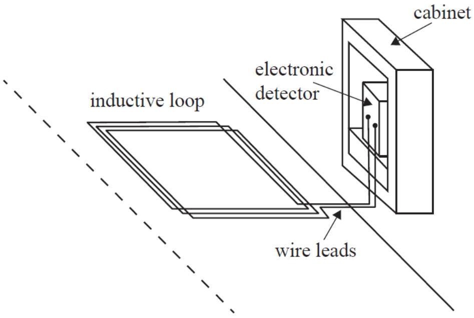
ELECTRICITY: INDUCTORS QUESTIONS

Electrical systems 2019: QUESTION TWO

Inductive loops are also used to sense the presence of cars. Inductive loops are wire coils embedded into the surface of the road and are powered by an AC supply of known voltage and frequency.



One particular inductive loop has 4.00 Ω of resistance and is powered by a 24.0 V_{RMS}, 1.20 × 10^2 Hz AC power supply. The loop is a 1.60 m × 0.600 m rectangular shape, with three coils of wire.

(a) Calculate the peak voltage of this power supply.

(b) The strength of the magnetic field inside the loop is 0.0413 T. Calculate the maximum magnetic flux in each of the three coils of wire of the inductive loop.

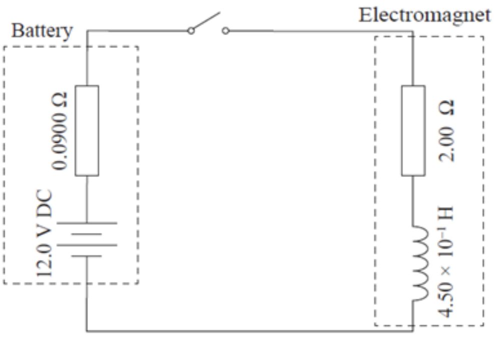
When a car drives over the inductive loop, the steel in the car's body and engine interacts with the magnetic field of the inductive loop. The overall effect of this interaction is to reduce the inductance of the loop.

(c) Explain the effect decreased inductance would have on current in the circuit.

(d) The new inductance is 5.00 × 10^{-3} H. Determine the RMS current in the circuit.

QUESTION TWO (2018;2)

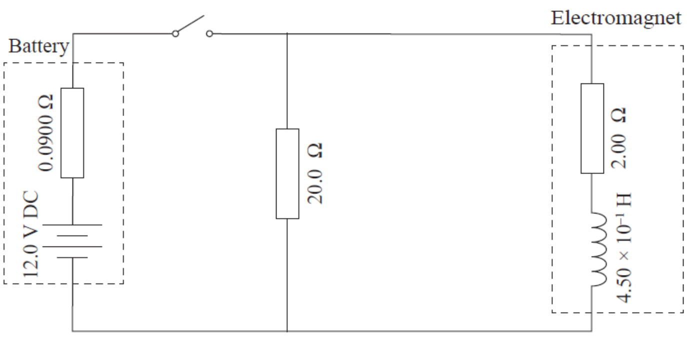
Casey is using an electromagnet that has an inductance of 4.50 × 10^{-1} H and a resistance of 2.00 Ω. Casey connects it to a 12.0 V DC battery with an internal resistance of 0.0900 Ω.



(a) Determine the current through the electromagnet a few minutes after the switch is closed.

(b) Casey opens the switch and a large spark jumps across the terminals of the open switch. Explain how the coil can produce such a high voltage when the switch is opened.

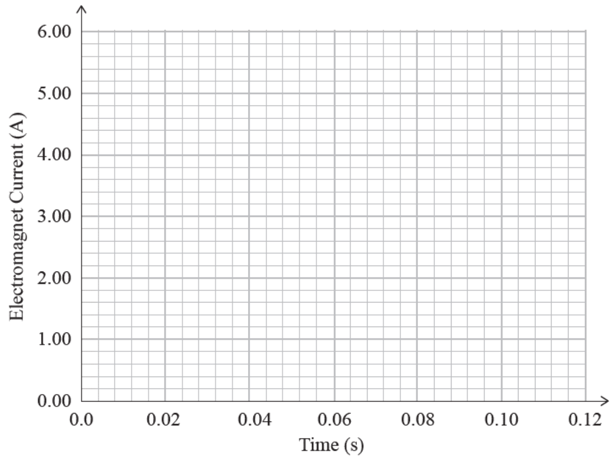
To prevent damaging sparks, Casey places a 20.0 Ω resistor in parallel with the electromagnet. At one point, shortly after the switch is closed, the rising current drawn from the battery has reached 2.00 A and a back EMF of 9.00 V has been induced across the inductor.



(c) Show that the current through the electromagnet at this time is 1.41 A.

After many more minutes, the current through the coil is a steady 5.72 A. The switch is now opened.

(d) Plot the graph of current versus time for the electromagnet as the current falls to zero and explain how the presence of the 20.0 Ω resistor protects against the high voltage sparks that Casey witnessed earlier.

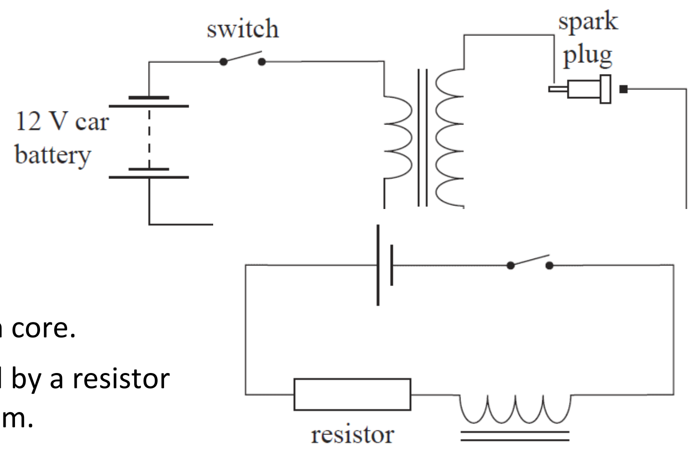


QUESTION TWO (2017;2)

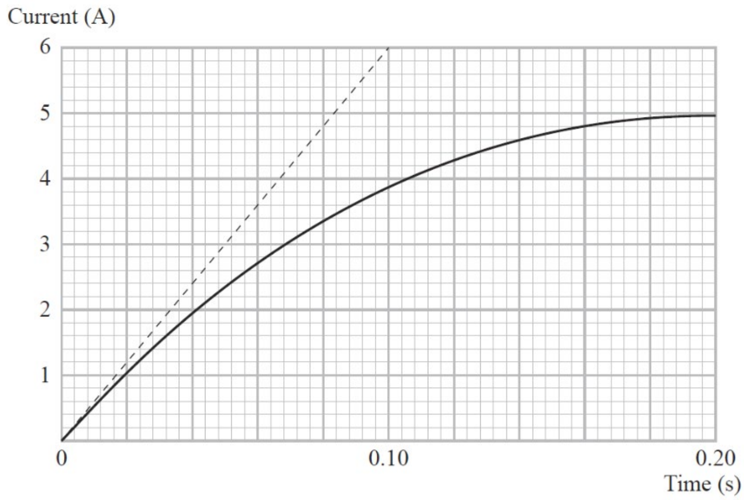
In a car engine, an induction coil is used to produce a very high voltage spark. An induction coil acts in a similar way to a transformer.

The diagram shows the circuit arrangement that will enable a spark to be produced in the spark plug when the switch is opened. The induction coil has 50 turns in the primary coil and 8000 turns in the secondary coil. Both coils are wrapped around an iron core.

The primary coil of the induction coil can be modelled by a resistor in series with an ideal inductor as shown in the diagram.



The following graph shows the current changing with time after the switch is closed (solid line).



(a) State the value of the voltage across the ideal inductor once current has reached a maximum value of 5.0 A.

(b) Explain why the current does not immediately reach maximum value as soon as the switch is closed.

(c) Immediately after the switch is closed, the back EMF across the ideal inductor is 12.0 V. Using the dotted line on the graph, calculate the self-inductance of the ideal inductor.

(d) Sparks require a very high voltage to be produced. Explain how it is possible for a spark to be produced across the gap in the spark plug when the switch is opened.

THE TRANSFORMER (2016;2)

Transformers can be used to increase or decrease the size of an AC voltage. Wei has a transformer that is designed to convert 240 V into 12.0 V.

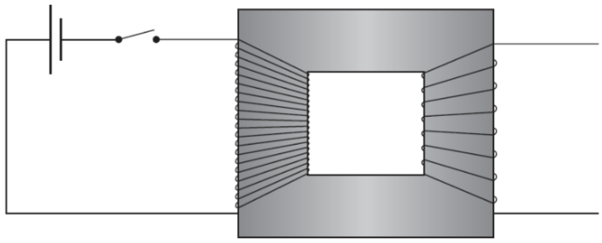
The secondary coil has 40 turns.

(a) Calculate the number of turns on the primary coil.

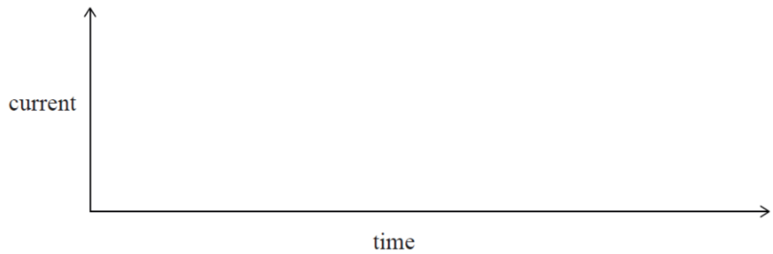
(b) Explain how an alternating voltage across the primary coil creates an alternating current in a light bulb connected to the secondary coil.

Each coil of a transformer acts as an inductor.

A primary coil is attached to a battery and switch as shown in the diagram below. The switch is closed and then some time later the switch is opened.



(c) Sketch a graph showing how the current in the coil changes when the switch is closed and then some time later is opened. Give a comprehensive explanation for the shape of your graph.



(d) Calculate the energy stored in the primary coil's magnetic field when the switch has been closed for several seconds.

battery voltage = 6.0 V

resistance of primary coil = 35 Ω

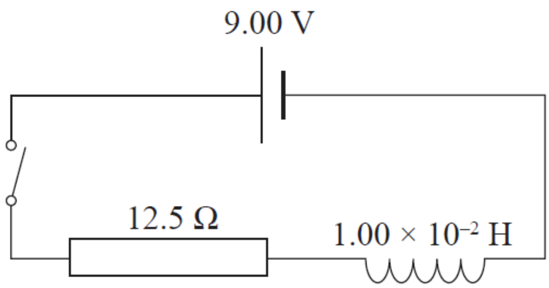
inductance of primary coil = 0.10 H

ELECTROMAGNETIC INDUCTION (2015;3)

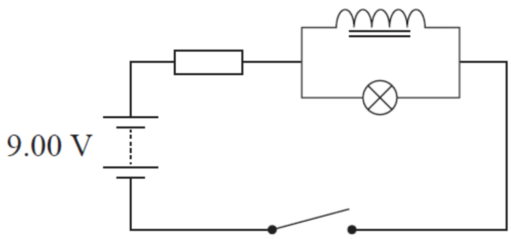
There are a number of techniques used to detect cars and bicycles waiting at traffic lights. The most common technique is the inductive loop circuit.

(a) State how an inductor stores energy.

(b) One type of inductor loop circuit is shown. This circuit contains a 9.00 V battery, with an inductor of 1.00 x 10 $^{-2}$ H, and a total resistance of 12.5 Ω in the circuit. Soon after closing the switch, the current is 0.260 A. Find the voltage across the resistor and the voltage across the inductor, and therefore calculate the rate of change of current.

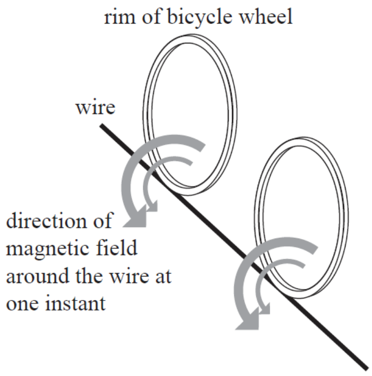


(c) A different inductive loop circuit is constructed, as shown below. When the switch is closed, the bulb is bright and then gets dimmer. Explain, in terms of current, why the inductor makes the circuit behave this way.



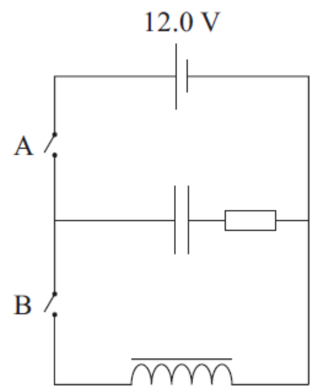
(d) Inductive loops at traffic lights can be adjusted to detect bicycles with metal rims. Below is a simplified diagram of a bike waiting for the traffic lights to change.

The inductive loop circuit uses Faraday's law to detect changes in the inductance when a bicycle is above the circuit. The high-frequency, alternating current induces a magnetic field in the metal bicycle rim. The magnetic field induced in the bicycle rim reduces the overall magnetic field. The inductance of the circuit is reduced, and this is detected by the traffic lights. Explain the underlying physical concepts used in this situation. In your answer, you should:



- describe the nature of the magnetic field that is created by the alternating current in the wire
- explain why a high-frequency alternating current is needed to induce a significant magnetic field in the rims of the bicycle wheels
- explain why the induced magnetic field in the rims of the bicycle wheels is in the opposite direction to the magnetic field around the wire.

ENERGY (2014;3)

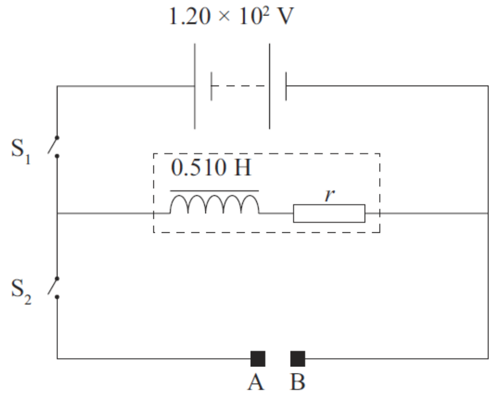


In the circuit shown, switch B is kept open and switch A is closed, allowing charge to flow onto the plates of the capacitor. Now switch A is opened and switch B is closed. The current changes with time.

(d) Explain the effect that inductors have on currents that change with time.

(e) Discuss how energy is stored in the capacitor and inductor at the instant switch B is closed, and then while the capacitor is discharging.

Using an inductor to produce a spark (2013;2)



In the circuit shown, for a spark to be produced between the gap AB, the voltage across AB must be greater than 1.20×10^2 V.

Switch 1 is closed and the current in the circuit rises to a constant value of 1.70 A.

(a) Calculate the energy stored in the inductor when the current has risen to its maximum value.

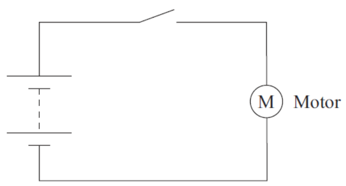
(b) Calculate the value of r shown on the diagram AND explain its effect on the maximum current.

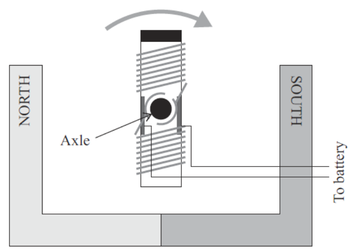
(c) Explain the effect of inductance on the time it takes for the current to rise to its maximum value.

(d) Switch 2 is closed in addition to switch 1. Explain what happens to the voltage across the inductor.

(e) Switch 1 is opened, leaving switch 2 closed. Explain why a spark could be produced across the gap.

THE MOTOR (2012;2)





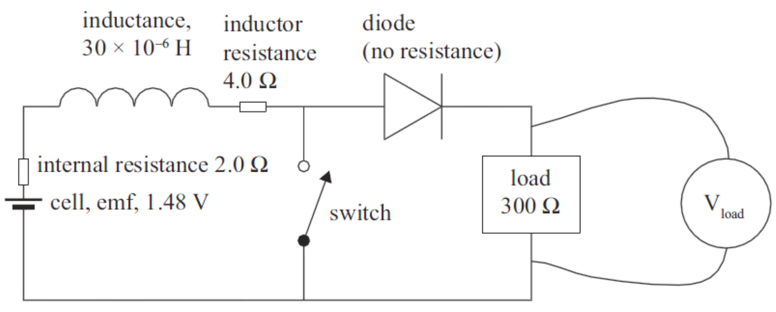
When Hugo presses a button on the car's remote control, a switch closes to allow current to flow in the coil of the motor. This causes the coil to rotate, which makes the car's wheels turn. The motor has a very simple design – the current in the coil causes it to rotate in the magnetic field between the two magnets, as shown in the diagram. As the coil rotates, a "back EMF" is produced in the coil.

(a) Explain how this back EMF will increase the life of the battery. In your answer you should:

- Explain why an EMF will be induced in the coil as it turns
- Explain how this EMF will change as the coil rotates faster
- Explain the effect of this EMF on the current drawn from the battery.

BOOST CONVERTER (2011;3)

With a boost converter a 1.48 V cell is able to produce a much higher voltage across a load. The inductor section of a boost converter is shown in the diagram. The diode only allows current through the load in the clockwise direction.



(a) Calculate the steady current that will flow in the circuit after it has been set up with the switch **open**.

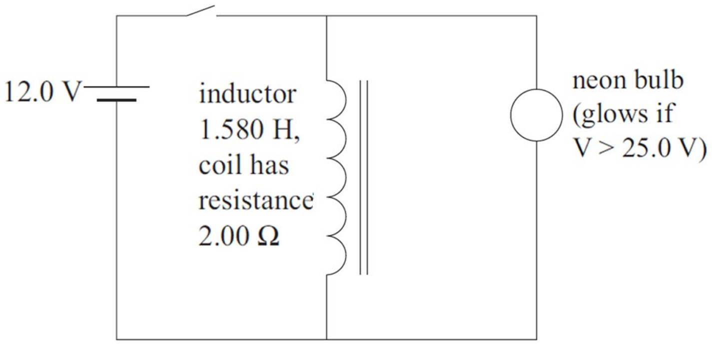
(b) The switch is **closed** and the circuit is left for a few minutes. Discuss how the voltage across the load will be different to the voltage when the switch was open.

(c) When the boost converter is working, its switch opens and closes at a high frequency. Explain how the circuit is able to produce a voltage across the load that is greater than the EMF of the battery.

(d) Shortly after the switch is opened, the inductor produces an EMF of 15 V in the same direction as the cell. By applying Kirchhoff's voltage law, or otherwise, calculate the voltage across the load at this instant.

PORTABLE POWER (2010;1)

(c) Another group of students wants to understand how a 12.0 V battery can be used in a circuit to produce a high enough voltage to light a 25.0 V neon bulb. They are shown the circuit below.The instructions tell them to close the switch, slowly count to ten and then open the switch. The students see that the neon bulb flashes when they switch **off** the circuit.

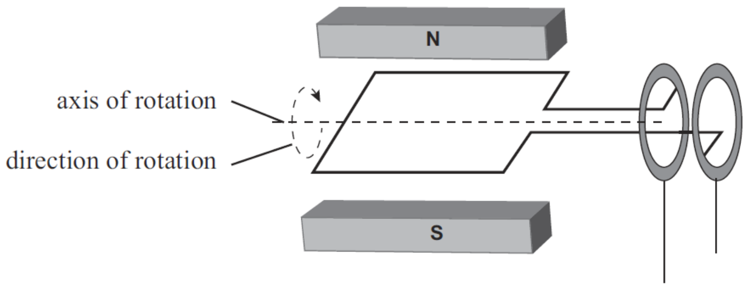


(i) Explain why the bulb only lights when the circuit is switched off.

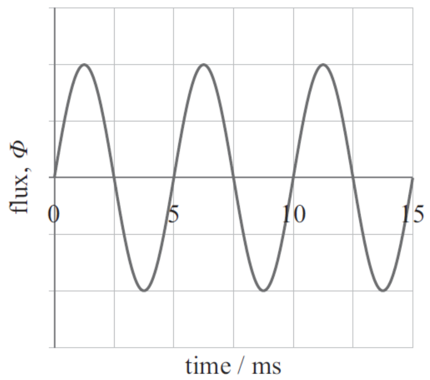
(ii) Explain why the students have to count to ten before turning off.

GENERATORS (2010;3)

The diagram below shows a coil turning in a uniform magnetic field, working as an AC generator.



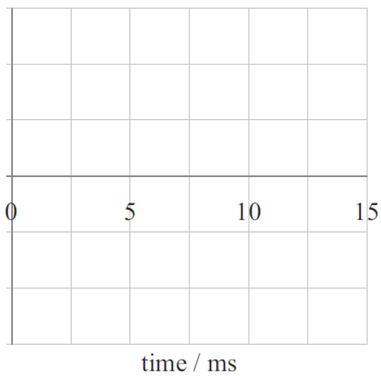
coil area = 0.015 m²
B = 0.35 T
number of turns = 500



(a) Calculate the maximum flux cutting a single loop of the coil as it rotates.

(b) Given that $V_{max} = \Phi_{max} N \omega$ (where N is the number of turns), calculate the rms voltage produced when the coil is rotated at 220 radians per second.

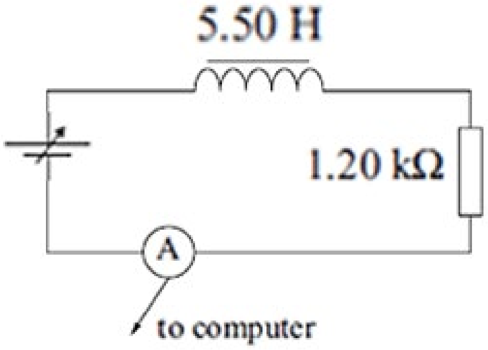
(c) When the coil turns at a steady speed, the flux cutting the coil varies as shown in the graph. (1 ms = 1×10^{-3} s). Describe and explain how the induced voltage will vary with time. You may use words, equations and / or sketches on the adjacent graph to explain your answer.



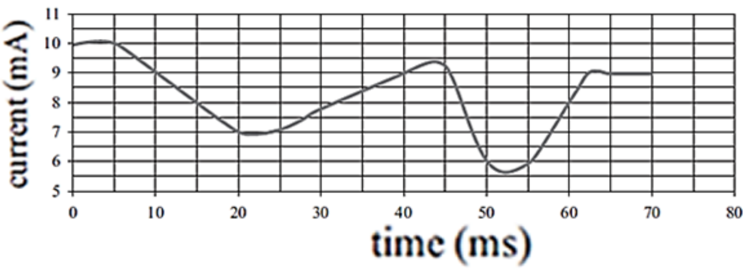
(d) The coil is made to rotate faster. Explain how this will affect the output voltage. You may use words, equations and / or sketches on the adjacent grid to explain your answer.

INDUCTOR PROPERTIES (2009;2)

Lafi builds a simple inductor circuit, as illustrated. She uses a computer data logger to continuously monitor the current in the circuit. The resistance of the inductor wiring is negligible.



Lafi changes the voltage of the supply and this makes the current vary as shown.



(a) For most of the time, even though the resistance of the inductor is effectively zero, there is a voltage across it. Explain why.

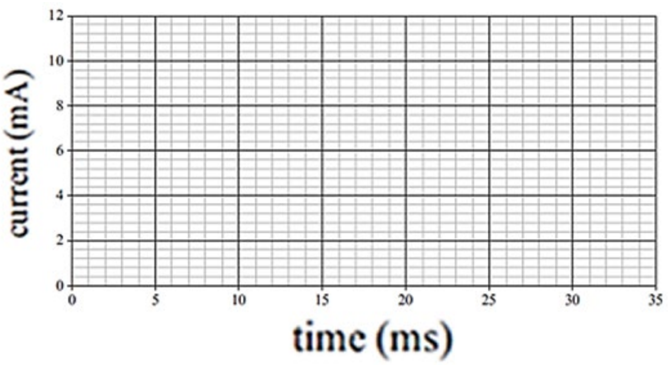
(b) Between t = 10.0 ms and t=15.0 ms, the current can be considered to be dropping at a steady rate from 9.00 mA to 8.00 mA.

(i) Show that the size of the voltage induced across the inductor during this time period is 1.10 V.

(ii) Describe and explain the direction of the induced voltage.

(c) At one moment, while Lafi is changing the current, the supply voltage is 11.5 V and the current is 7.75 mA. Calculate the rate of change of current that could cause these readings.

(d) Lafi then swaps her power supply for a 12 V D.C. battery. By calculating appropriate values, sketch a graph to accurately describe the change in current when she switches on the circuit.



TORCH INVESTIGATION (2008;1)

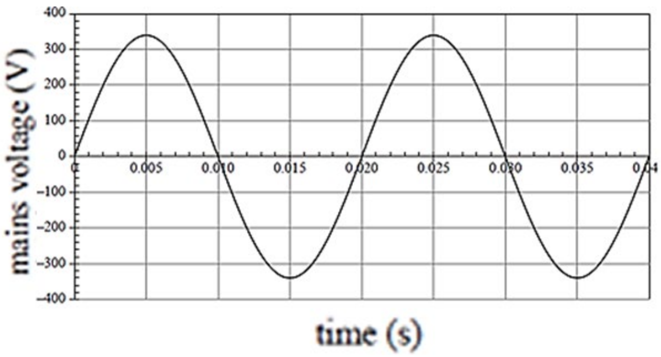
Jess is investigating a torch to find out the characteristics of the battery and the lamp. The torch uses a filament lamp. The filament is a long coil of fine wire that heats up and glows when it carries sufficient current. For the purposes of calculation, assume that the resistance of the filament remains constant. Jess measures the battery voltage when the lamp is switched off and finds the voltage to be 6.12 V. When Jess switches on the lamp, the voltage drops to 5.87 V. The current through the lamp is then 0.743 A. Jess suggests that it could take a few milliseconds for the lamp to reach full brightness when it is switched on, and that the lamp's filament coil could be acting as an inductor.

(f) Assuming the time constant for the filament is 1.2 ms calculate the inductance of the filament coil. Give your answer to the correct number of significant figures.

(g) Inductance can be defined from the equation $\varepsilon = -L\frac{\Delta I}{\Delta t}$.

Use this definition to explain why an inductor would delay a bulb reaching full brightness after it is switched on.

(h) The lamp is connected to an AC supply from a transformer. The supply for the transformer is a 50 Hz mains supply, with a peak voltage of 340 V. The graph below shows the variation of the mains supply with time.



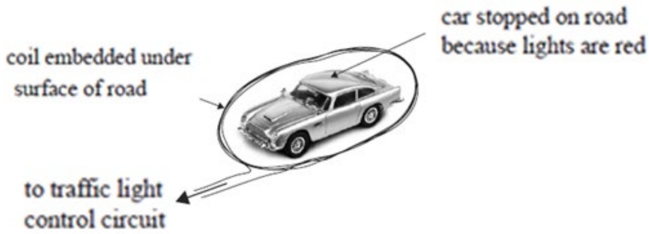
Use the graph to show that the maximum rate of change of voltage in the primary coil of the transformer is approximately 100×10^3 Vs^{-1}.

(i) The output of the transformer from the secondary coil is labelled “6 V AC”. The lamp connected to this output appears to light with the same brightness as it did when it was connected to the battery. Explain whether the 6 V from the secondary coil of the transformer output is a peak value or an r.m.s value.

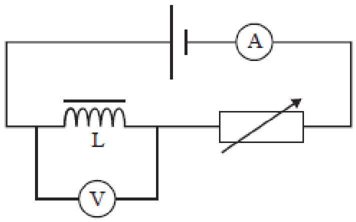
(j) The current in the primary coil changes at a maximum rate of 8.7 A s^{-1}. Calculate the mutual inductance of the transformer.

INDUCTORS AND AC CIRCUITS (2007;2)

Traffic lights can be controlled by using an inductive loop to detect the presence of a car on the road. The loop is a large coil of wire embedded under the road surface. When a car stops over the loop, the inductance of the loop changes. This is sensed by an electrical circuit that causes the traffic lights to change from red to green.



The inductance of the coil of wire must be measured. A possible way of doing this is to use a circuit like the one below. The inductor, L, in the circuit models the coil of wire under the road.

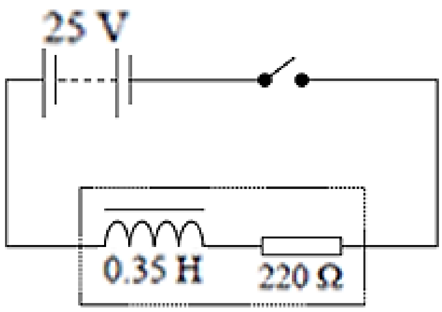


The resistance of the rheostat is changed so that the current in the circuit drops steadily from its maximum value of 1.62 A to 0.13 A in 1.2 s. While the current is dropping, the voltmeter reads 4.0 mV.

(a) Explain why there is a voltage across the inductor.
(b) Calculate the inductance of the inductor.

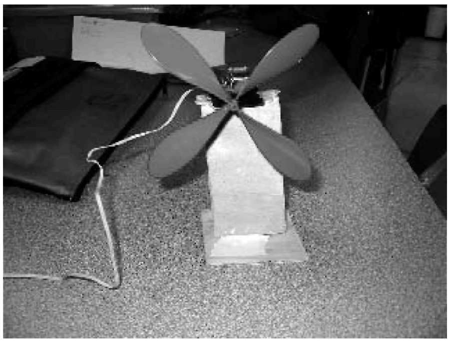
SNUBBER SWITCH (2006;2)

In the circuit shown, a power supply of 25V is connected to an inductor with inductance 0.35 H and resistance of 220 Ω. The switch is closed, and after a time of 8.0×10^{-3} s, the circuit current has reached a value that is sufficiently close to the steady current value for any difference to be ignored.



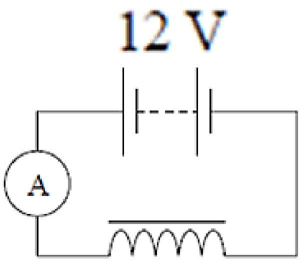
(a) Show that the average voltage induced in the inductor during this time period is 5.0 V.
(b) Calculate the flux in the coil after this time period.
(c) Explain why, when the switch is opened, the maximum induced voltage will be much larger than when the switch is closed.

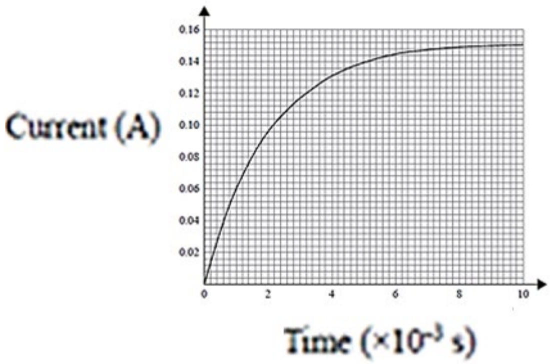
WIND POWER (2005;2)



Jill is making a model wind turbine. It includes a generator constructed from a strong horseshoe magnet and a coil of wire, with 500 turns.

Jill decides to investigate the electrical properties of the coil of wire by connecting it in the circuit shown. She finds that the current takes some time to reach a steady value. A graph of the increase in current against time is also shown.





When the current is steady the ammeter gives a reading of 0.152 A.

(a) Calculate the resistance of the coil. Give your answer to the correct number of significant figures.
(b) Explain why the ammeter took some time to reach a steady reading.
(c) Calculate the self-inductance of the coil.

THE 'COIL' (2004;3)

In the engine of a car the 'coil' is the device that generates the high voltage required to create the spark that ignites the petrol vapour.

The 'coil' is essentially made up of two coils of wire. One coil is called the primary coil. Wrapped around it is the secondary coil. The secondary coil normally has hundreds of times more turns of wire than the primary coil.

The diagram shows a simplified view of this arrangement of coils.

Current from the battery flows through the primary coil. When the circuit is suddenly broken, the magnetic field in the primary coil, and hence also in the secondary coil, collapses (falls rapidly). The mutual induction that takes place between the two coils produces the high voltage needed to create a spark. Describe what is meant by mutual induction.

In questions (b) to (g), assume that the secondary coil is not connected so the primary coil experiences self-induction only.

In Jessie's car, the primary coil has 150 turns, cross-sectional area of 2.00×10^{-3} m^2, and resistance 0.750 Ω. The magnetic field in the primary coil, when it is connected to the 12 V battery, is 4.20×10^2 T.

(a) Calculate the flux in the primary coil when it is connected to the battery.

When the circuit is broken, there is an average voltage of 85.0 V across the primary coil.

(b) Explain why there is a voltage across the primary coil when the circuit is broken.

(c) Show that the time it takes the flux in the primary coil to collapse is 1.48×10^{-4} s.

(d) Show that the self-inductance of the primary coil is 7.9×10^{-4} H.

(e) (i) Calculate the time constant for the primary circuit when it is completed.

(ii) Justify the number of significant figures to which you have rounded your answer.

(g) Explain why the time taken for the current to build in the primary coil, when the circuit is completed, is longer than the time taken to fall when the circuit is broken.

When the secondary coil is connected, mutual induction takes place, and there is a maximum voltage of 410 V across the primary coil.

(h) Calculate the maximum voltage induced across the secondary coil.