



مؤسسة الإمارات للتعليم المدرسي
EMIRATES SCHOOLS ESTABLISHMENT



KHALIFA BIN ZAYED SECONDARY SCHOOL

PHYSICS

GRADE 12 ADVANCE

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TERM 3 , UNIT 10

Electromagnetic Oscillations and Currents

Student Name

LC Circuits

Now we'll consider simple single-loop circuits containing inductors and capacitors: LC circuits. We'll see that LC circuits have currents and voltages that vary sinusoidally with time, rather than increasing or decreasing exponentially with time, as in RC and RL circuits. These variations of voltage and current in LC circuits are called electromagnetic oscillations.

the energy stored in the electric field of a capacitor with capacitance C is given by

$$U_E = \frac{1}{2} \frac{q^2}{C},$$

where q is the magnitude of the charge(C)
 C is the capacitance of the capacitor(F)

The energy stored in the magnetic field of an inductor with inductance L is given by

$$U_B = \frac{1}{2} Li^2,$$

where i is the current flowing (A)
 L is the inductance of the inductor (H)

How does the (LC Circuits) work?

- 1- the capacitor is initially fully charged (with the positive charge on the bottom plate) and then connected to the circuit. At that time, the energy in the circuit is contained entirely in the electric field of the capacitor.

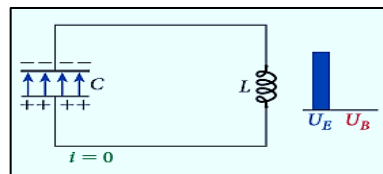


Figure a

- 2- The capacitor begins to discharge through the inductor in Figure 30.2b. At this point, current is flowing through the inductor, which generates a magnetic field. (A green arrow or label below each circuit diagram indicates the direction and the magnitude of the instantaneous current, i .) Now part of the energy of the circuit is stored in the electric field of the capacitor and part in the magnetic field of the inductor.

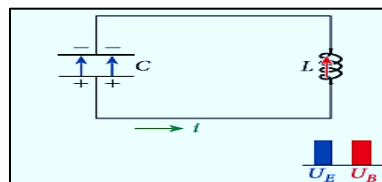


Figure b

- 3- The current begins to level off as the inductor's increasing magnetic field induces an emf that opposes the current. In Figure 30.2c, the capacitor is completely discharged, and maximum current is flowing through the inductor. (When the magnitude of i has its maximum value, it is designated as $i_{\max}$ in the figure.) All the energy of the circuit is now stored in the magnetic field of the inductor.

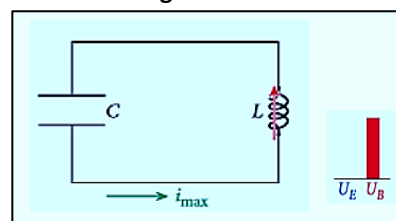


Figure c

- 4- the current continues to flow, decreasing from its maximum value, which causes the magnetic field in the inductor to decrease. In Figure 30.2d, the capacitor begins to charge with the opposite polarity (positive charge on the top plate). Energy is again stored in the electric field of the capacitor, as well as in the magnetic field of the inductor.

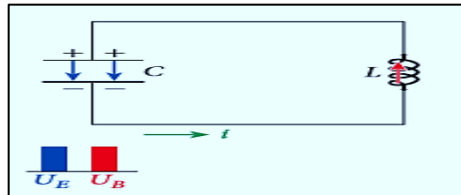


Figure d

- 5- In Figure 30.2e, the energy in the circuit is again entirely contained in the electric field of the capacitor. Note that the electric field now points in the opposite direction from the original field in Figure 30.2a. The current is zero, as is the magnetic field in the inductor

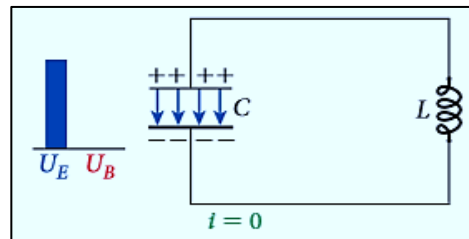


Figure e

- 6- In Figure 30.2f, the capacitor begins to discharge again, producing a current flowing in the direction opposite to that in parts (b) through (d) of the figure; this current in turn creates a magnetic field in the opposite direction in the inductor. Again, part of the energy is stored in the electric field and part in the magnetic field. In Figure 30.2g

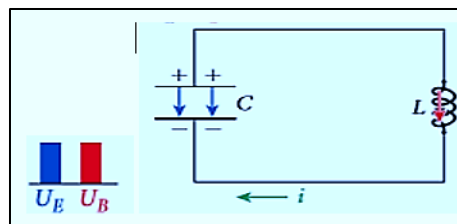


Figure f

- 7- the energy is all stored in the magnetic field of the inductor, but with the magnetic field in the opposite direction from that in Figure 30.2c and with the maximum current in the opposite direction from that in Figure 30.2c.

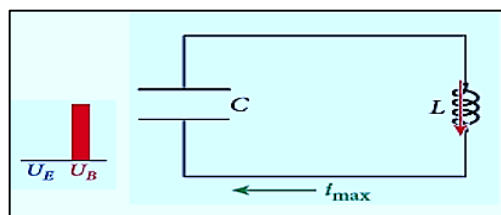
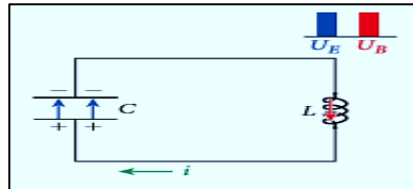
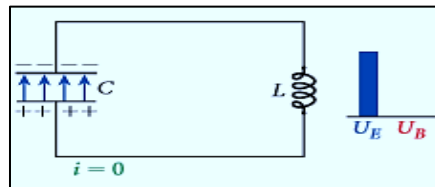


Figure g

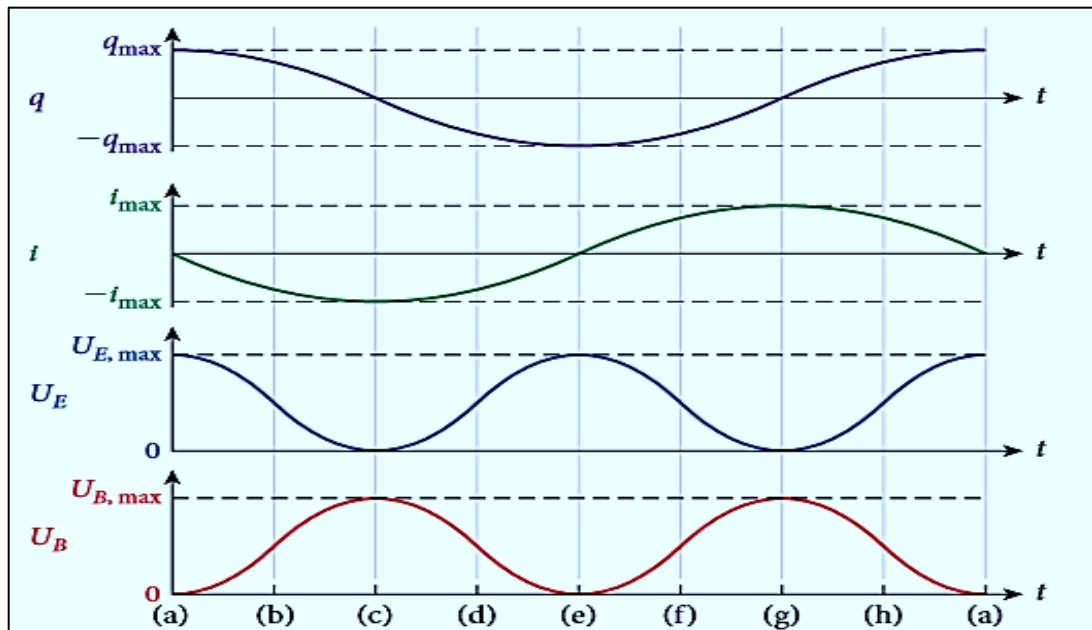
- 8- the capacitor begins to charge again, meaning there is energy in both the electric and magnetic fields.



- 9- The state of the circuit then returns to that shown in Figure 30.2a. The circuit continues to oscillate indefinitely because there is no resistor in it, and the electric and magnetic fields together conserve energy.



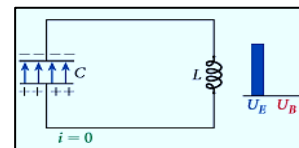
- A real circuit with a capacitor and an inductor does not oscillate indefinitely; instead, the oscillations die away with time because of small resistances in the circuit or electromagnetic radiation
- Variation of the charge, current, electric energy, and magnetic energy as a function of time for a simple, single-loop LC circuit. The letters along the bottom refer to the parts of



Q1) Figure shows that the charge on the capacitor in an LC circuit is largest when the current is zero.

What about the potential difference across the capacitor?

- The potential difference across the capacitor is largest when the current is the largest.
- The potential difference across the capacitor is largest when the charge is the largest.
- The potential difference across the capacitor does not change.



Driven AC Circuits

many interesting effects occur in a circuit in which the current oscillates continuously. This section investigates some of these effects, starting with a time-varying source of emf and then considering in turn a resistor, a capacitor, and an inductor connected to this source

the driving emf, given by

$$V_{\text{emf}} = V_{\text{max}} \sin \omega t,$$

where ω is the angular frequency of the emf and V_{max} is the maximum amplitude or value of the emf

alternating current (AC), The current, i , as a function of time is given by

$$i = I \sin(\omega t - \phi),$$

where I is the amplitude of the current and the angular frequency of the time-varying current is the same as that of the driving emf, but the phase constant ϕ is not zero. Note that, as is the convention, the phase constant is preceded by a negative sign

Circuit with a resistor

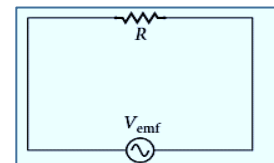
Applying Kirchhoff's Loop Rule to this circuit, we obtain

$$V_{\text{emf}} - v_R = 0,$$

$$V_{\text{emf}} = v_R$$

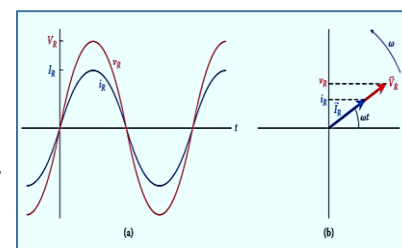
$$v_R = V_{\text{max}} \sin \omega t = V_R \sin \omega t,$$

where v_R is the voltage drop across the resistor



Alternating voltage and current for a single-loop circuit containing a source of time-varying emf and a resistor:

- voltage and current as functions of time;
- phasors representing voltage and current, showing that they are in phase.



According to Ohm's Law, $V = iR$, so we can write

$$V_R = I_R R.$$

$$i_R = \frac{v_R}{R} = \frac{V_R}{R} \sin \omega t = I_R \sin \omega t.$$

The current flowing through the resistor and the voltage across the resistor are in phase, which means that the phase difference between the current and the voltage is zero.

Circuit with a Capacitor

The voltage across the capacitor is given by Kirchhoff's Loop Rule

$$V_{\text{emf}} - v_C = 0,$$

$$V_{\text{emf}} = V_C$$

where v_C is the voltage drop across the capacitor

$$v_C = V_{\text{max}} \sin \omega t = V_C \sin \omega t,$$

where V_C is the maximum voltage across the capacitor. Since $q = CV$ for a capacitor, we can write

$$q = C v_C = C V_C \sin \omega t.$$

$$i_C = \frac{dq}{dt} = \frac{d(C V_C \sin \omega t)}{dt} = \omega C V_C \cos \omega t.$$

by defining a quantity that is similar to resistance, called the **capacitive reactance**, X_C :

$$X_C = \frac{1}{\omega C}.$$

This definition allows us to express the current, i_C , as

$$i_C = \frac{V_C}{X_C} \cos \omega t,$$

Alternating voltage and current for a single-loop circuit containing a source of emf and a capacitor:

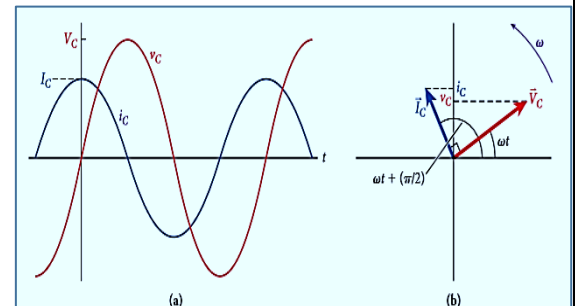
- (a) voltage and current as functions of time;
- (b) phasors representing voltage and current, showing that they are out of phase by $\pi/2$ rad (90°).

$$I_C = V_C / X_C,$$

We can use $\cos \theta = \sin(\theta + \pi/2)$

$$i_C = I_C \cos \omega t.$$

$$i_C = I_C \sin(\omega t + \pi/2).$$



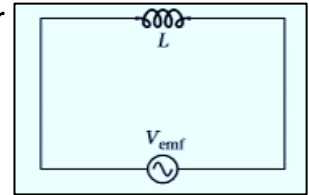
The amplitude of the voltage across the capacitor and the amplitude of the current through the capacitor are related by

$$V_C = I_C X_C.$$

Circuit with an inductor

apply Kirchhoff's Loop Rule to this circuit to obtain the voltage across the inductor

$$v_L = V_{\max} \sin \omega t = V_L \sin \omega t,$$



where V_L is the maximum voltage across the inductor. A changing current in an inductor induces an emf given by

$$v_L = L \frac{di_L}{dt}.$$

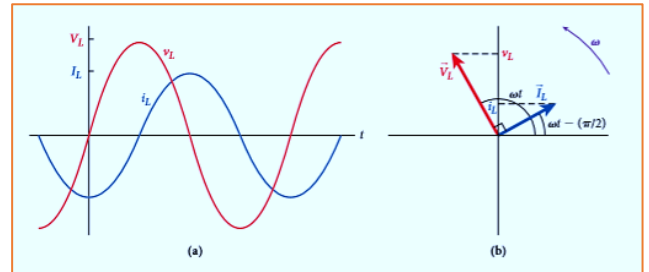
Note that for positive di/dt the voltage drop across the inductor is positive because the direction of current is the direction of decreasing potential. Thus, we can write

$$L \frac{di_L}{dt} = V_L \sin \omega t, \quad \Rightarrow \quad \frac{di_L}{dt} = \frac{V_L}{L} \sin \omega t.$$

$$i_L = \int \frac{di_L}{dt} dt = \int \frac{V_L}{L} \sin \omega t dt = -\frac{V_L}{\omega L} \cos \omega t.$$

Alternating voltage and current for a single-loop circuit containing a source of emf and an inductor:

- (a) voltage and current as functions of time;
- (b) phasors representing voltage and current, showing that they are out of phase by $-\pi/2$ rad (-90°).



The inductive reactance, which, like the capacitive reactance, is similar to resistance, is defined as

$$X_L = \omega L.$$

Using the inductive reactance, we can express i_L as

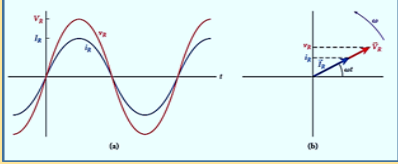
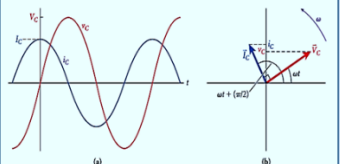
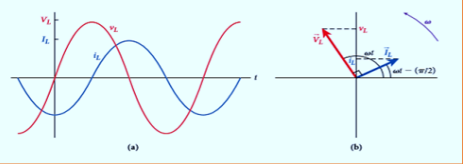
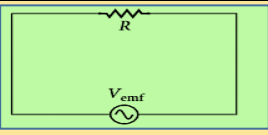
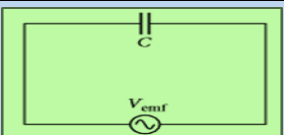
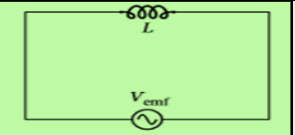
$$i_L = -\frac{V_L}{X_L} \cos \omega t = -I_L \cos \omega t,$$

where I_L is the maximum current.

$$V_L = I_L X_L,$$

Because $-\cos \theta = \sin(\theta - \pi/2)$, we can rewrite $i_L = -I_L \cos \omega t$ as follows:

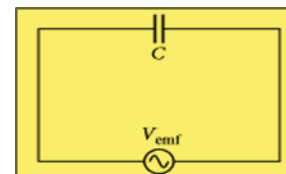
$$i_L = I_L \sin(\omega t - \pi/2).$$

	a resistor R	Capacitor C	inductor L
Voltage ΔV	$v_R = V_{\max} \sin \omega t = V_R \sin \omega t,$	$v_C = V_{\max} \sin \omega t = V_C \sin \omega t,$	$v_L = V_{\max} \sin \omega t = V_L \sin \omega t,$
Current I	$i_R = \frac{v_R}{R} = \frac{V_R}{R} \sin \omega t = I_R \sin \omega t.$	$i_C = I_C \sin(\omega t + \pi/2).$	$i_L = I_L \sin(\omega t - \pi/2).$
Ohms law	$V_R = I_R R.$	$V_C = I_C X_C.$	$V_L = I_L X_L,$
		$X_C = \frac{1}{\omega C}.$	$X_L = \omega L.$
Phase ϕ	0	$+\pi/2$	$-\pi/2$
		$\omega = 2\pi f$	$\omega = 2\pi f$
			
			

Summary for (R C,L)

Q2) A circuit containing a capacitor, has a source of time varying emf that provides a voltage given by $v_C = V_C \sin(\omega t)$. *What is the current, i_C , through the capacitor when the potential difference across it is largest ($v_C = V_{\max}$)?*

- a) $i_C = 0$
- b) $i_C = +I_{\max}$
- c) $i_C = -I_{\max}$



Q3) Consider a circuit with a source of time-varying emf given by $V_{\text{emf}} = (120 \sin(377 \text{ rad/s})t) \text{ V}$. and a capacitor with capacitance ($C = 5.00 \mu\text{F}$.)

What is the current in the circuit at $t = 1.00 \text{ s}$?

Q4) At *what frequency (ω)* will a $10.0\text{-}\mu\text{F}$ capacitor have reactance $X_C = 200. \Omega$?

0.226 A

500. rad/s.

Q5) A capacitor with capacitance ($C = 5.00 \times 10^{-6} \text{ F}$) is connected to an AC power source having a peak value of ($V = 10.0 \text{ V}$) and ($f = 100. \text{ Hz}$).

- 1- *Find the reactance of the capacitor*
- 2- *Find the maximum current in the circuit.*

318 Ω .

31.4 mA.

Q6) An inductor with inductance ($L = 47.0 \text{ mH}$) is connected to an AC power source having a peak value of ($V = 12.0 \text{ V}$) and ($f = 1000. \text{ Hz}$).

- 1- *Find the reactance of the inductor(L)*
- 2- *Find the maximum current in the circuit*

$X_L = 29.5 \Omega$

$I_C = 0.41 \text{ A}$

Q7) An electrical circuit contains a pure inductor with inductance ($L = 0.314 \text{ H}$) is connected to a source emf that changes with time{ $V_L = 220 \sin(100\pi t)$ }

- 1- Calculate the frequency of the electrical source (f)
- 2- Calculate the maximum value of the voltage (V)
- 3- Calculate the reactance of the inductor (X_L)
- 4- Calculate the maximum value of the current (I)
- 5- Write the equation for the current as function of time

50 Hz

220 V

98.6 Ω

2.23 A

Q8) An electrical circuit contains capacitor ($C = 16.0 \text{ } \mu\text{F}$) is connected to a source emf that the current source changes with time{ $I_c = 2 \sin(100\pi t + \frac{\pi}{2})$ }

- 1- Calculate the frequency of the electrical source (f)
- 2- Find the capacitive reactance (X_C)
- 3- Calculate the maximum value of the current (I)
- 4- Calculate the maximum value of the voltage(V)
- 5- Write the equation for the voltage as function of time

50 Hz

199 Ω

2A

398 V

Transformers

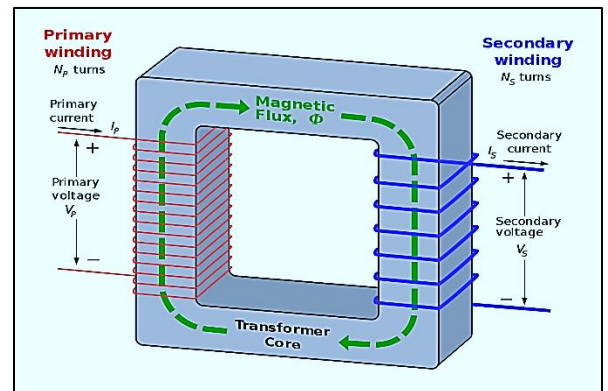
Alternating currents and voltages are transformed from high to low values by a device called, appropriately, a transformer.

Type of transformers

- 1- A transformer that takes voltages from lower to higher values is called a step-up transformer.
- 2- a transformer that takes voltages from higher to lower values is called a step-down transformer.

A transformer consists of two sets of coils wrapped around an iron core (Figure). The primary coil, with N_P turns, is connected to a source of emf described by

$$\frac{V_P}{N_P} = \frac{V_S}{N_S},$$
$$V_S = V_P \frac{N_S}{N_P}.$$



How does transformer work ?

The secondary coil of a transformer has N_S turns. The time-varying emf in the primary coil induces a time-varying magnetic field in the iron core. This core passes through the secondary coil. Thus, a time-varying voltage is induced in the secondary coil, as described by Faraday's Law of Induction:

$$V_{\text{emf}} = -N \frac{d\Phi_B}{dt},$$

- If a resistor, R , is connected across the secondary windings, a current, I_S , will begin to flow through the secondary coil.
- The power in the secondary circuit is then $P_S = I_S V_S$.
- Energy conservation requires that the power delivered to the primary coil be transferred to the secondary coil, so we can write

$$P_P = I_P V_P = P_S = I_S V_S.$$

Note”

- Real transformers do have some losses. Part of these losses result from the fact that the alternating magnetic fields from the coils induce eddy currents in the iron core of the transformer. To counter this effect, transformer cores are constructed by laminating layers of metal to inhibit the formation of eddy currents. Modern transformers can transform voltages with very little loss.
- The continuous current is constant in intensity and direction, and is generated in the primary winding. It does not travel to the secondary winding through the iron core. A magnetic field constant, and since the field is constant, then there is no inductive current in the secondary winding (inductive electric force)
- At the power electrical station there is a voltage transformer(a step-up transformer) .
- (to reduce current) in order to reduce the energy loss when it is sent to Consumption area.
- In the consumption area, there are voltage converters(a step-down transformer.)

Q26) A transformer has 800 turns in the primary coil and 40 turns in the secondary coil.

- a) What happens if an AC voltage of 100. V is across the primary coil?
- b) If the initial AC current is 5.00 A, what is the output current?
- c) What happens if a DC current at 100. V flows into the primary coil?
- d) If the initial DC current is 5.00 A, what is the output current?

(a) The voltages across each coil is given by $V_p / N_p = V_s / N_s$, so when $V_p = 100. \text{ V}$, the voltage on the secondary coil is

$$V_s = N_s V_p / N_p = (40)(100. \text{ V}) / (800) = 5.00 \text{ V}.$$

(b) The current on the secondary coil when $I_p = 5.00 \text{ A}$ is

$$I_s = I_p V_p / V_s = (5.00 \text{ A})(100. \text{ V}) / (5.00 \text{ V}) = 100. \text{ A}.$$

(c) When the voltage is DC, no magnetic flux is created within the secondary coil, so there is no voltage on the secondary coil.

(d) When the voltage is DC, the voltage on the secondary coil is zero, so the secondary coil does not carry a current.

Q27) A transformer contains a primary coil with 200 turns and a secondary coil with 120 turns. The secondary coil drives a current I through a $1.00\text{-k}\Omega$ resistor. If an input voltage $V_{\text{rms}} = 75.0 \text{ V}$ is applied across the primary coil, **what is the power dissipated in the resistor?**