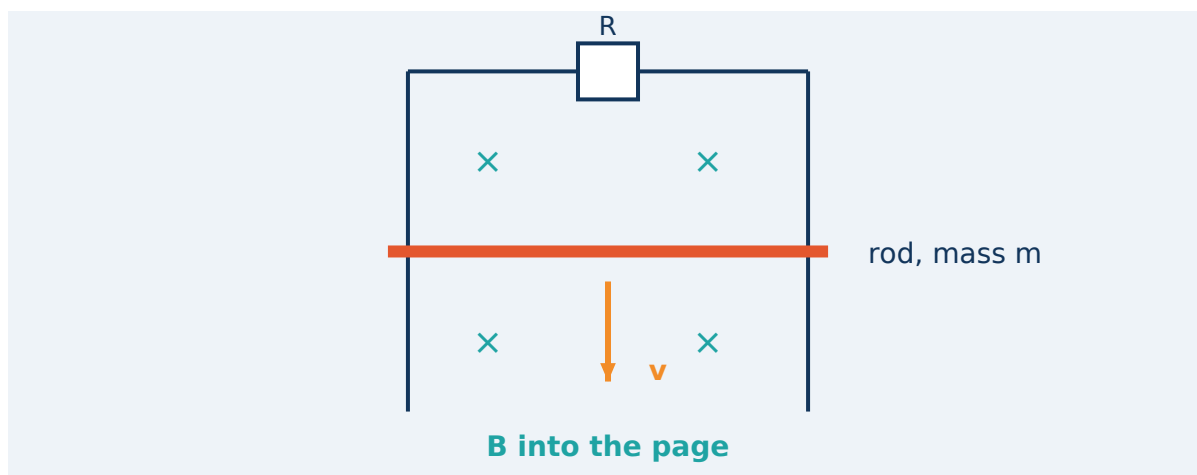
1. Calculate the angular frequency.

2. Calculate the frequency in hertz.
3. State what happens to the frequency if the capacitance is multiplied by 4.

Problem 16 Terminal speed of a falling rod (hard)

A rod of mass 0.050 kg and length 0.40 m slides without friction down vertical rails joined by a 0.20Ω resistor. The field is 0.50 T , horizontal and perpendicular to the rails (use $g = 9.81 \text{ m/s}^2$).

1. Write the magnetic force on the rod in terms of v .
2. Set the force equal to the weight to find the terminal speed.
3. Explain in terms of energy where the rod's lost gravitational energy goes.



Rod of length l falling on frictionless vertical rails.

Problem 17 Decaying field through a loop (hard)

A circular loop of radius 5.0 cm lies perpendicular to a field $B(t) = 0.80 e^{-t/0.40}$ tesla, with t in seconds.

1. Calculate the area of the loop.
2. Calculate the induced emf at $t = 0$.
3. Calculate the induced emf at $t = 0.40 \text{ s}$.

Problem 18 Energy dissipated while the current decays (hard)

For the circuit with $L = 0.80 \text{ H}$ and $R = 40 \Omega$, the current decays from 0.60 A after the battery is removed.

1. Calculate the initial energy in the inductor.
2. Calculate the energy still stored after one time constant.
3. Calculate the energy dissipated in R during the first time constant.

Problem 19 Charge and current in an LC circuit (hard)

A $100 \mu\text{F}$ capacitor is charged to 12 V and then connected across a 25 mH inductor with negligible resistance.

1. Calculate the total energy.
2. Calculate the maximum current.
3. Calculate the period.
4. Calculate the charge on the capacitor at the instant the current is half its maximum.

Problem 20 Timing in an LR circuit (hard)

An inductor of 0.50 H is in series with a 25 Ω resistor and a 10 V battery.

1. Derive an expression for the time at which the current reaches 90 % of its final value and evaluate it.
2. Find the time at which the energy stored in the inductor reaches half of its final value.
3. Explain why this second time is shorter than the first.