ALTERNATING CURRENT

21.1 Characteristics of alternating currents

Candidates should be able to:

1 understand and use the terms period, frequency and peak value as applied to an alternating current or voltage

2 use equations of the form $x = x_0 \sin \omega t$ representing a sinusoidally alternating current or voltage

3 recall and use the fact that the mean power in a resistive load is half the maximum power for a sinusoidal alternating current

4 distinguish between root-mean-square (r.m.s.) and peak values and recall and use $I_{\text{r.m.s.}} = I_0 / \sqrt{2}$ and $V_{\text{r.m.s.}} = V_0 / \sqrt{2}$ for a sinusoidal alternating current

21.2 Rectification and smoothing

Candidates should be able to:

1 distinguish graphically between half-wave and full-wave rectification

2 explain the use of a single diode for the half-wave rectification of an alternating current

3 explain the use of four diodes (bridge rectifier) for the full-wave rectification of an alternating current

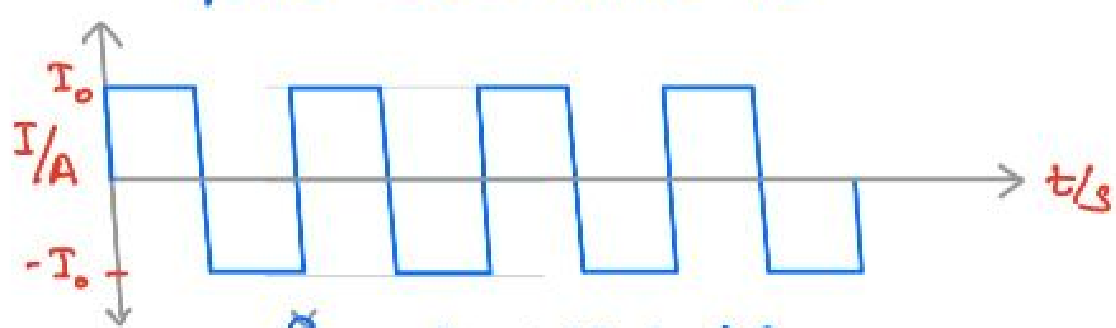
4 analyse the effect of a single capacitor in smoothing, including the effect of the values of capacitance and the load resistance

Alternating current:

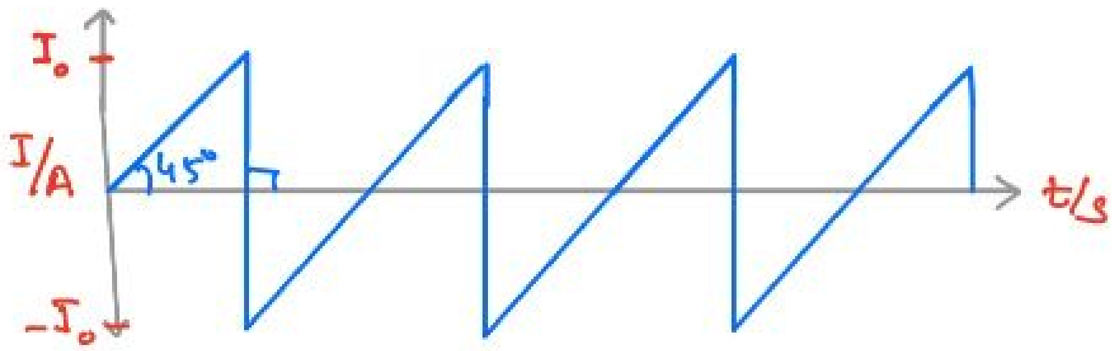
Identification:- The current whose magnitude and direction changes many times in a unit time in AC.

Waveform:-

pure sine wave AC



Square wave AC.



Saw-tooth wave AC

Important terms :-

1- **Time period**: T

2- **Frequency**: No. of complete cycles per unit time.

$$f = \frac{n}{t}$$

For one cycle, $n = 1$, $t = T$

$$\boxed{f = \frac{1}{T}}$$

3- **Angular frequency**: (ω)

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

4- **Peak value of AC** :-

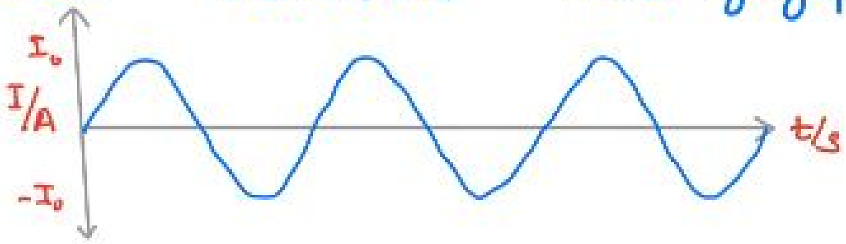
Def. It is the maximum value of AC for both half cycles.

Symbol: I_o

5- **Equation of AC in syllabus** :-

$$I = I_o \sin \omega t$$

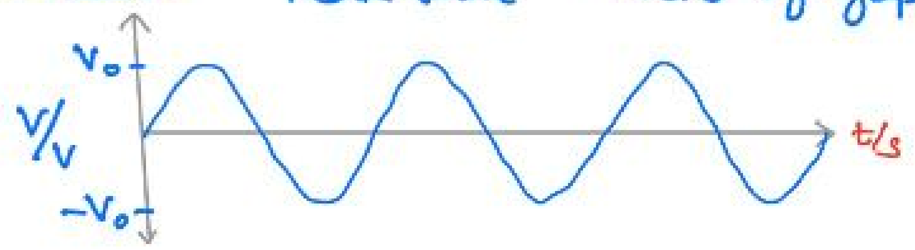
- I → Y-axis
- I_o → Peak value
- $\sin$ → Trend of graph
- ω → Constant time period.
- t → x-axis



Similarly, for a sine wave voltage,

$$V = V_0 \sin \omega t$$

- V → Y-axis
- V_0 → Peak value
- $\sin \omega t$ → Trend of graph
- ω → constant time period
- t → x-axis



v.imp

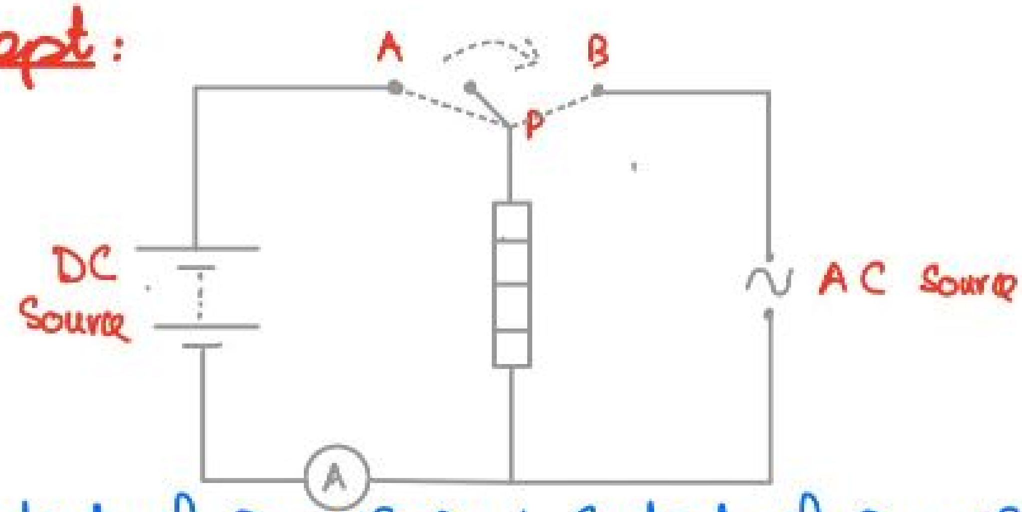
6- Root-mean-square value of AC.

Def. r.m.s. of AC is equal to constant DC which convert electrical energy into any other form at the same rate in the same component/load as DC.

OR

r.m.s. of AC is equal to steady DC which dissipates heat energy in a resistor/load at the same rate as DC.

Concept:



Contact of P with A	Contact of P with B
$t = 10$ minutes	$t = 10$ minutes
$E = 4000\ J$	$E = 4000\ J$
$I_{dc} = 2.8A$	$I_{rms} = I_{dc} = 2.8A$

$$I_{rms} = I_{dc} = 2.8A$$

Formula analysis:-

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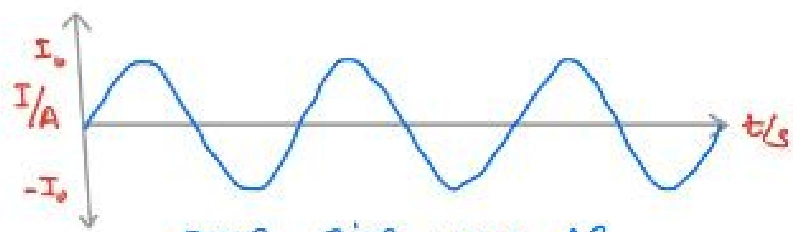
(a) For a Sine wave AC:-



pure sine wave AC

Step 1: Square of AC to make it DC.

Step 2: Mean value of squared current.

$$I_{ms} = \frac{0 + I_0^2}{2}$$

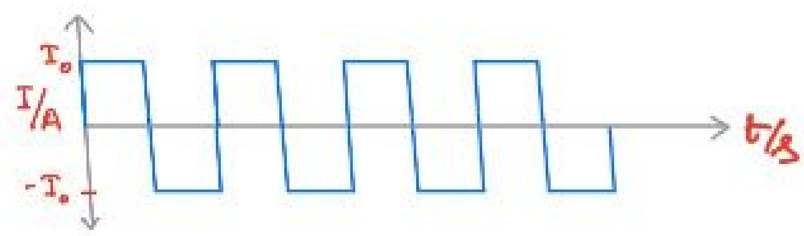
$$I_{ms} = \frac{I_0^2}{2}$$

Step 3: Square root of mean value of squared current.

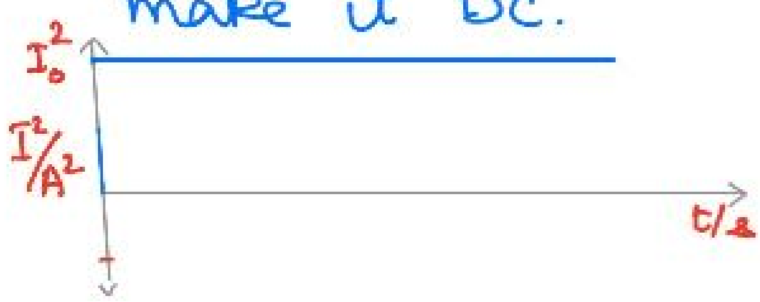
$$I_{rms} = \sqrt{\frac{I_0^2}{2}}$$

$$\boxed{I_{rms} = \frac{I_0}{\sqrt{2}}}$$

(b) For a Square wave AC



Step 1: Square of AC to make it DC.



Step 2: Mean value of squared current.

$$I_{ms} = \frac{I_0^2 + I_0^2}{2} = \frac{2I_0^2}{2}$$

$$I_{ms} = I_0^2$$

Step 3: Square root of mean value of squared current.

$$I_{rms} = \sqrt{I_0^2}$$

$$\boxed{I_{rms} = I_0}$$

Similarly, for a sine wave voltage

$$V_{rms} = \frac{V_0}{\sqrt{2}}$$

Similarly, for a sine wave voltage

$$V_{rms} = V_0$$

Power of AC:-

i) **Peak power**: P_0

$$P_0 = V_0 I_0 = I_0^2 R = \frac{V_0^2}{R}$$

(ii) **Mean Power**: $\langle P \rangle$

For sine wave AC:

$$\langle P \rangle = V_{rms} I_{rms}$$

But for a sine wave AC

$$V_{rms} = \frac{V_0}{\sqrt{2}} \text{ and } I_{rms} = \frac{I_0}{\sqrt{2}}$$

Therefore,

$$\langle P \rangle = \left(\frac{V_0}{\sqrt{2}}\right)\left(\frac{I_0}{\sqrt{2}}\right)$$

$$\langle P \rangle = \frac{V_0 I_0}{2}$$

$$\boxed{\langle P \rangle = \frac{P_0}{2}}$$

For a sine wave AC, mean power is equal to half of peak power.

For Examiner's Use

7 (a) Explain what is meant by the *root-mean-square* (r.m.s.) value of an alternating voltage.

R.m.s. value of alternating voltage is equal to constant Direct voltage which converts electrical energy into any other form at the same rate in the same component as Direct voltage. [2]

(b) An alternating voltage *V* is represented by the equation

$$V = 220 \sin(120\pi t),$$

$$V = V_0 \sin \omega t$$

where *V* is measured in volts and *t* is in seconds.

For this alternating voltage, determine

(i) the peak voltage,

peak voltage = 220 V [1]

(ii) the r.m.s. voltage,

$$V_{rms} = \frac{V_0}{\sqrt{2}} = \frac{220}{\sqrt{2}}$$

r.m.s. voltage = 156 V [1]

(iii) the frequency.

$$\omega = 120\pi$$

$$2\pi f = 120\pi$$

frequency = 60 Hz [1]

(c) The alternating voltage in **(b)** is applied across a resistor such that the mean power output from the resistor is 1.5 kW.

Calculate the resistance of the resistor.

$$\langle P \rangle = \frac{V_{rms}^2}{R}$$

$$1.5 \times 10^3 = \frac{(156)^2}{R}$$

$$R = \_\_\_\_ \Omega$$

resistance = ... Ω [2]

10 The output potential difference (p.d.) of an alternating power supply is represented by

$$V = 320\sin(100\pi t)$$

$V = V_0 \sin \omega t$

where V is the p.d. in volts and t is the time in seconds.

(a) Determine the root-mean-square (r.m.s.) p.d. of the power supply.

$V_{rms} = \frac{V_0}{\sqrt{2}} = \frac{320}{\sqrt{2}}$

r.m.s. p.d. = ...226............ V [1]

(b) Determine the period T of the output.

$\omega = 100\pi$

$\frac{2\pi}{T} = 100\pi$

$T = \frac{2}{100}$

T = ...0.020............ s [2]

(c) The power supply is connected to resistor R and a diode in the circuit shown in Fig. 10.1.

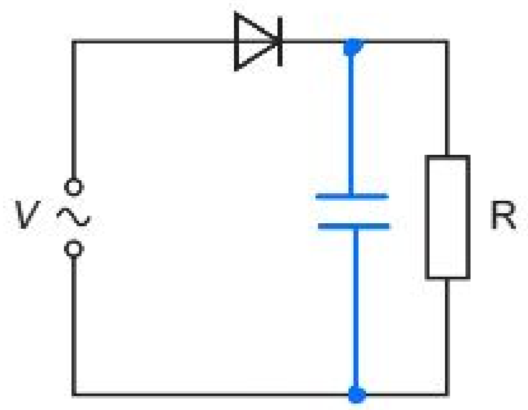


Fig. 10.1

(i) State the name of the type of rectification produced by the diode in Fig. 10.1.

............Half-wave rectification............ [1]

(ii) On Fig. 10.2 sketch the variation with time t of the p.d. V_R across R from time t = 0 to time t = 40 ms.

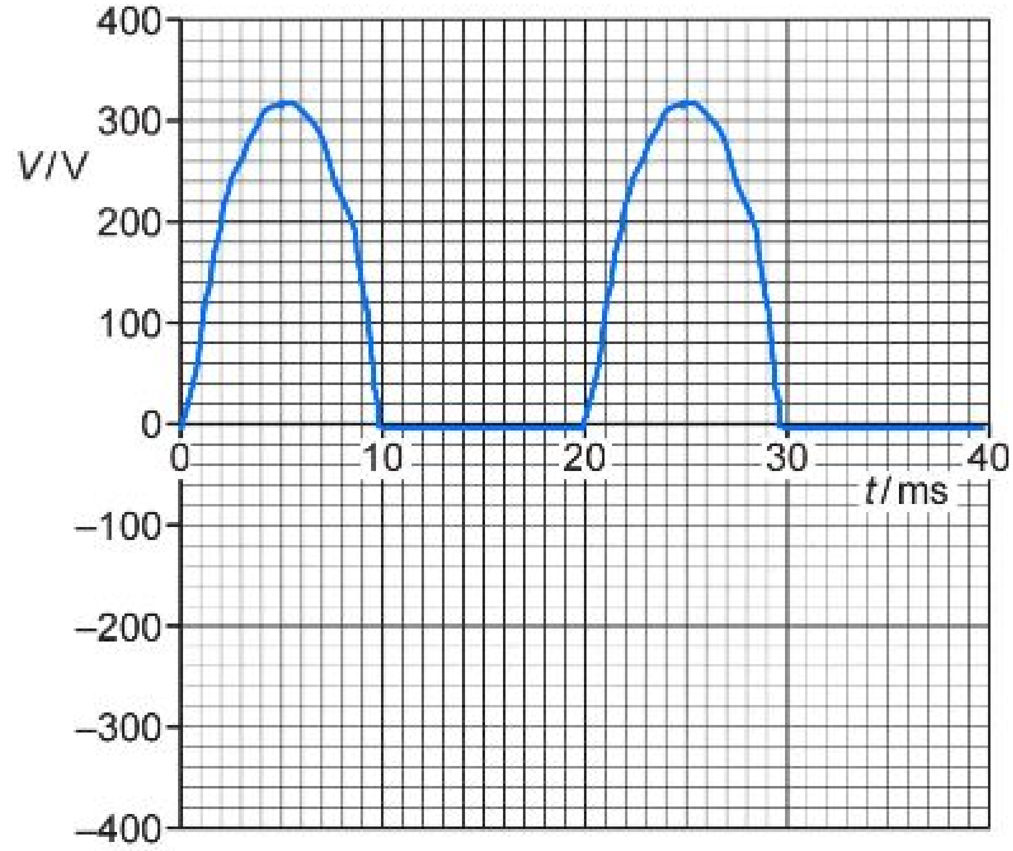


Fig. 10.2

[3]

(iii) On Fig. 10.1, draw the symbol for a component that may be connected to produce smoothing of V_R.

[1]

[Total: 8]

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

r.m.s value of AC is equal to constant DC which dissipate heat enery at the same rate in the same component as DC. [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.

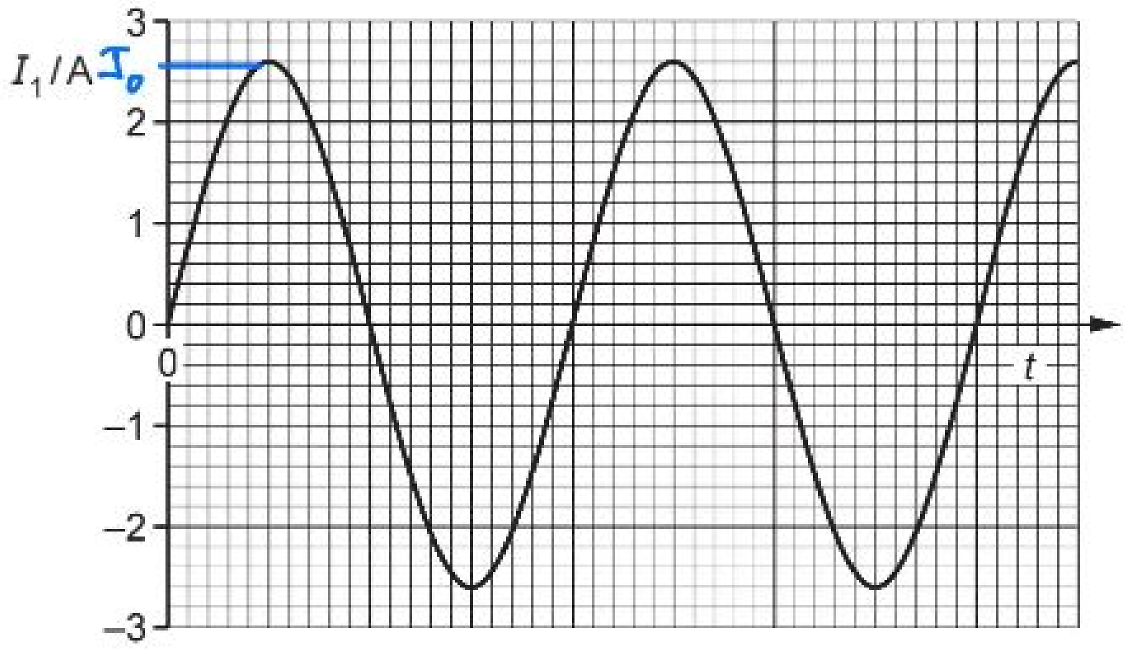


Fig. 10.1

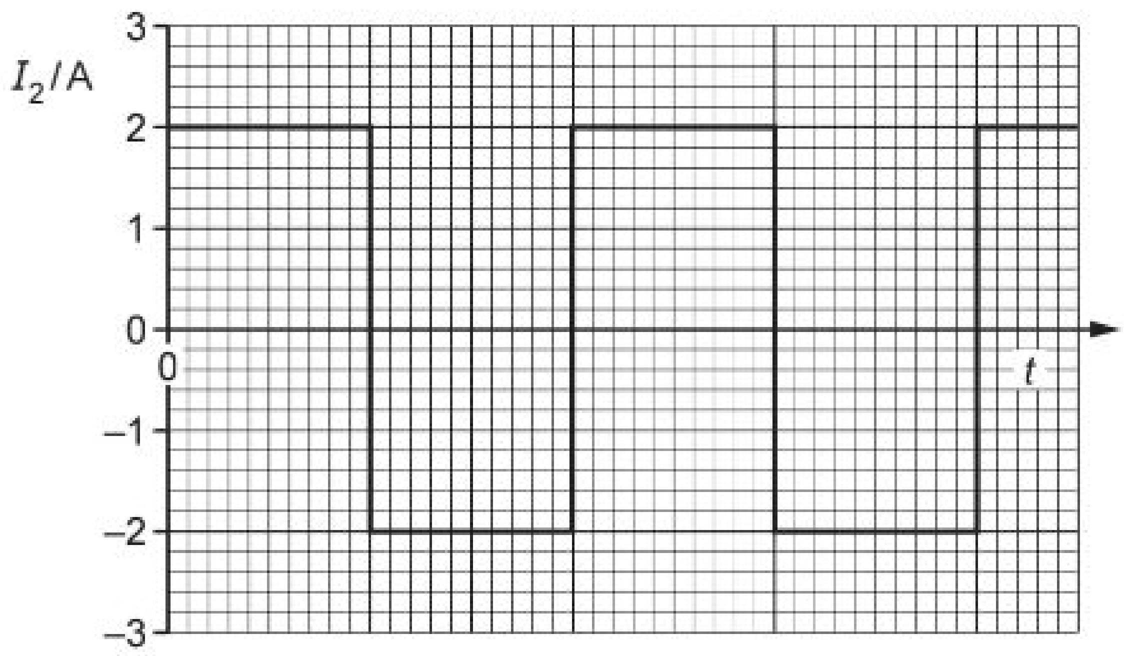


Fig. 10.2

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

$I_{rms} = \frac{I_0}{\sqrt{2}} = \frac{2.6}{\sqrt{2}}$

peak value = ...2.6.......... A

r.m.s. value = ...1.84.......... A

[1]

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

Square wave AC, $I_{rms} = I_0$

peak value = ...2.0.......... A

r.m.s. value = ...2.0.......... A

[1]

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

$$V = 240 \sin kt$$

$V = V_0 \sin \omega t$

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

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

Determine k to two significant figures.

$K = \omega = 2\pi f$

$K = 2(3.14)(50)$

$K = 314$

k = ...314.......... $\text{rad}\,\text{s}^{-1}$ [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.

$V_{rms} = \frac{V_0}{\sqrt{2}} = \frac{240}{\sqrt{2}} = 170$

$\langle P \rangle = \frac{V_{rms}^2}{R}$

$3.2 \times 10^3 = \frac{(170)^2}{R}$

$R = 9.0$

resistance = ...9.0Ω.......... Ω [2]

[Total: 8]

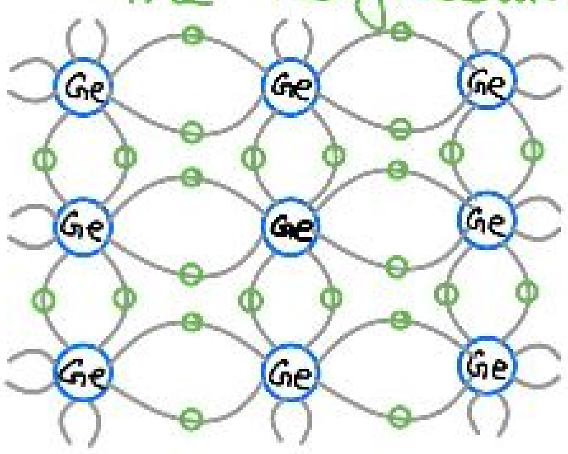
Types of material:

1- Conductor, $\rho = 10^{-6}\ \Omega cm$
2- Insulator, $\rho \approx 10^{12}\ \Omega cm$
3- Semi-conductor, $\rho \approx 10^{6}\ \Omega cm$

$R = \rho \frac{L}{A}$

$R \propto \rho$

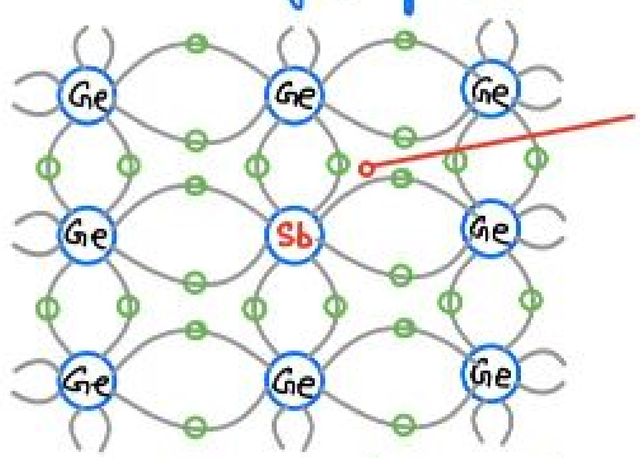
→ Group IV of periodic table i.e Ge, Si, C and they have four valence electron and form covalent bonds with the neighbouring atoms.



To increase conduction, we need to add impurity so that charge carriers are increased for greater number density (n).

N-type material:- Add pentavalent impurity (Group V) element to group IV element in the ratio $1 : 10^8$

Group IV : Group V
10^8 : 1

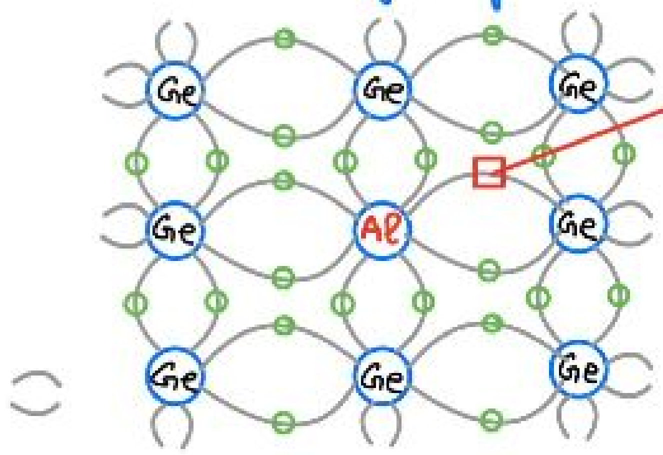


Charge carriers in N-type are free electrons which define current.

P-type material:- Add trivalent impurity (Group III) element to group V element in the ratio $1 : 10^8$

Group IV : Group III

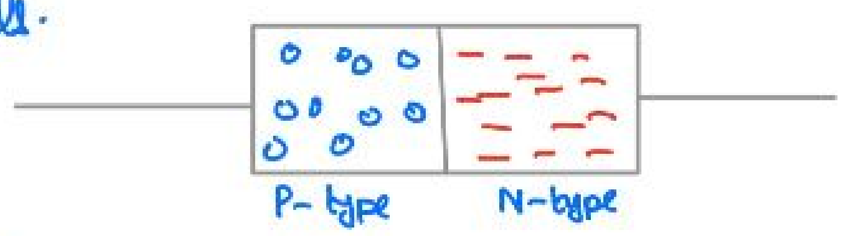
10^8 : 1



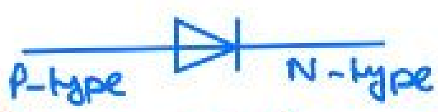
1 Hole (deficiency of an electron
So this deficiency shows that the net charge on the crystal is +ve.

Charge carriers in P-type are holes which define current.

Diode - PN junction:- It is the junction between a P-type (+ve type - holes) and N-type (-ve type - electrons) materials.

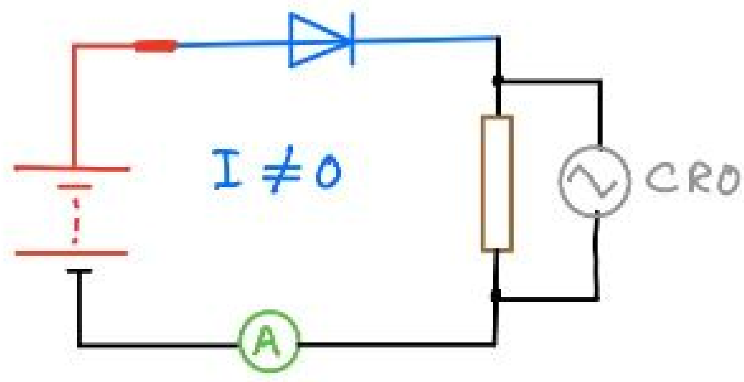


Symbol,

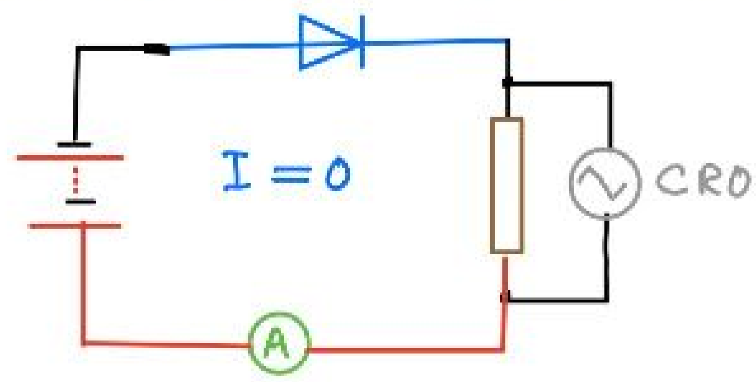


Biasing of a Diode:- This is the method to connect a diode across the terminals of an emf source.

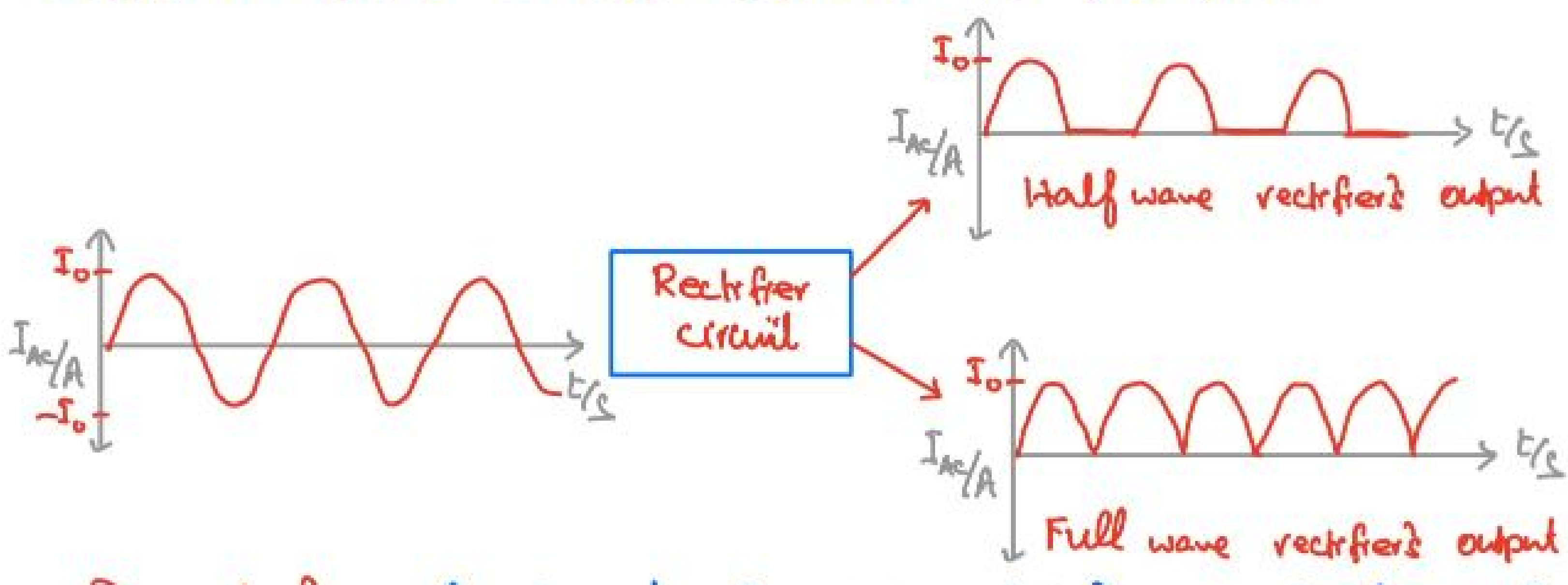
(i) **Forward biasing:-** If P-type is connected to +ve and N-type to the -ve terminal of battery then Diode is forward biased and conducts ie Diode acts as a closed switch in forward biasing.



(ii) Reversed biasing:- If P-type is connected to -ve and N-type to the +ve terminal of battery then Diode is reversed biased and does not conduct, ie Diode acts as an open switch in reversed biasing.



Rectifier:- A circuit which converts an Alternating current into Direct current is rectifier.



Principle: A Diode (PN junction) conducts only when it is forward biased.

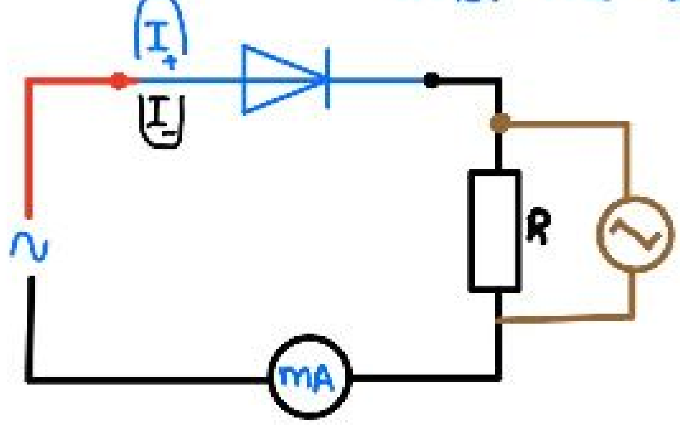
when it is forward biased.

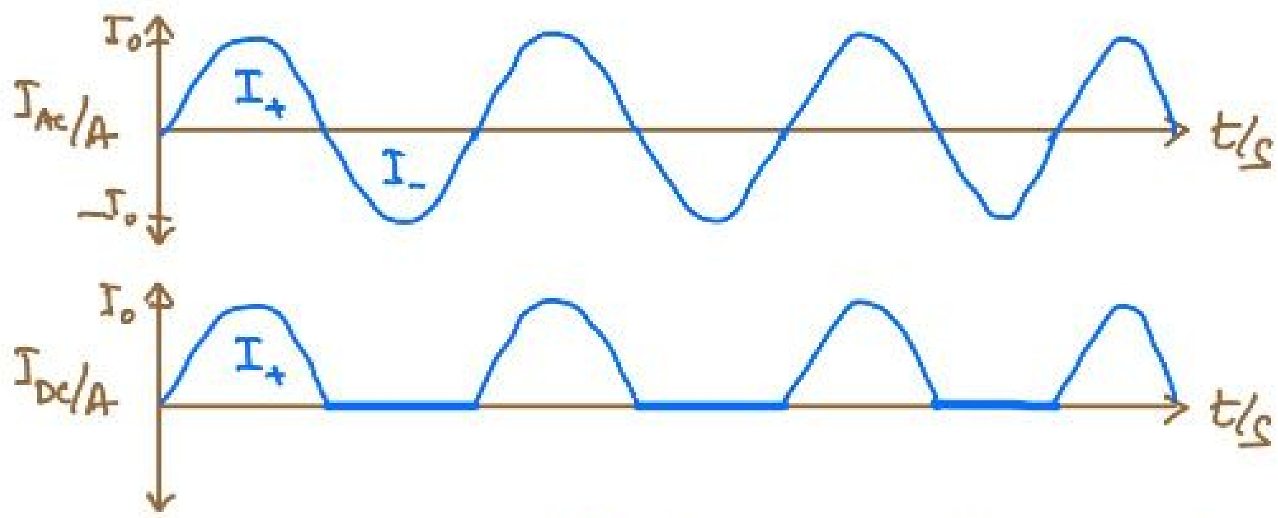
Types of Rectifiers:

1- Half wave rectifier:

Achieved ⟶ using single Diode

Connectivity ⟶ in series between AC source and the load

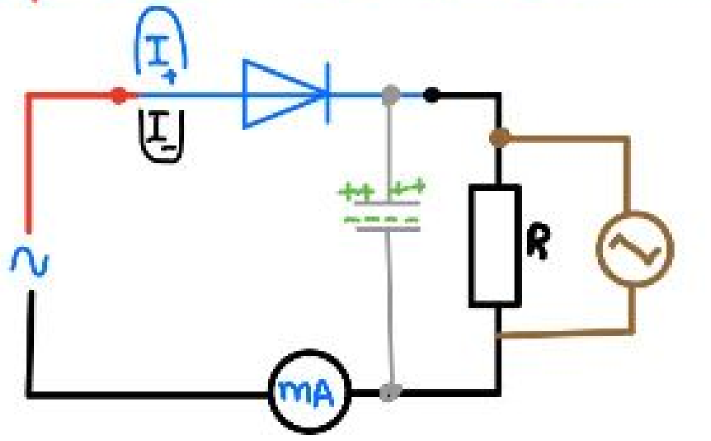




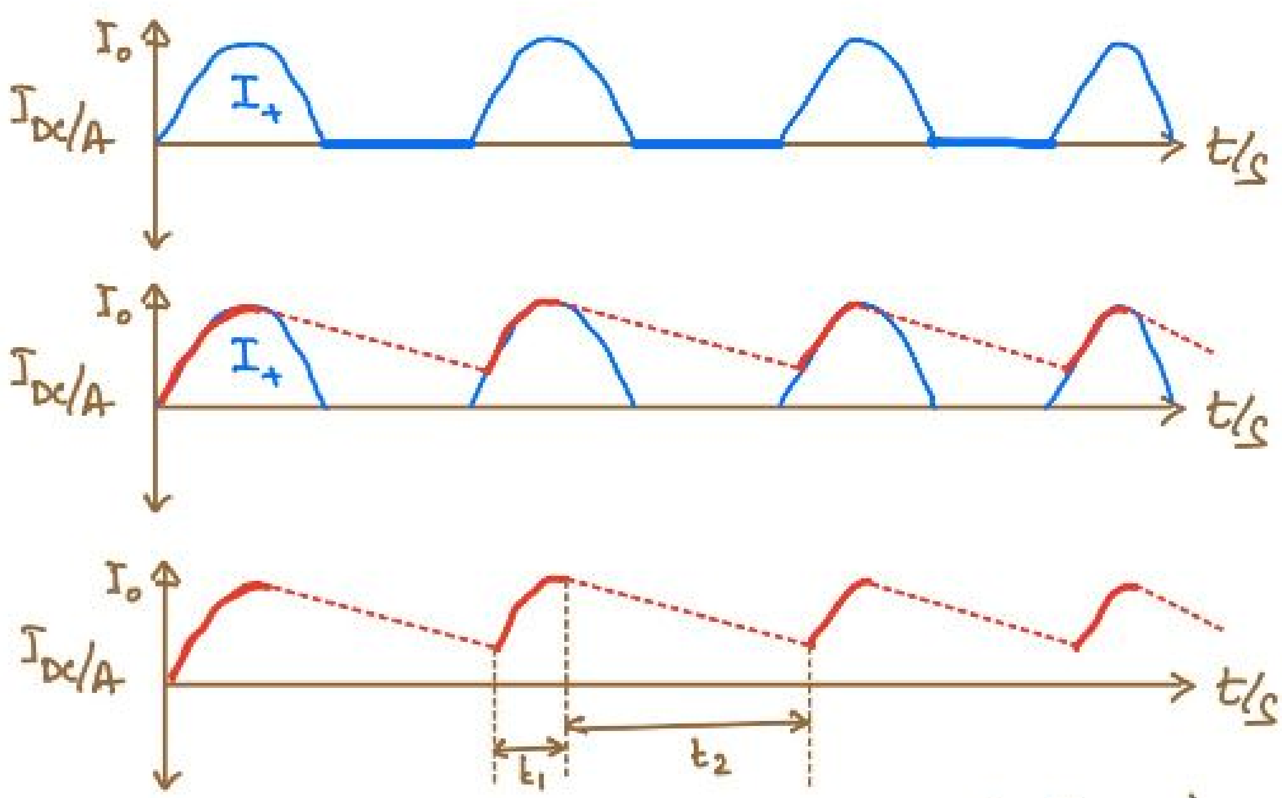
Working: For +ve half cycles of AC, diode is forward biased and conducts. So the upper peaks of AC are obtained at the CRO screen.

For -ve half cycles of AC, diode is reversed biased and does not conduct. So the lower peaks of AC are filtered by diode to make it DC.

Use of Capacitor to smooth the output:-



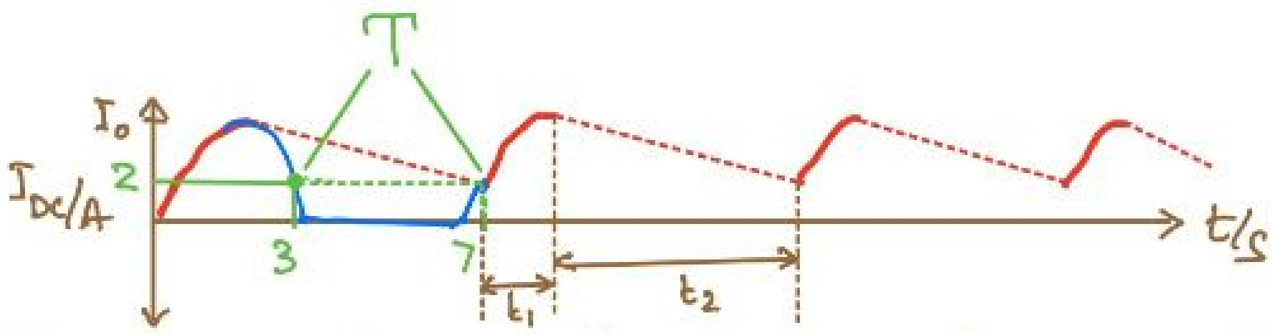
$V = I R$



t_1 - Charging time of Capacitor

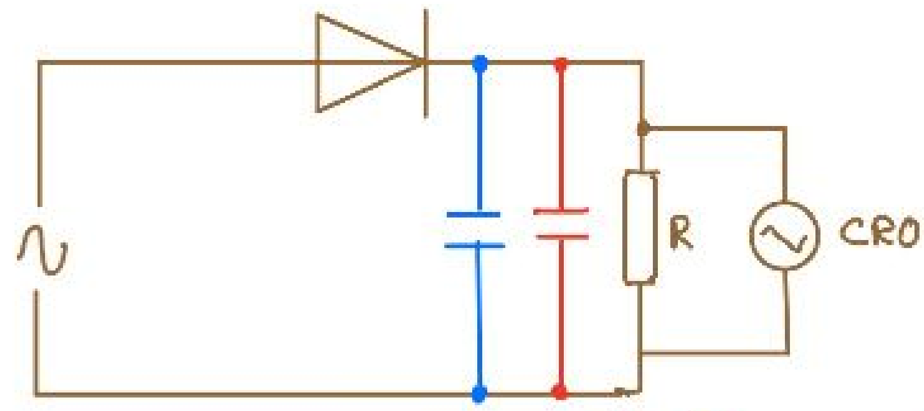
t_2 - Discharging time of Capacitor.

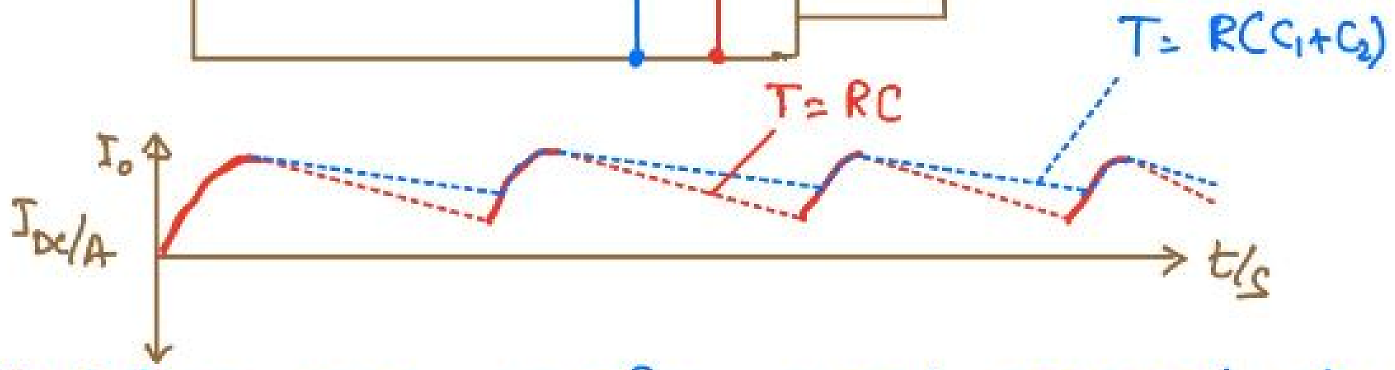
Connect a capacitor across the load, which charges up to its maximum value up to the peak of half cycle and then discharges through the load when current in it decreases to provide common p.d. across parallel combination depending upon time delay relationship $T = RC$.



Therefore, size of ripples decreases to provide a more smooth output.

Q)

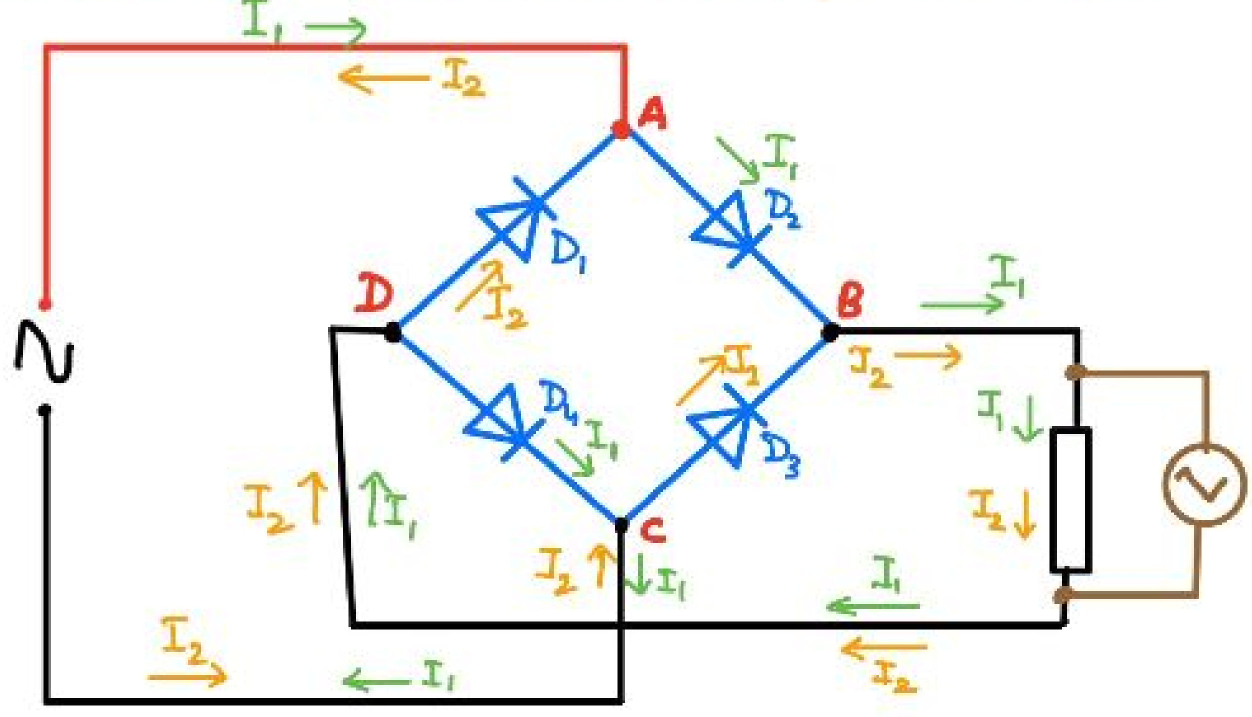


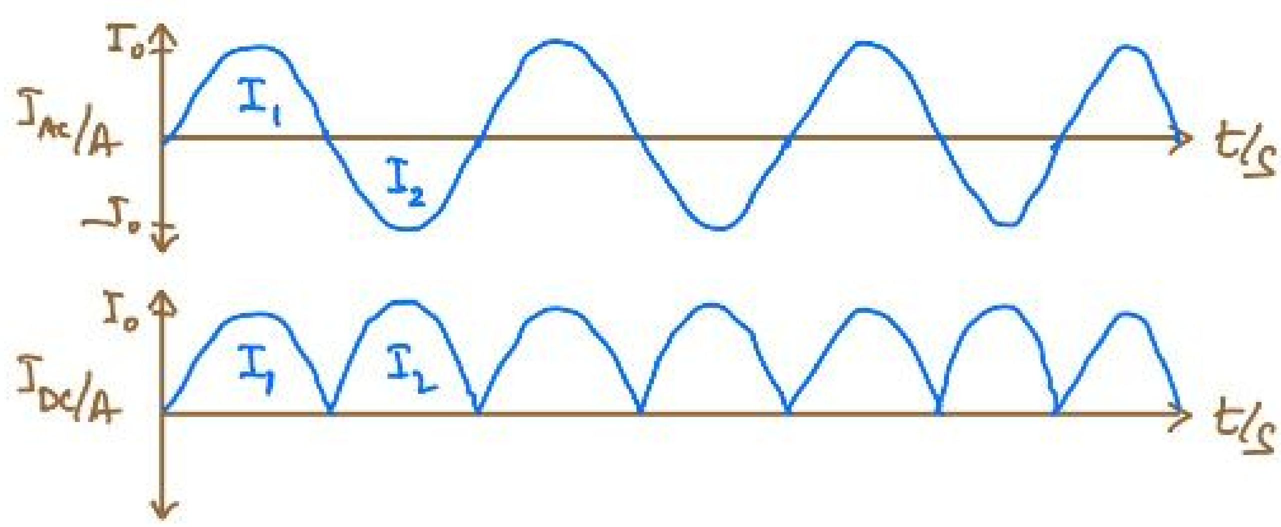


Sketch a new waveform output obtained at the CRO if another capacitor of same capacitance is connected across load.

$T = RC$ and $C = C_1 + C_2$ ie effective capacitance increases, so time delay increases. Hence output becomes more smooth as shown above.

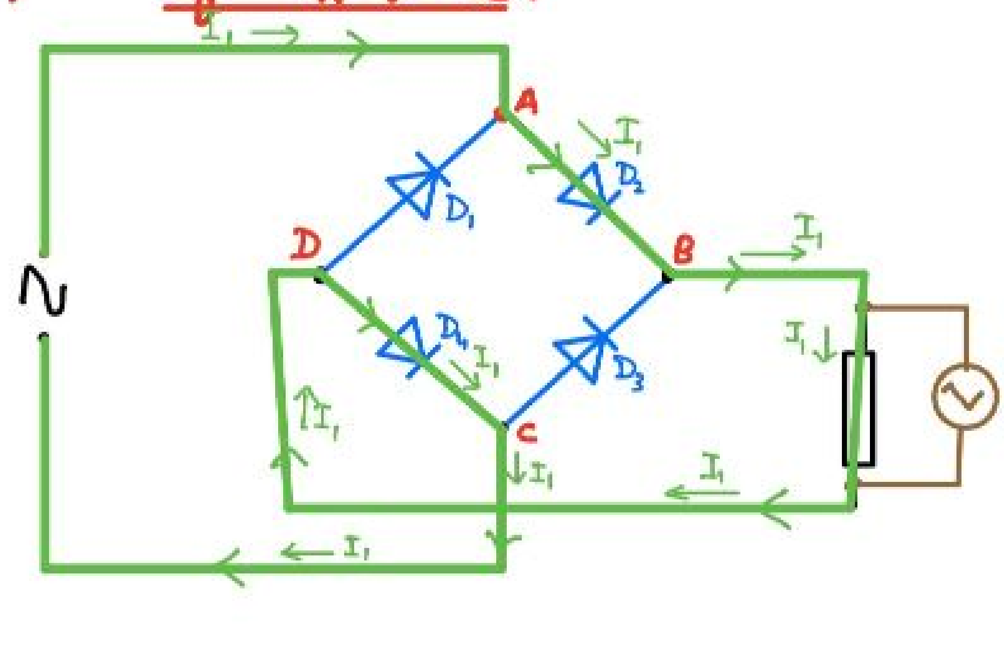
Full wave rectifier / Bridge rectifier:-





Working:

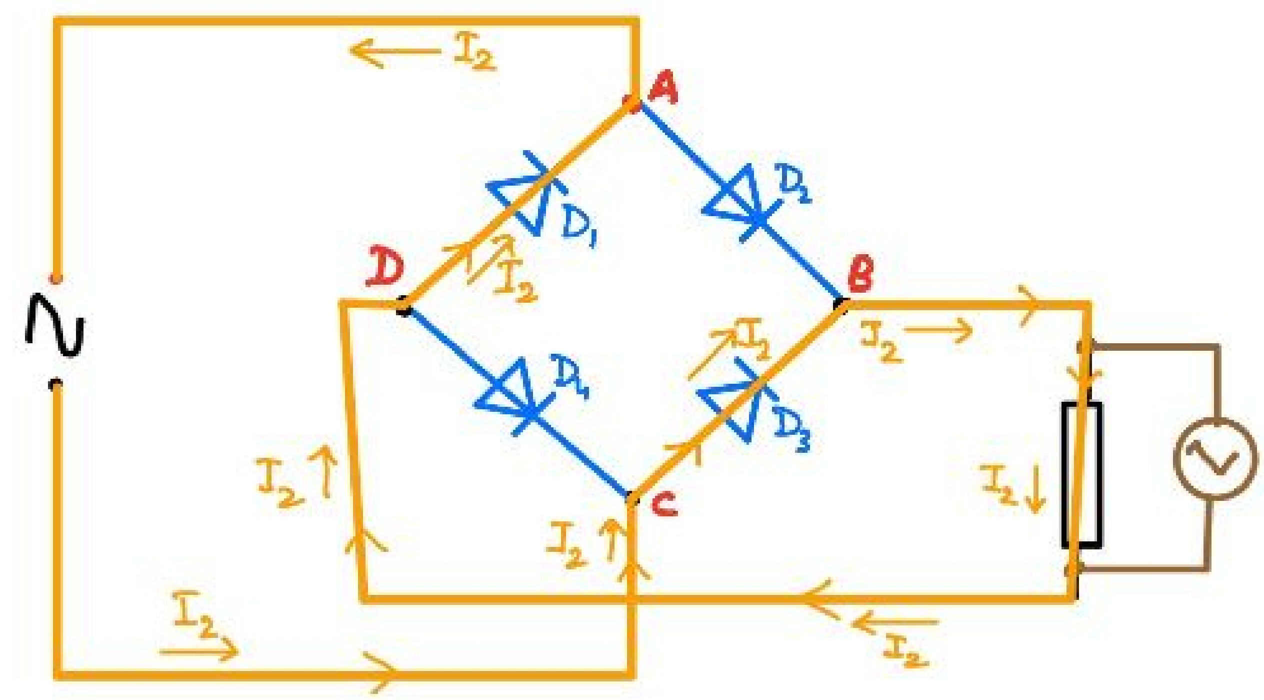
Case 1: If $V_A > V_C$:



Current I_1 from source $\longrightarrow I_A \longrightarrow I_{D_2}$ (D_1 - reversed biased) $\longleftarrow I_B \longleftarrow I_R$ (D_3 - reversed biased) $\longleftarrow I_D$

$\longrightarrow I_{D_4}$ ($V_D > V_c$ and $V_D < V_A$) $\longrightarrow I_c$ ($V_B > V_c$) Current I_1 flows back to the source

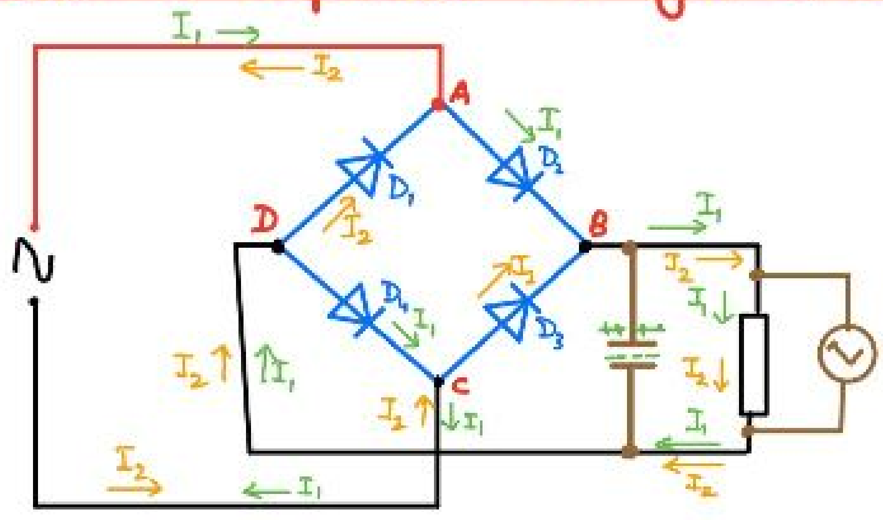
Case 2: If $V_A < V_c$:

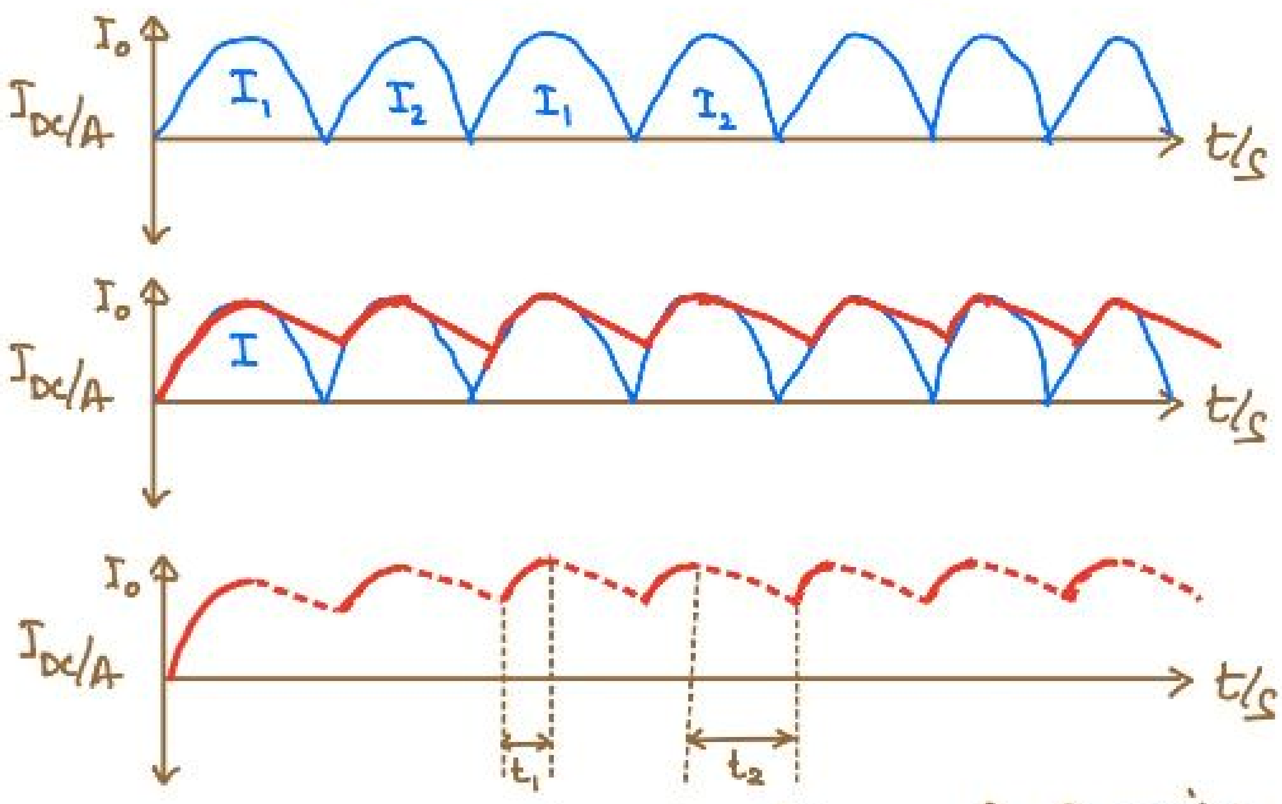


Current I_2 from source $\longrightarrow I_c \longrightarrow I_{D_3}$ (D_4 - reversed biased) $\longrightarrow I_B \longrightarrow$ (D_2 - reversed biased) $I_R \longrightarrow I_D \longrightarrow I_{D_1}$ ($V_D > V_A$) $\longrightarrow I_A$ ($V_B > V_A$) and $V_D < V_c$ $\longrightarrow$ Current I_2 flows back to source

Analysis: Since the direction of current through the resistor R is same for both half cycles of AC, so all the peaks are upside up at the output i.e DC is obtained in the resistor.

Connect a capacitor to get a smooth output:-





$V = I R$
↓ ↓

t_1 – Charging time of Capacitor

t_2 – Discharging time of Capacitor.

Connect a capacitor across the load, which charges up to its maximum value up to the peak of half cycle and then discharges through the load when current in it decreases to provide common p.d. across parallel combination depending upon time delay relationship $T = RC$.

10 The rectified output of a sinusoidal signal generator is connected across a resistor R of resistance 1.5 kΩ, as shown in Fig. 10.1.

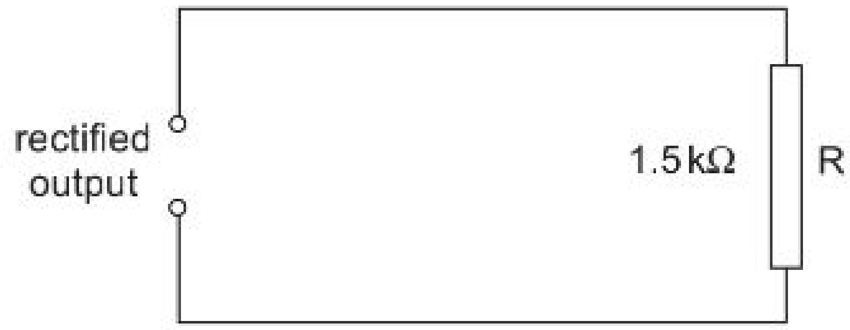


Fig. 10.1

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

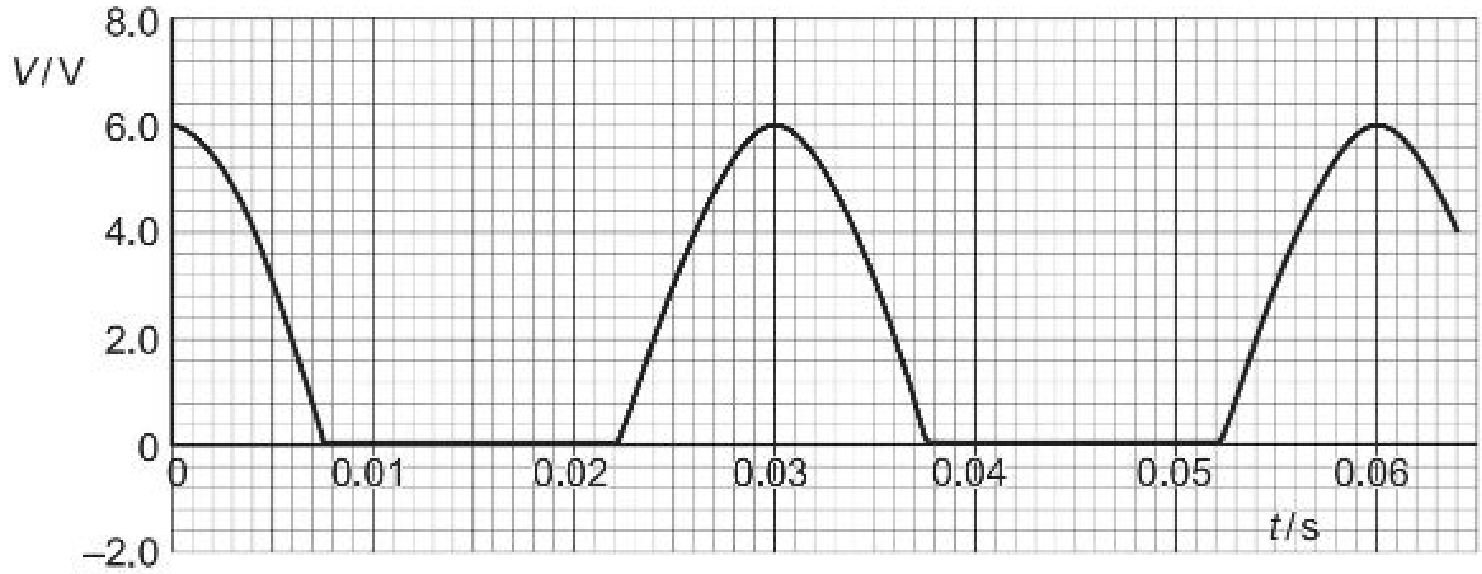


Fig. 10.2

(a) State how the rectification shown in Fig. 10.2 may be achieved.

Single Diode connected in series between the AC source and the Load. [2]

(b) A capacitor is now connected in parallel with the resistor R. The resulting variation with time t of the potential difference V across R is shown in Fig. 10.3.

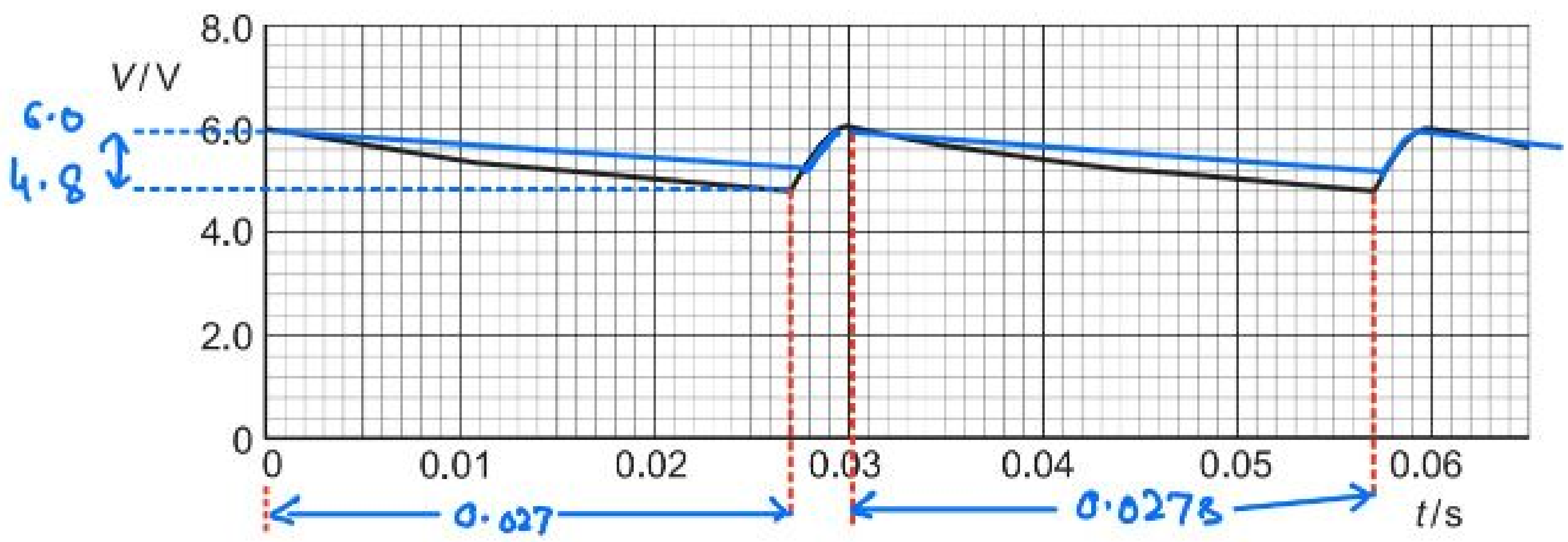


Fig. 10.3

(i) Using Fig. 10.3, determine

1. the mean potential difference across the resistor R,

$$\langle V \rangle = \frac{6.0 + 4.8}{2} = 5.4$$

potential difference = ...5.4...... V

2. the mean current in the resistor R,

$$\langle V \rangle = \langle I \rangle R$$

$$5.4 = [\langle I \rangle][1.5 \times 10^3]$$

mean current = ...0.0036 = 3.60×10^{-3}...... A

3. the time in each cycle during which the capacitor discharges through the resistor.

time = ...0.027...... s

[3]

(ii) Using your answers in **(i)**, calculate

1. the charge passing through the resistor during one discharge of the capacitor,

$$\text{Average current} = \frac{\text{Total charge}}{\text{Total time}}$$

$$3.60 \times 10^{-3} = \frac{Q}{0.027} \Rightarrow Q = 9.72 \times 10^{-5}$$

charge = ... C

2. the capacitance of the capacitor.

$$Q = CV$$

$$9.72 \times 10^{-5} = C(6.0 - 4.8)$$

$$C = \frac{9.72 \times 10^{-5}}{1.2}$$

capacitance = ...8.1×10^{-5}...... F

[4]

$\uparrow$
$C = C_1 + C_2$

(c) A second capacitor is now connected in parallel with the resistor R and the first capacitor. On Fig. 10.3, draw a line to show the variation with time *t* of the potential difference *V* across the resistor. [1]

$T = RC$ ($\uparrow$ $\uparrow$) ie time delay increases. This decreases the ripple size

[Total: 10]

9 **(a)** The output of a power supply is represented by:

$$V = 9.0 \sin 20t$$

$V = V_0 \sin \omega t$

where V is the potential difference in volts and t is the time in seconds.

Determine, for the output of the supply:

(i) the root-mean-square (r.m.s.) voltage, $V_{r.m.s.}$ $V_0 = 9.0\,V$

$$V_{rms} = \frac{V_0}{\sqrt{2}} \Rightarrow V_{rms} = \frac{9.0}{\sqrt{2}}$$

$V_{r.m.s}$ = ...6.36.......... V [1]

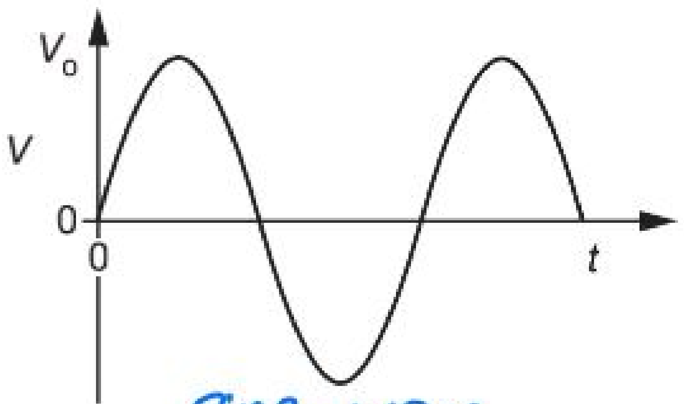
(ii) the period T. $\omega = 20$

$$\frac{2\pi}{T} = 20 \Rightarrow T = \frac{2(3.14)}{20}$$

$T = 0.314$

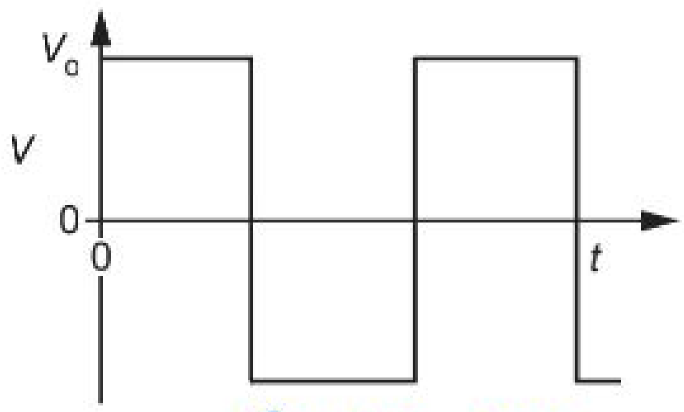
T = ... s [2]

(b) The variations with time t of the output potential difference V from two different power supplies are shown in Fig. 9.1 and Fig. 9.2.



Sine wave

Fig. 9.1



Square wave

Fig. 9.2

The graphs are drawn to the same scale.

State and explain whether the same power would be dissipated in a 1.0 Ω resistor connected to each power supply.

For sine wave, $V_{rms} = \frac{V_0}{\sqrt{2}}$ } r.m.s voltage are different.

For square wave, $V_{rms} = V_0$

$P = \frac{(V_{rms})^2}{R}$ and $R = 1.0$, Therefore, Power dissipation is different. [1]

(c) A capacitor C of capacitance 47 μF is connected across the output terminals of a bridge rectifier, as shown in Fig. 6.1.

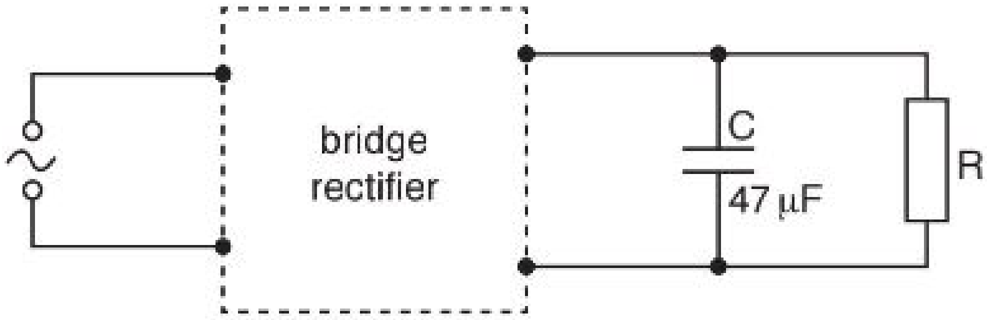


Fig. 6.1

The variation with time t of the potential difference V across the resistor R is shown in Fig. 6.2.

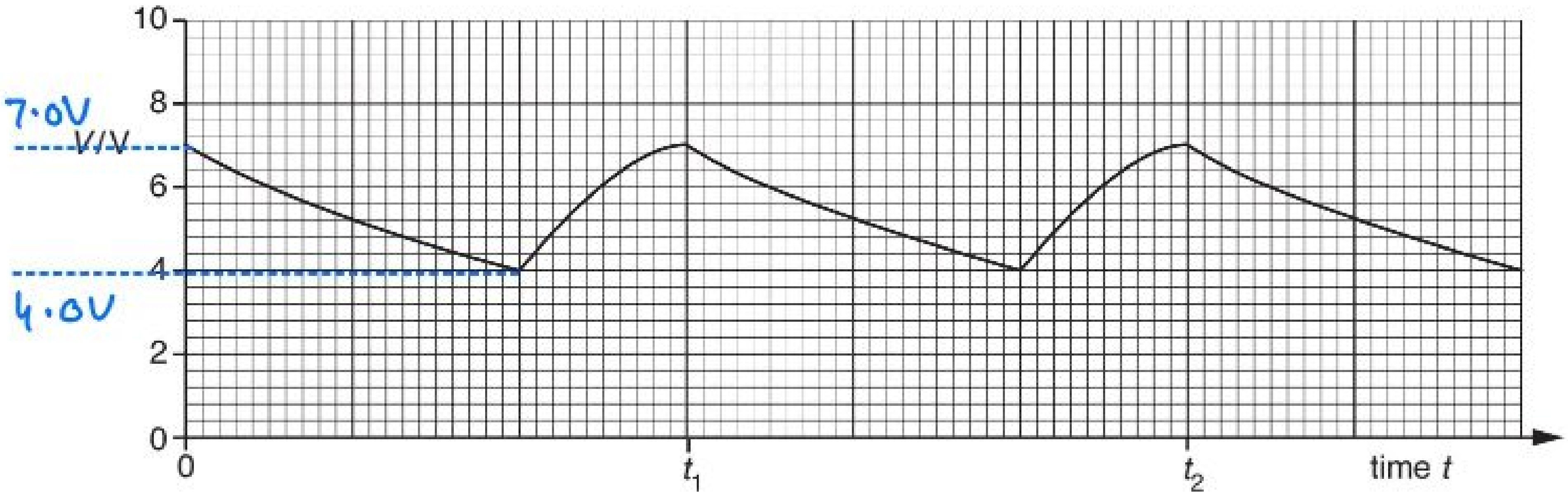


Fig. 6.2

Use data from Fig. 6.2 to determine the energy transfer from the capacitor C to the resistor R between time t_1 and time t_2.

Change of p.d. during given discharging time

$= 7.0 - 4.0 = 3.0V$

$\Delta E = \frac{1}{2} C V_2^2 - \frac{1}{2} C V_1^2$

$= \frac{1}{2}(47 \times 10^{-6})[4^2 - 7^2]$

energy = ... J [3]

$= - \underline{-7.75 \times 10^{-4}}$ J

[Total: 7]

–ve sign shows that energy is lost by capacitor.

ALTERNATING CURRENT (CIE Past Paper Questions)

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alternating current/voltage, $x = x_0 \sin \omega t$

Q.1 (a) Fig. 1.1 is the circuit of a bridge rectifier.

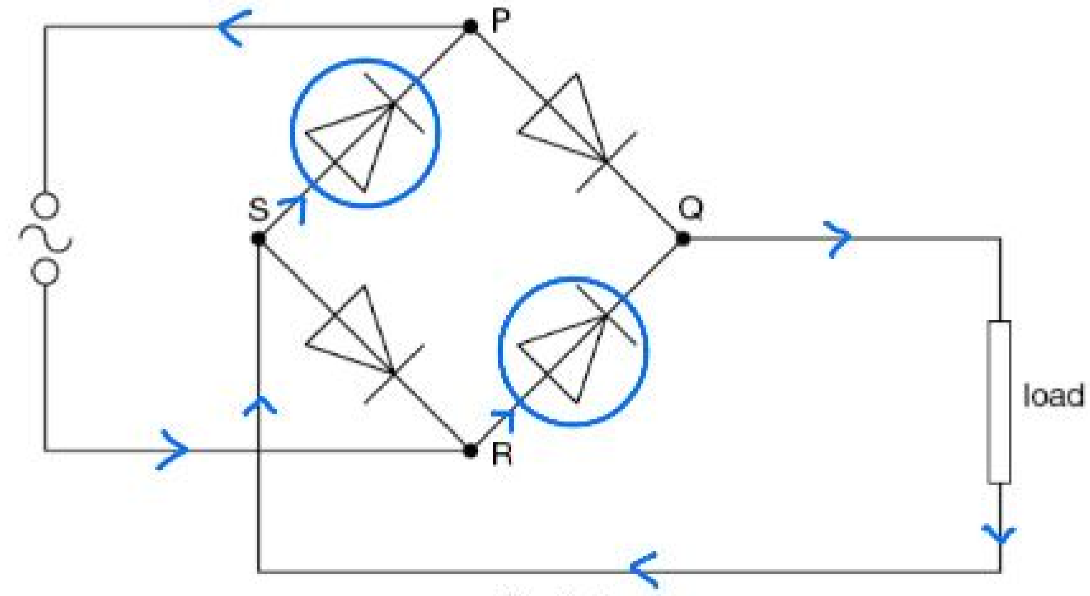

fig. 1.1

An alternating supply connected across PR has an output of 6.0V r.m.s.

(i) On Fig. 1.1, circle those diodes that are conducting when R is positive with respect to P. [1]

(ii) Calculate the maximum potential difference between points Q and S, assuming that the diodes are ideal.

$V_{rms} = \frac{V_0}{\sqrt{2}} \Rightarrow 6.0 = \frac{V_0}{1.41}$

$V_0 = 8.46V$

potential difference = ... V [2]

(iii) State and explain how a capacitor may be used to smooth the output from the rectifier. You may draw on Fig. 1.1 if you wish.

Connectivity → across load
Charging → up to peak of half cycle
Discharging → through the load when p.d. across it decrease. [3]

Q. 2.

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Q. 5. The variation with time t of the sinusoidal current I in a resistor of resistance 450 Ω is shown in Fig. 7.1.

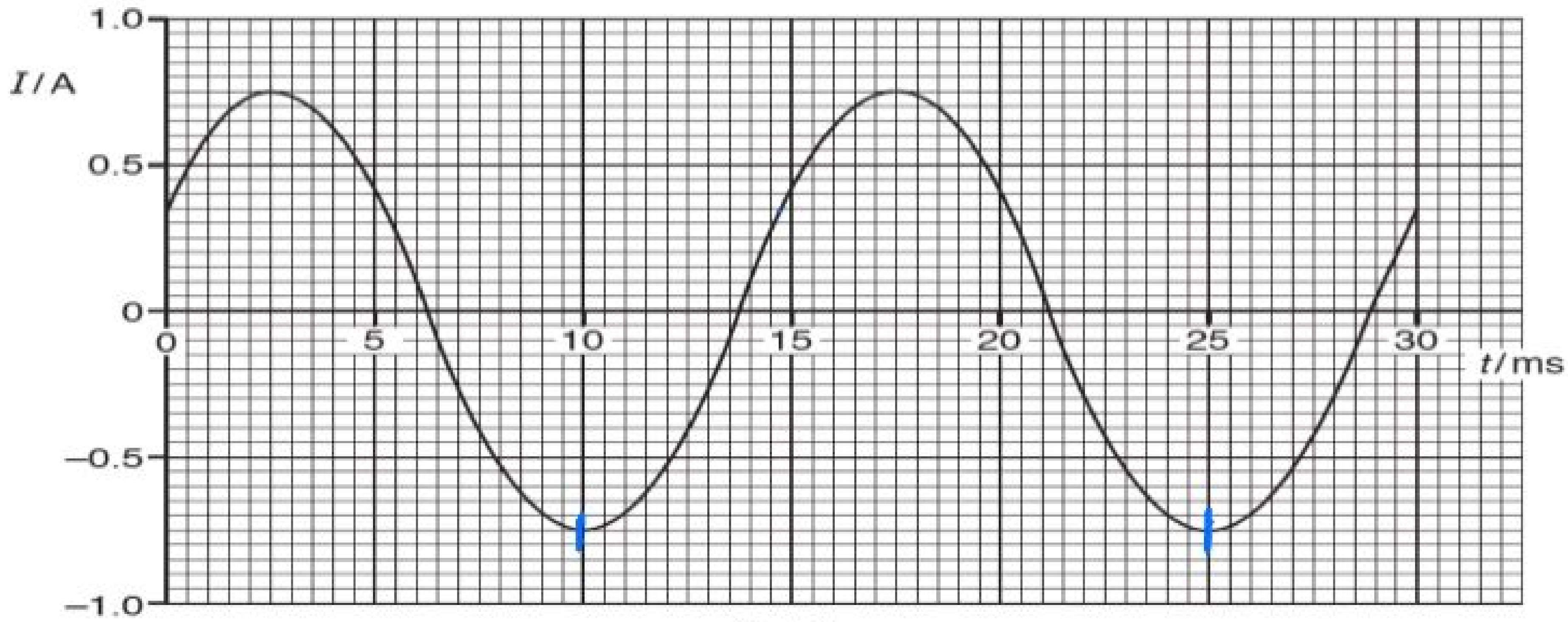

Fig. 5.1

Use data from Fig. 5.1 to determine, for the time t = 0 to t = 30 ms,

(a) the frequency of the current,

$T = (25 - 10) = 15\,ms$

$f = \frac{1}{T} = \frac{1}{15\times10^{-3}}$

frequency = ...66.7...... Hz [2]

(b) the mean current,

$\langle I \rangle = \frac{0.75 + (-0.75)}{2}$

mean current = ...0...... A [1]

(c) the root-mean-square (r.m.s.) current,

$I_{rms} = \frac{I_0}{\sqrt{2}} = \frac{0.75}{\sqrt{2}}$

r.m.s. current = ...0.53...... A [2]

(d) the energy dissipated by the resistor.

$E = (I_{rms})^2 R t$

$= (0.53)^2 (450)(30\times10^{-3})$

$= 3.8\,J$

energy = ... J [2]

[Total: 7]

6.

A sinusoidal alternating voltage supply is connected to a bridge rectifier consisting of four ideal diodes. The output of the rectifier is connected to a resistor R and a capacitor C as shown in Fig. 6.1.

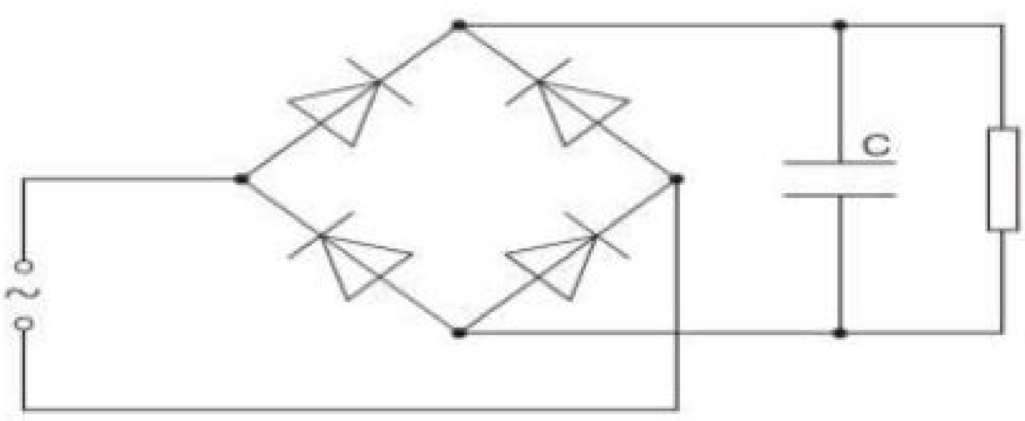

Fig. 6.1

The function of C is to provide some smoothing to the potential difference across R.
The variation with time t of the potential difference V across the resistor R is shown in Fig. 6.2.

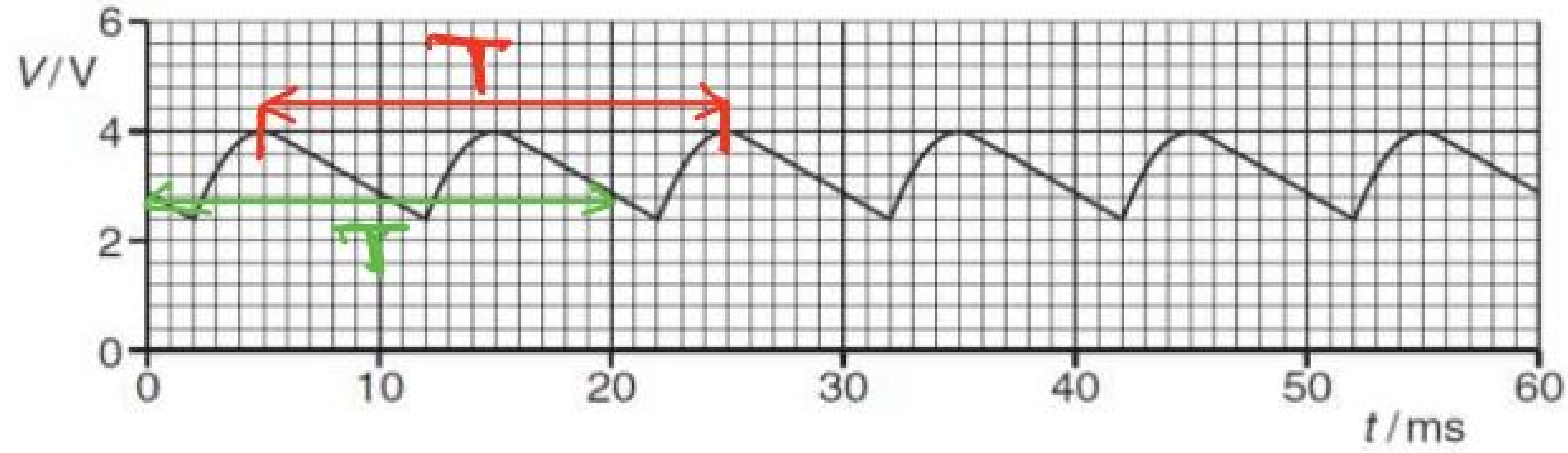

Fig. 6.2

(a) Use Fig. 6.2 to determine, for the alternating supply,

(i) the peak voltage,

peak voltage = 4.0 V [1]

(ii) the root-mean-square (r.m.s.) voltage,

$$V_{rms} = \frac{V_0}{\sqrt{2}} = \frac{4.0}{\sqrt{2}}$$

r.m.s. voltage = 2.82 V [1]

(iii) the frequency. Show your working.

$T = 20\,ms$

$$f = \frac{1}{T} = \frac{1}{20\times10^{-3}} = \frac{1000}{20}$$

frequency = 50 Hz [2]

(b) The capacitor C has capacitance 5.0 μF.
For a single discharge of the capacitor through the resistor R, use Fig. 6.2 to

(i) determine the change in potential difference,

$\Delta V = 4.0 - 2.4$

change = 1.6 V [1]

(ii) determine the change in charge on each plate of the capacitor,

$$\Delta Q = C(\Delta V)$$

$$\Delta Q = (5.0 \times 10^{-6})(1.6)$$

$$= 8.0 \times 10^{-6}$$

change = ... C [2]

(iii) show that the average current in the resistor is 1.1×10^{-3} A.

$$\text{Average current} = \frac{\text{Total charge}}{\text{Total time}}$$

$$\langle I \rangle = \frac{8.0 \times 10^{-6}}{20 \times 10^{-3}}$$

$$= 4.0 \times 10^{-10} \text{ A}$$

[2]

(c) Use Fig. 6.2 and the value of the current given in **(b)(iii)** to estimate the resistance of resistor R.

$$\langle V \rangle = \langle I \rangle R$$

$$\frac{4.0 + 2.4}{2} = (4.0 \times 10^{-3}) R$$

$$R = \underline{\qquad\qquad} \Omega$$

resistance = ... Ω [2]