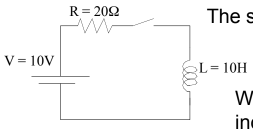


The switch in the circuit is closed at t=0.

$$\boxed{\varepsilon = -L\frac{di}{dt}}$$

What is the initial current in the inductor, immediately after the switch is closed (at t=0+) ?

A) 0 A B) 0.5 A
C)1.0 A D) 2 A
E) None of these.

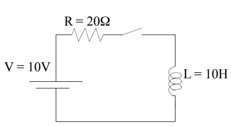
CAPA #13 is due Friday
New online participation survey is still up!

Reading: 34.3-5

Last: Inductors in circuits
Today: Inductors, and AC circuits
Next: Maxwell's equations, putting it all together!

Clicker Question

The switch in the circuit below is closed at t=0.



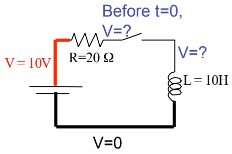
What is the initial rate of change of current di/dt in the inductor, immediately after the switch is closed ?

A) 0 A/s B) 0.5A/s
C)1A/s D) 10A/s
E) None of these.

Hints: What is the initial current through the circuit?
Given that - what is the initial voltage across the inductor?

Clicker Question

The switch in the circuit below is closed at t=0.



What is the initial rate of change of current di/dt in the inductor, immediately after the switch is closed ?

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Hints: What is the initial current through the circuit?
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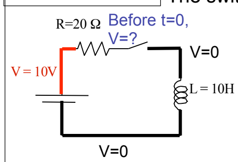
Clicker Question

The switch in the circuit below is closed at t=0.



What is the initial rate of change of current di/dt in the inductor, immediately after the switch is closed ?

A) 0 A/s B) 0.5A/s
C)1A/s D) 10A/s
E) None of these.

Hints: What is the initial current through the circuit?
Given that - what is the initial voltage across the inductor?

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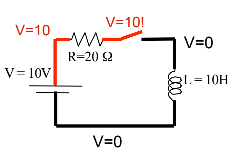
The switch in the circuit below is closed at t=0.



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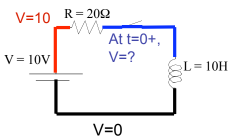
A) 0 A/s B) 0.5A/s
C)1A/s D) 10A/s
E) None of these.

Hints: What is the initial current through the circuit?
Given that - what is the initial voltage across the inductor?

Clicker Question The switch in the circuit below is closed at t=0.

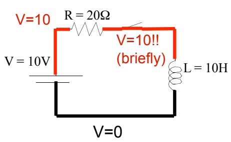


What is the initial rate of change of current di/dt in the inductor, immediately after the switch is closed ?

A) 0 A/s B) 0.5A/s
C)1A/s D) 10A/s
E) None of these.

Hints: What is the initial current through the circuit?
Given that - what is the initial voltage across the inductor?

Clicker Question The switch in the circuit below is closed at t=0.



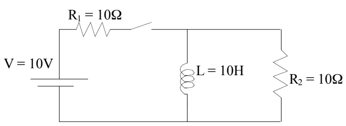
What is the initial rate of change of current di/dt in the inductor, immediately after the switch is closed ?

A) 0 A/s B) 0.5A/s
C)1A/s D) 10A/s
E) None of these.

Hints: What is the initial current through the circuit?
Given that - what is the initial voltage across the inductor?

Clicker Question

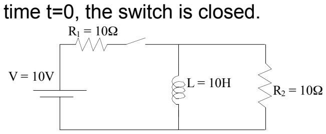
An LR circuit is shown below. Initially the switch is open. At time t=0, the switch is closed. What is the current thru the inductor L immediately after the switch is closed (time = 0+)?



A) Zero
B) 1 A
C) 0.5A
D) None of these.

Clicker Question

An LR circuit is shown below. Initially the switch is open. At time t=0, the switch is closed.



After *a long* time, what is the current from the battery?
A) 0A B) 0.5A C) 1.0A D) 2.0A
E) None of these.

AC Circuits

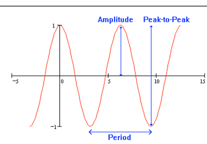
The Voltage in your wall sockets at home is AC.

AC stands for Alternating Current, but would perhaps more appropriately be called Alternating Voltage.

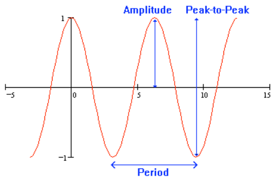
Alternating = Sinusoidal with time

$$V(t) = V_{peak}\sin(\omega t)$$

$$\omega = 2\pi f = \frac{2\pi}{T}$$



ω is the **radial frequency** (radians / second)
f is the **frequency** in (cycles / second = Hertz)
T is the **period** in (seconds), i.e. time for one cycle



In the United States of America

f = 60 cycles/second or Hertz
T = (1 / 60) seconds
V_{peak} = 170 Volts

One might be interested in something like the average Voltage.
But, the average V(t) = 0.

$$V_{rms} = V(\text{root mean square}) = \sqrt{\langle V^2 \rangle}$$

Time Average of Voltage squared.

$$V_{rms} = V_p \sqrt{\langle \sin^2(\omega t) \rangle} = V_p \sqrt{1/2} = V_p / \sqrt{2}$$

Time Average of $\sin^2$ or $\cos^2$ over many cycles = 1/2

$$V_{rms} = 170V / \sqrt{2} = 120\,Volts$$

This is how we refer to the US Standard Voltage.

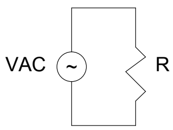
The term “AC Voltage” or “VAC” means $V_{rms} = V_{peak} / \sqrt{2}$

The term “AC Current” [somewhat redundant] means

$$i_{rms} = i_{peak} / \sqrt{2}$$

RMS values of AC Voltage and Current are always implied if not explicitly stated otherwise. This is because the old DC formulas involving V, i, R, P (power) all hold for AC circuits if we use the RMS values.

Example: AC Voltage across a resistor



$$V(t) = V_p \sin(\omega t)$$

$$i(t) = \frac{V}{R} = \frac{V_p \sin(\omega t)}{R} = i_{peak} \sin(\omega t)$$

$$P(t) = iV = i_{peak} V_p \sin^2(\omega t)$$

Instantaneous Power is oscillating from zero to maximum.

We might be interested in the average (over time) power delivered to the resistor.

$$P(t) = iV = i_{peak} V_{peak} \sin^2(\omega t)$$

$$< P(t) >= i_{peak} V_{peak} < \sin^2(\omega t) >= \frac{1}{2} i_{peak} V_{peak}$$

$$< P(t) >= \left(\frac{1}{\sqrt{2}} i_{peak} \right) \left(\frac{1}{\sqrt{2}} V_{peak} \right)$$

$$\boxed{P_{ave} = i_{rms} V_{rms}}$$

Same form as before, but now RMS values.

A light bulb is attached to a wall plug. (120 VAC, 60 Hz)
How many times a second is the ***instantaneous*** power output to the bulb equal to zero?

A: Never, there is always power
B: 30 times/sec
C: 60 times/sec
D: 120 times/sec
E: Other

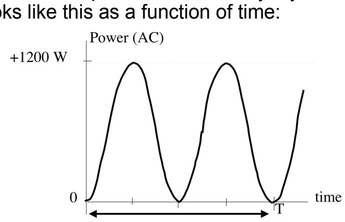
A 100 W light bulb is attached to a wall plug. (120 VAC, 60 Hz)
What is the **peak** power output to the bulb?

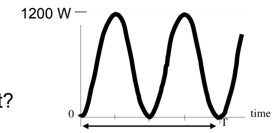
A) 100 W
B) Sqrt[2]*100 W = 141 W
C) 200 W
D) Other

A 600 Watt hairdryer is attached to 120 VAC circuit. What is the ***peak*** current through the hairdryer (to within 5%)?

A: 0 A B) 5 A C) 7 A D) 10 A
E) Other

The *instantaneous* power consumed by my De-luxe Toaster Oven looks like this as a function of time:



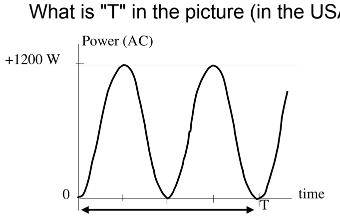


Which of the following is correct?

P ave	V rms	I rms
A: 1200 W	120 V	10 A (=1200/120)
B: 1200 W	170 V	7 A (=1200/170)
C: 600 W	120 V	5 A (= 600/120)
D: 600 W	170 V	3.5 A (=600/170)

E: None of the above is right.

What is "T" in the picture (in the USA)?



A: 1/30 s B: 1/60 s C: 1/120 s D: Other

Why do we use AC Voltage in the United States and most of the world?

1. Ease of generating from a power generator. Recall a rotating coil in a magnetic field creates an induced current, but it is sinusoidally alternating.
   (First large scale test at Niagara Falls)

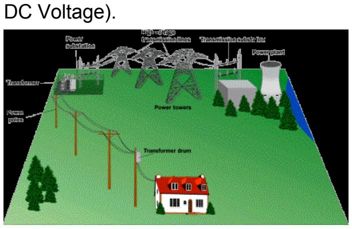
2. AC turns out to be easy to change from one peak Voltage level to another. This is using a **Transformer**.

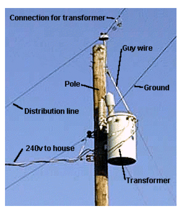
Light bulbs and appliances with motors (vacuum cleaners, blenders, …) use AC Voltage to operate.

But devices with electronic circuits (TV's, computers, phones, …) need DC Voltage (constant) to function.

The "power supply" in TV's, computers, etc. convert AC Voltage from the wall into DC Voltage (typically 2-15 Volts) that the circuitry needs.

AC Voltage is used to distribute power to homes (rather than DC Voltage).





Electrical power is transmitted from power plants to cities with big aluminum power cables.

Much energy is wasted because of resistance in the cables, the cables heat up (i^2R losses). To reduce this waste, power is transmitted at very high voltage (100 kV to 1 MV !)

$$\boxed{P(\text{from plant to city}) = iV = \text{constant}}$$

Set by the needs of the city and the capacity of the plant.

Example: Power Plant output $P_0 = 10^8$ Watts = 100 MegaWatts
Resistance of cables = R = 10 Ω

$$P_0 = iV \qquad i = P_0 / V$$

$$P_{lost} = i^2 R_{cable} = \frac{P_0^2}{V^2} R_{cable}$$

$$\boxed{\frac{P_{lost}}{P_0} = \frac{P_0}{V^2} R_{cable}}$$

Fraction of Power from Plant Wasted

What if we transmit at 50,000 Volts?

$$\boxed{\frac{P_{lost}}{P_0} = \frac{P_0}{V^2} R_{cable} = 0.4 = 40\%}$$

What if we transmit at 200,000 Volts?

$$\boxed{\frac{P_{lost}}{P_0} = \frac{P_0}{V^2} R_{cable} = 0.025 = 2.5\%}$$

This is an acceptable operating level.

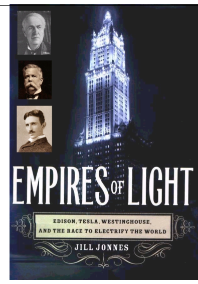
Clicker Question

An electrical engineer at a power plant wants to reduce the energy wasted during power transmission from the plant to the city. The power output P_o=iV of the plant is fixed at 100 MW. The engineer decides to double the Voltage V. By what factor does the power lost in the cable ($P_{lost}=i^2R_{cable}$) decrease? (Hint: if P_{plant}=iV is fixed, when V goes up, i goes down.)

A: No decrease
B: factor of 2 decrease
C: factor of 4 decrease
D: factor of 8 decrease

DC versus AC

Lots of good books on the science and the people involved.



Magnetic Energy Density

Recall that for a capacitor C, there is stored potential energy in the electric field.

$$U = \frac{1}{2} C V^2$$

The energy is stored in the electric field and the density is:

$$u_E = \frac{U}{Volume} = \frac{1}{2} \varepsilon_0 |\vec{E}|^2$$

For an inductor L, with current i, there is stored energy in the magnetic field.

$$U = \frac{1}{2} L i^2$$

The energy density in the magnetic field is:

$$u_B = \frac{U}{Volume} = \frac{1}{2}\frac{1}{\mu_0} |\vec{B}|^2$$

Clicker Question

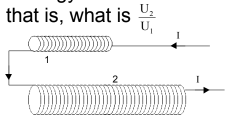
The same current i is flowing through solenoid 1 and solenoid 2. Solenoid 2 is twice as long and has twice as many turns as solenoid 1, and has twice the diameter. (Hint) for a solenoid B = μ_o n i)

What is the ratio of the magnetic energy contained in solenoid 2 to that in solenoid 1, that is, what is $\frac{U_2}{U_1}$

A) 2 B) 4

C) 8 D) 16

E) None of these.



It takes work to get current flowing through an inductor.

You must work against the back EMF which opposes any change in the current.

That work = potential energy stored = U = ½ Li^2

And is thus stored in the inductor's magnetic field.

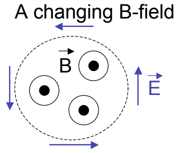
EMF around a (stationary) closed loop is defined as:

$$\varepsilon = \oint_{Loop} \vec{E} \cdot d\vec{l}$$

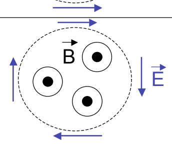
And thus Faraday's Law can be written as:

$$\boxed{\oint_{Loop} \vec{E} \cdot d\vec{l} = -\frac{d}{dt} \int_{surf} \vec{B} \cdot d\vec{A}}$$

A changing B-field creates a new kind of E-field.

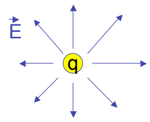


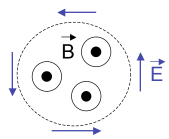
If B is decreasing → E-field is CCW



If B is increasing → E-field is Clockwise

The (non-Coulomb) E-field is very different from the Coulomb E-field created by single electric charges.





$$\Delta V = -\oint \vec{E} \cdot d\vec{l} = 0 \qquad \varepsilon = \oint_{Loop} \vec{E} \cdot d\vec{l} \neq 0$$

If there are only stationary charges, no currents, then there are no B-fields.

In this case there is no Magnetic Flux in this situation only!

$$\boxed{\varepsilon = \oint_{Loop} \vec{E} \cdot d\vec{l} = 0 \text{ (special case only)}}$$