21. Alternating Currents

21.1 Characteristics of alternating currents

Paper 4

Question Paper

1 A circuit contains a power supply that provides a sinusoidal alternating input voltage V_{IN}. There is an output voltage V_{OUT} across a load resistor R, as shown in Fig. 7.1.

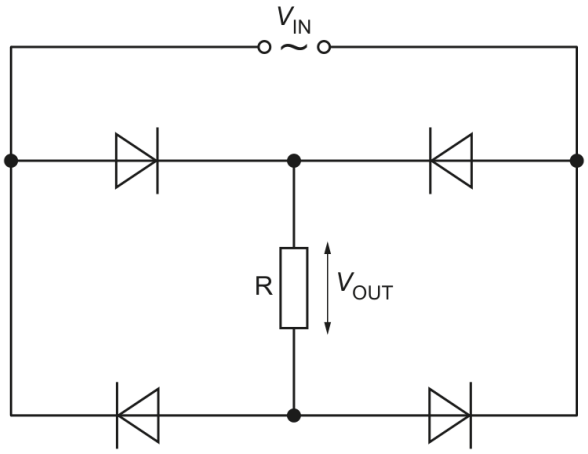


Fig. 7.1

(b) Fig. 7.2 shows the variation of V_{OUT} with time t.

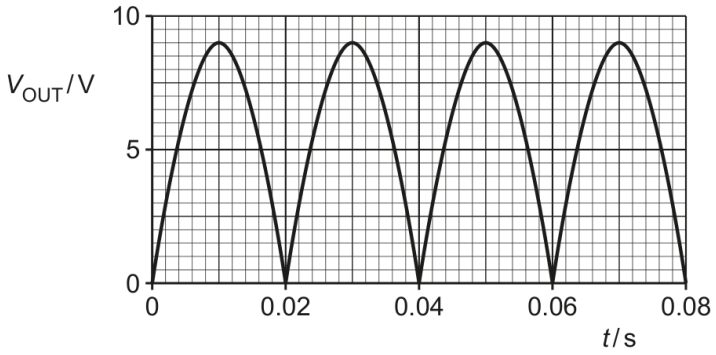


Fig. 7.2

(i) The load resistor R has a resistance of 370 Ω.

Show that the maximum power dissipated in R is 0.22 W.

[2]

(iii) Calculate the mean power dissipated in R.

mean power = ... W [1]

(c) The circuit of Fig. 7.1 is disconnected, and R is connected directly across the power supply.

Explain, without calculation, how the mean power now dissipated in R compares with the answer in **(b)(iii)**.

.....

.....

..... [2]

2 **(b)** Fig. 7.1 shows a coil at rest in a uniform magnetic field that is parallel to the axis of the coil.

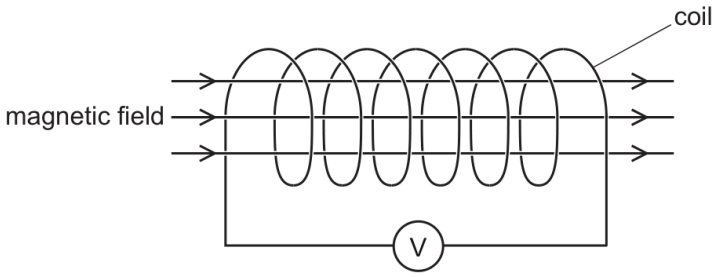


Fig. 7.1

The coil is connected to a centre-zero voltmeter.

The flux density B of the uniform magnetic field varies with time t as shown in Fig. 7.2.

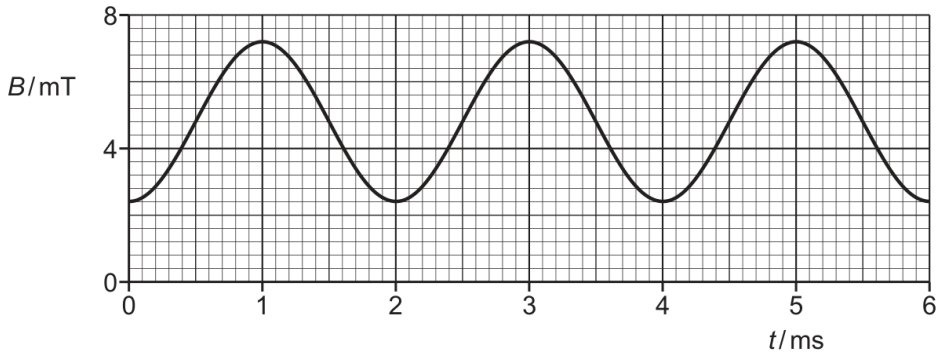


Fig. 7.2

The coil consists of 340 turns, each of cross-sectional area $3.2 \times 10^{-4}\,m^2$.

(v) The variation of V with t can be described by

$$V = A \sin Bt$$

where A and B are constants.

Determine the values of A and B. Give units with your answers.

A = ... unit .....

B = ... unit .....

[3]

3 **(a)** State what is meant by the frequency of an alternating current.

.....

..... [1]

(b) An alternating current I in a resistor of resistance 680 Ω varies with time t according to

$$I = 3.5 \sin(40\pi t)$$

where I is in A and t is in s.

(i) Show that the period of the alternating current is 50 ms.

[1]

(ii) On Fig. 8.1, sketch the variation of I with t between $t = 0$ and $t = 100$ ms.

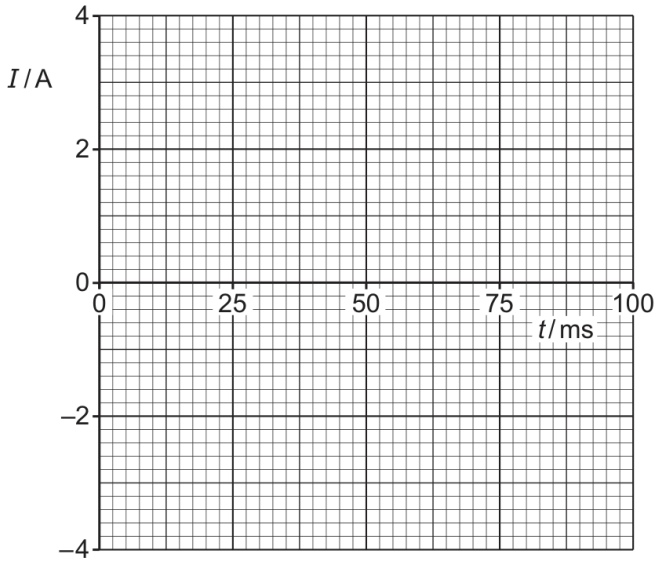


Fig. 8.1

[3]

(iii) Determine the root-mean-square (r.m.s.) current in the resistor.

r.m.s. current = ...A [1]

(c) Use data from **(b)**, including your answer in **(b)(iii)**, to show by calculation that the mean power in the 680 Ω resistor is half of the peak power.

[3]

4 Part of an electric circuit is shown in Fig. 5.1.

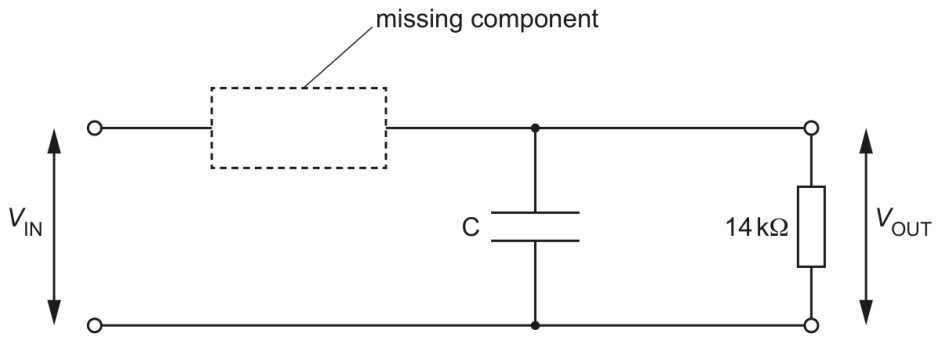


Fig. 5.1

The circuit is used to produce half-wave rectification of an alternating voltage of potential difference (p.d.) V_{IN}.

The output p.d. across the 14 kΩ resistor is V_{OUT}.

(b) Fig. 5.2 shows the variation with time t of V_{IN}.

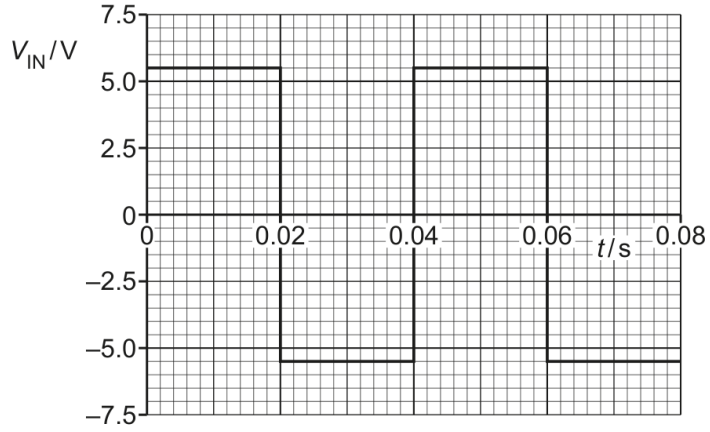


Fig. 5.2

Fig. 5.3 shows the variation with t of V_{OUT}.

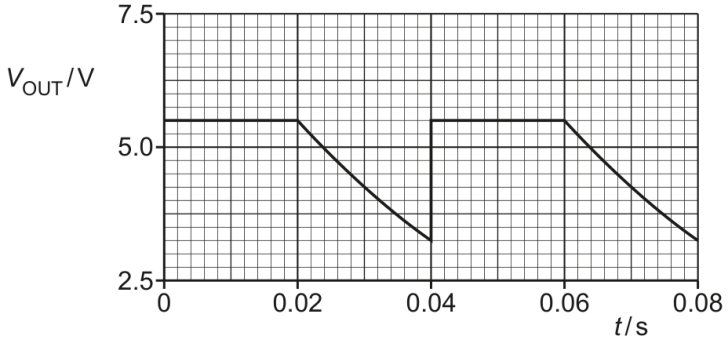


Fig. 5.3

(i) Determine the frequency of V_{IN}.

frequency = ... Hz [1]

5 Four diodes are used in a bridge rectifier circuit to produce rectification of a sinusoidal a.c. input voltage V_{IN}.
Fig. 7.1 shows part of the circuit, but three of the diodes are missing.

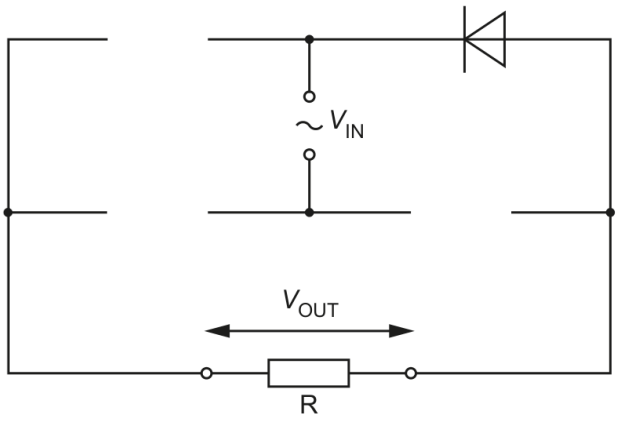


Fig. 7.1

The p.d. across the load resistor R is the output p.d. V_{OUT} of the bridge rectifier.

(b) V_{IN} has amplitude V_0 and period T. Fig. 7.2 shows the variation with time t of V_{IN}.

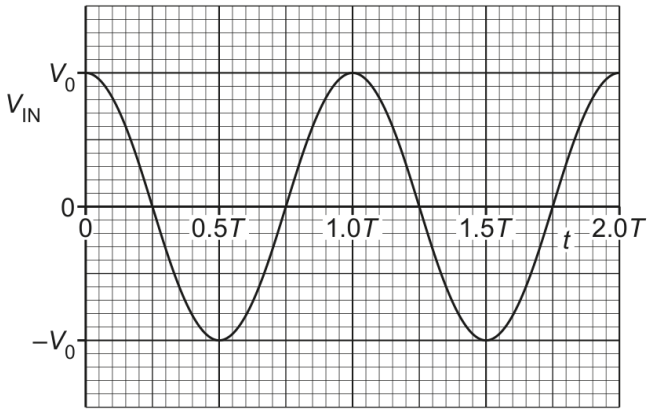


Fig. 7.2

(ii) The power dissipated in the resistor is P.

On Fig. 7.4, sketch the variation of P with t between $t = 0$ and $t = 2.0T$.

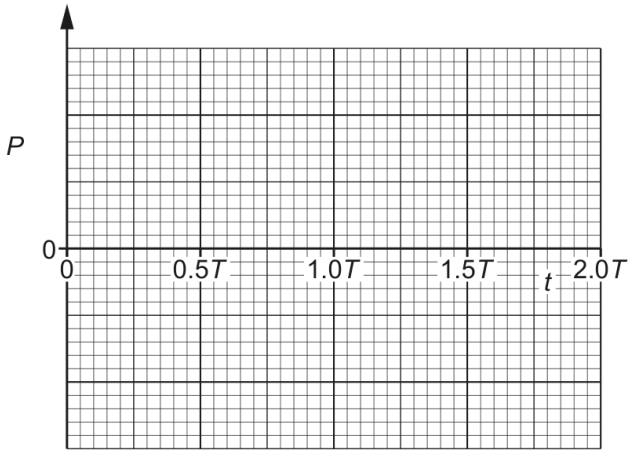


Fig. 7.4

[2]

(iii) Suggest, with a reason, how the root-mean-square (r.m.s.) value of V_{OUT} compares with the r.m.s. value of V_{IN}.

.....

..... [1]

6 A varying current I passes through a resistor of resistance R in the circuit shown in Fig. 7.1.

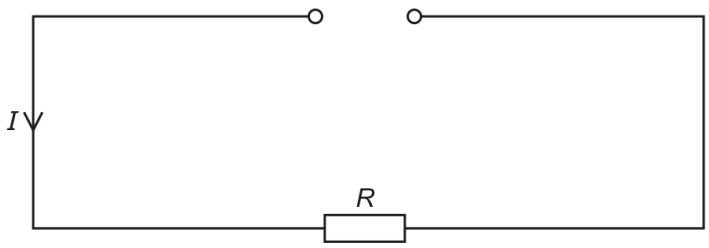


Fig. 7.1

Fig. 7.2 shows the variation with time t of I.

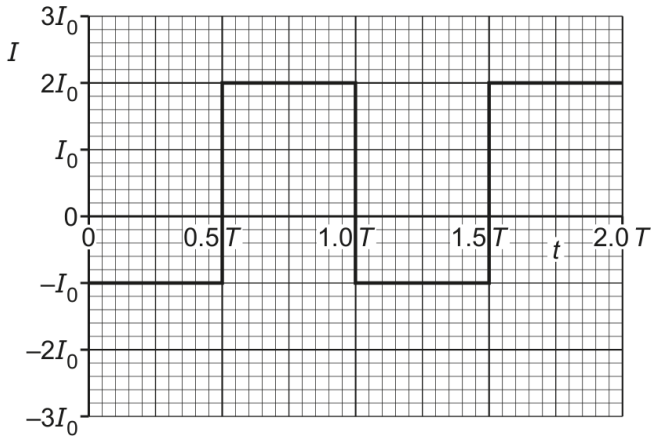


Fig. 7.2

The current has magnitude $2I_0$ when it is in the positive direction and I_0 when it is in the negative direction. The period of the variation of the current is T.

(a) Determine expressions, in terms of I_0 and R, for the power P dissipated in the resistor for the times when:

(i) the current is in the negative direction

$P =$ ..... [1]

(ii) the current is in the positive direction.

$P =$ ..... [1]

(b) On Fig. 7.3, sketch the variation of P with t between $t = 0$ and $t = 2.0T$. Label the power axis with an appropriate scale.

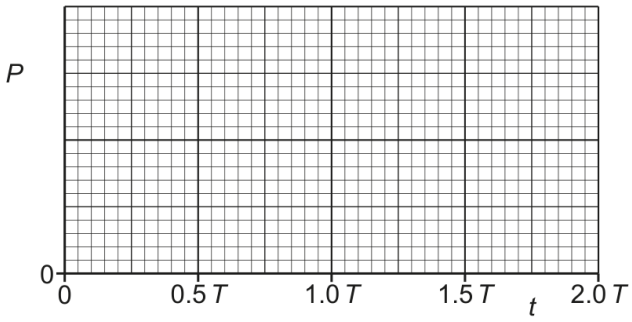


Fig. 7.3

[3]

(c) Use your answer in **(b)** to determine an expression, in terms of I_0 and R, for:

(i) the mean power $\langle P \rangle$ in the resistor

$\langle P \rangle$ = ... [1]

(ii) the root-mean-square (r.m.s.) current $I_{\text{r.m.s.}}$ in the resistor.

$I_{\text{r.m.s.}}$ = ... [2]

7 An electron in a metal rod moves randomly about a mean position. When an alternating voltage is applied to the ends of the rod, the mean position can be considered to oscillate with simple harmonic motion along the axis of the rod. Fig. 4.1 shows the variation with time t of the displacement x of the mean position from a fixed point on the axis of the rod.

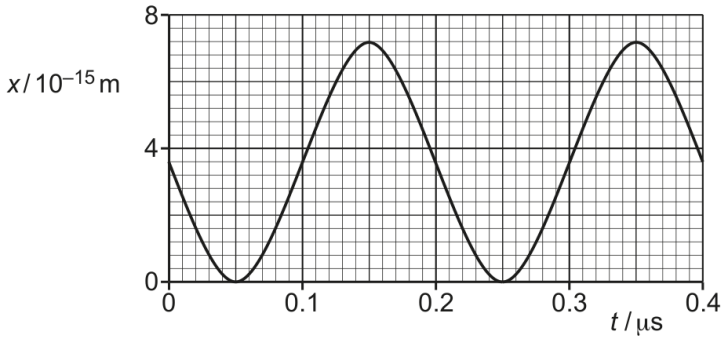


Fig. 4.1

(b) The rod has a cross-sectional area of 4.3 cm^2 and contains a number density of conduction electrons (charge carriers) of 8.5×10^{28} m^{-3}.

All of the conduction electrons in the rod may be assumed to be oscillating in phase with, and with the same amplitude as, the oscillation shown in Fig. 4.1.

(i) Use the information in **(a)(iii)** to calculate the magnitude I_0 of the maximum current in the rod.

I_0 = ...A [2]

(ii) On Fig. 4.2, sketch the variation of the current I in the rod with time t between $t = 0$ and $t = 0.40\,\mu s$.

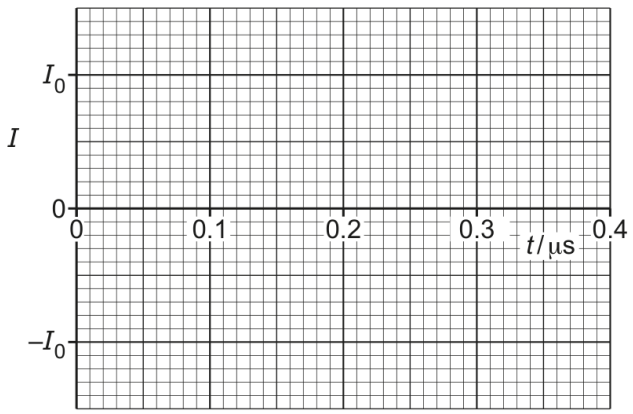


Fig. 4.2

[2]

(iii) Use your answers in **(a)(ii)** and **(b)(i)** to determine an expression for I in terms of t, where I is in A and t is in s.

I = ... [2]

(iv) Determine the root-mean-square (r.m.s.) current in the rod.

r.m.s. current = ...A [1]

8 Fig. 5.1 shows four diodes and a load resistor of resistance 1.2 kΩ, connected in a circuit that is used to produce rectification of an alternating voltage.

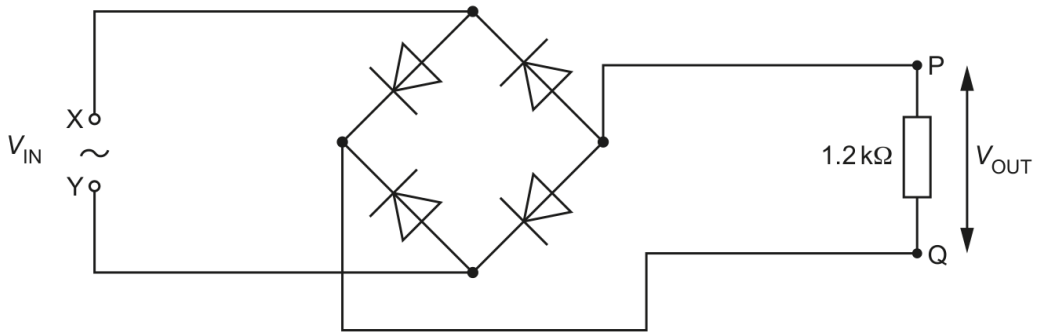


Fig. 5.1

(b) A sinusoidal alternating voltage V_{IN} is applied across the input terminals X and Y. The variation with time t of V_{IN} is given by the equation

$$V_{IN} = 6.0 \sin 25\pi t$$

where V_{IN} is in volts and t is in seconds.

(ii) The magnitude of the output voltage V_{OUT} varies with t as shown in Fig. 5.2.

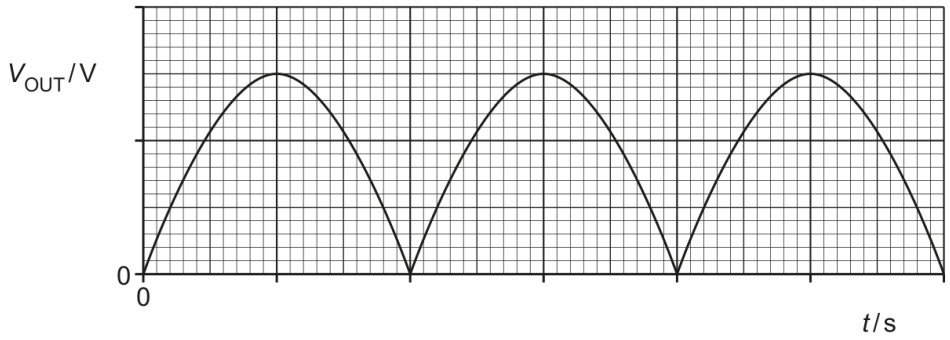


Fig. 5.2

On Fig. 5.2, label both of the axes with the correct scales. Use the space below for any working that you need.

[3]

9 **(a)** A sinusoidal alternating voltage has a root-mean-square (r.m.s.) potential difference (p.d.) of 4.2 V and a frequency of 50 kHz.

(i) The alternating voltage is applied across a resistor of resistance 760 Ω.

By considering the peak voltage, show that the maximum power dissipated by the resistor is 46 mW.

[2]

(ii) On Fig. 7.1, draw a smooth curve to show how the power P dissipated in the resistor varies with time t between $t = 0$ and $t = 40\,\mu s$. Assume that $P = 0$ when $t = 0$.

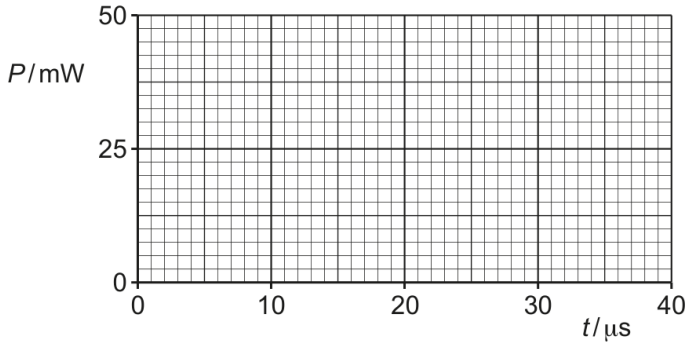


Fig. 7.1

[3]

(iii) Use your line in **(a)(ii)** to explain why the mean power dissipated in the resistor is 23 mW.

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.....

..... [1]

10 (b) Two coils of insulated wire are wound on an iron bar, as shown in Fig. 8.1.

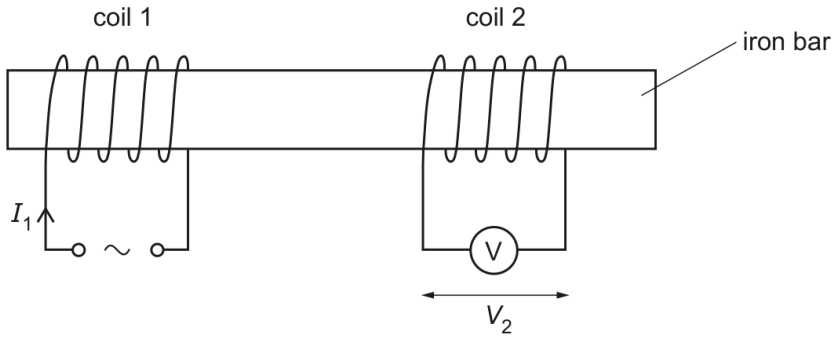


Fig. 8.1

There is a current I_1 in coil 1 that varies with time t as shown in Fig. 8.2.

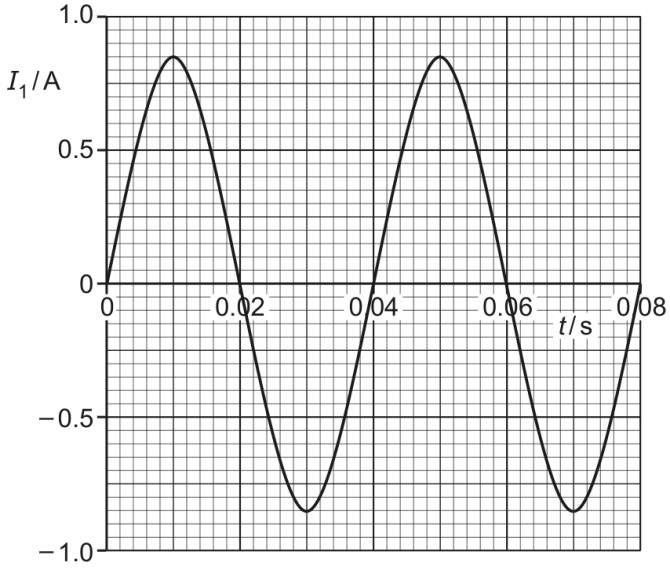


Fig. 8.2

(i) The variation with t of I_1 can be represented by the equation

$$I_1 = X \sin Yt$$

where X and Y are constants.

Use Fig. 8.2 to determine the values of X and Y. Give units with your answers.

X = ... unit .....

Y = ... unit .....

[3]

11 **(a)** By reference to heating effect, explain what is meant by the *root-mean-square* (*r.m.s.*) value of an alternating current.

.....

.....

..... [2]

(b) The variations with time t of two currents I_1 and I_2 are shown in Fig. 10.1 and Fig. 10.2.

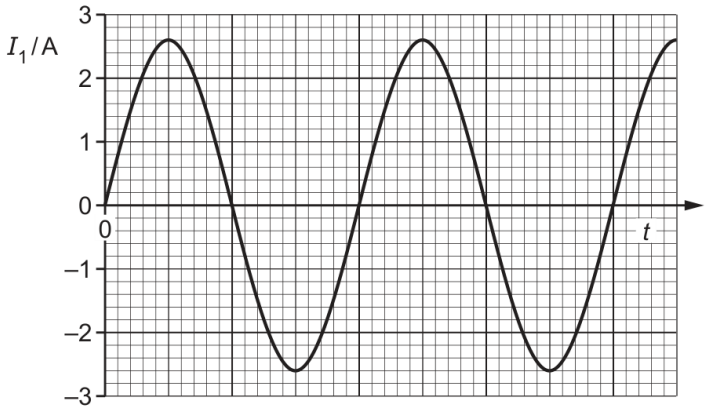


Fig. 10.1

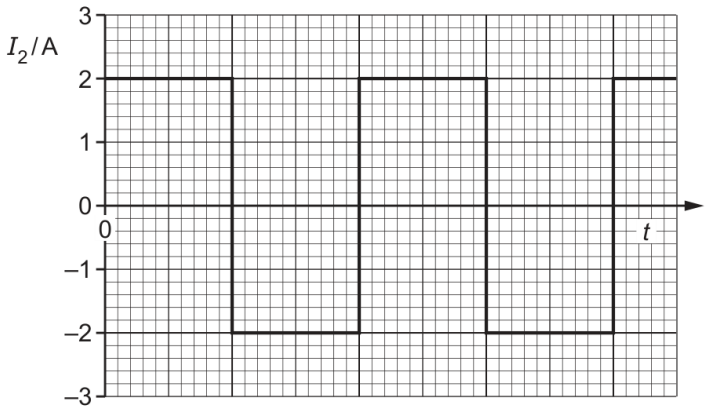


Fig. 10.2

(i) Use Fig. 10.1 to determine the peak value and the r.m.s. value of the current I_1.

peak value = ... A

r.m.s. value = ... A
[1]

(ii) Use Fig. 10.2 to determine the peak value and the r.m.s. value of the current I_2.

peak value = ... A

r.m.s. value = ... A
[1]

(c) The variation with time t of the supply voltage V to a house is given by the expression

$$V = 240 \sin kt$$

where V is in volts, t is in seconds and k is a constant with unit rad s^{-1}.

(i) The frequency of the supply voltage is 50 Hz.

Determine k to two significant figures.

k = ... rad s^{-1} [2]

(ii) The supply voltage is applied to a heater. The mean power of the heater is 3.2 kW.

Calculate the resistance of the heater.

resistance = ... Ω [2]

12 **(a)** State, by reference to the power dissipated in a resistor, what is meant by the *root-mean-square* (*r.m.s.*) value of an alternating voltage.

.....

.....

.....

..... [2]

(b) A coil is rotating freely, on frictionless bearings, at constant speed in a uniform magnetic field. This rotation causes an induced alternating electromotive force (e.m.f.) across the open terminals of the coil. The induced e.m.f. has r.m.s. value 12 V and frequency 50 Hz.

The speed of rotation of the coil is now doubled.

(ii) On Fig. 9.1, sketch the variation with time t of the induced e.m.f. E across the terminals of the coil at the **increased** speed of rotation. Your line should extend from time $t = 0$ to time $t = 20$ ms. Assume that $E = 0$ when $t = 0$.

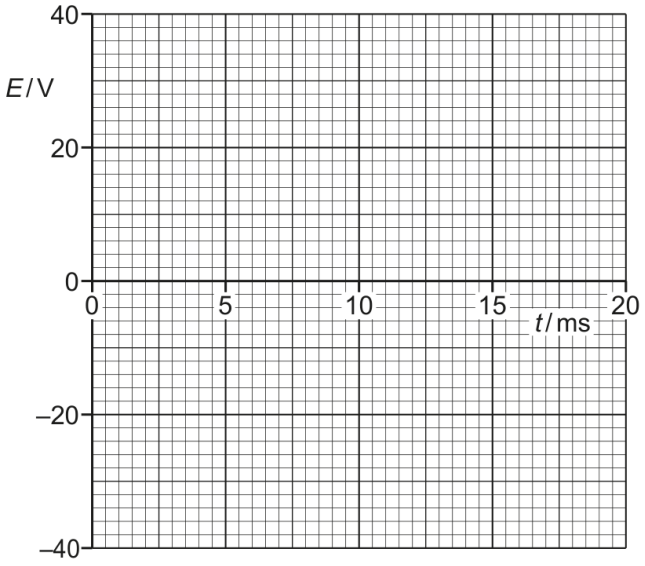


Fig. 9.1

[3]

13 Fig. 10.1 shows a simple laminated iron-cored transformer consisting of a primary coil of 25 000 turns and a secondary coil of 625 turns.

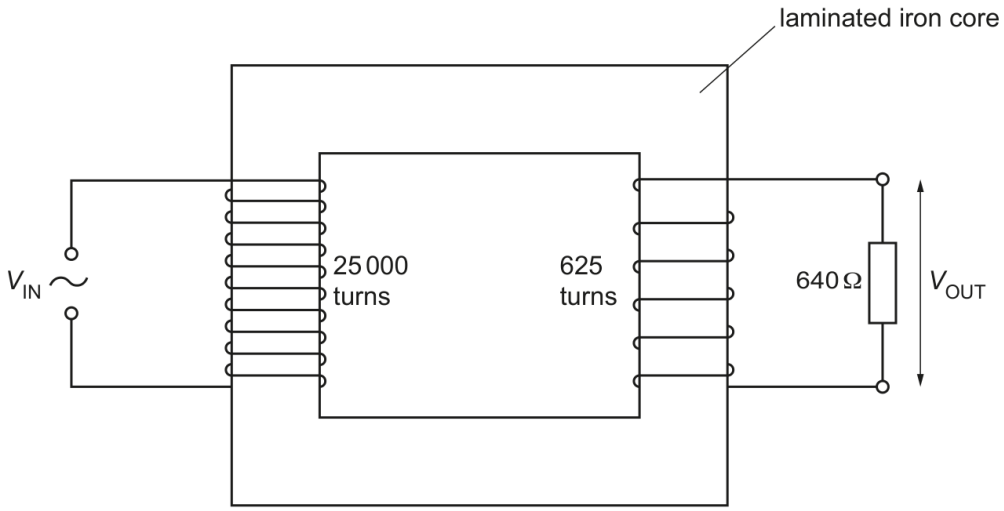


Fig. 10.1

The output potential difference (p.d.) V_{OUT} is applied to a load resistor of resistance 640 Ω.

(b) The input p.d. V_{IN} is a sinusoidal alternating voltage of peak value 12 kV and period 40 ms.

(ii) Calculate the root-mean-square (r.m.s.) current in the load resistor.

r.m.s. current = ... A [1]

(iii) On Fig. 10.2, sketch the variation with time t of the power P dissipated in the load resistor for time $t = 0$ to $t = 40$ ms. Assume that $P = 0$ when $t = 0$.

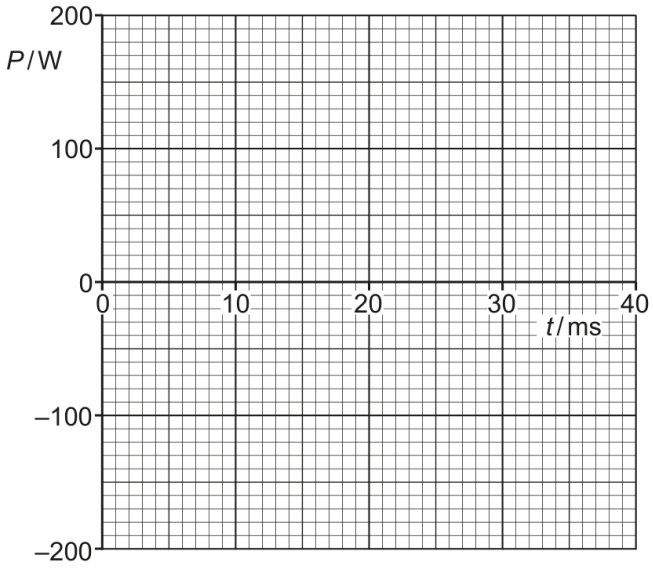


Fig. 10.2

[3]

(c) Explain, with reference to Fig.10.2, why the mean power in the load resistor is 70 W.

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.....

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..... [2]

14 A bridge rectifier contains four diodes. The output of the rectifier is connected to a resistor R, as shown in Fig. 10.1.

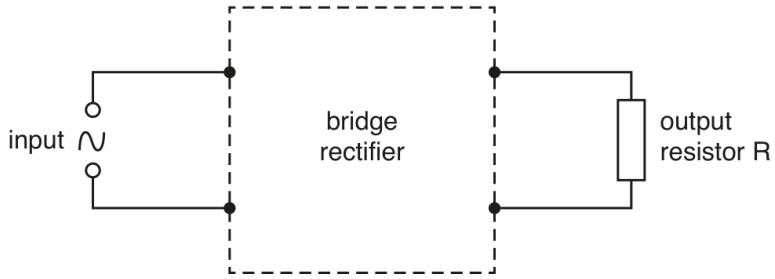


Fig. 10.1

The variation with time t of the input e.m.f. E to the rectifier is given by the expression

$$E = 15\cos(210t)$$

where t is measured in seconds and E in volts.

The variation with time t of the potential difference V across resistor R is shown in Fig. 10.2.

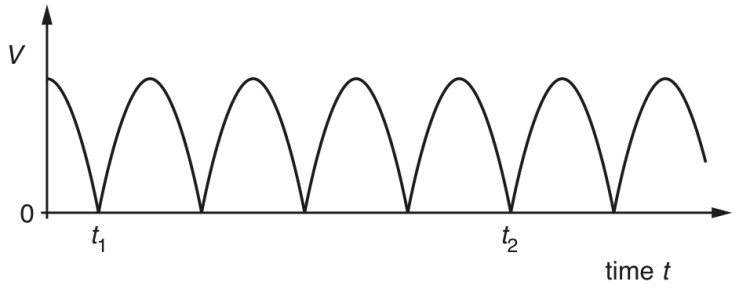


Fig. 10.2

Determine:

(a) the maximum potential difference V_{MAX} across resistor R

V_{MAX} = ...V [1]

(b) the time interval, to two significant figures, between time t_1 and time t_2.

time = ... s [3]

15 A bridge rectifier using four ideal diodes is shown in Fig. 10.1.

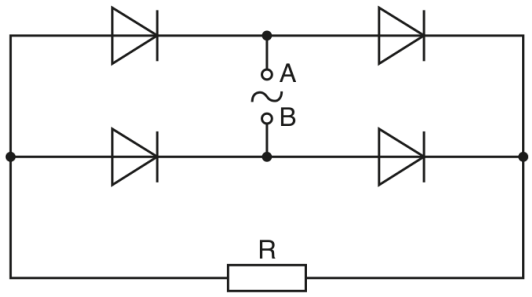


Fig. 10.1

The sinusoidal alternating electromotive force (e.m.f.) applied between points A and B has a root-mean-square (r.m.s.) value of 7.0 V.

(a) (ii) Calculate the maximum potential difference V_{MAX} across resistor R.

V_{MAX} = ... V [1]

16 (a) The root-mean-square (r.m.s.) value of the voltage of a sinusoidal alternating supply is 9.9 V. The frequency of the supply is 50 Hz.

Derive an expression for the variation with time t (in second) of the potential difference V (in volt) of the supply.

$V =$ ..... [2]