

2019

**RANK IMPROVEMENT
WORKBOOK**

Mechanical Engineering

Renewable Sources of Energy

Answer Key of Objective & Conventional Questions



MADE EASY
Publications

1

Fundamentals of Energy, Conservation and Storage

LEVEL 1 Objective Questions

1. (a)
2. (a)
3. (c)
4. (a)
5. (d)
6. (d)
7. (b)
8. (d)
9. (c)
10. (b)
11. (b)

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LEVEL 2 Objective Questions

12. (a)
13. (c)
14. (c)
15. (d)
16. (b)
17. (c)
18. (d)
19. (b)
20. (d)
21. (d)
22. (b)
23. (d)

■■■■

LEVEL 3 Conventional Questions**Solution : 24**

Global Warming Potential (GWP): The Global Warming Potential (GWP) is an index relative to the global warming impact of CO₂ is used to compare various greenhouse gases. The impact of the emission of the various greenhouse gases on the climate varies according to their atmospheric life. CO₂ is one of the main greenhouse gases in the atmosphere so, the GWP of CO₂ is fixed as 'one' and the global warming impact of the various gases is compared with that of CO₂. Since the atmospheric lifetime of the greenhouse gases varies therefore GWP is also time dependent. The time dependency spreads from 20 to 100 years and written as GWP₂₀ (for 20 years), GWP₁₀₀ (100 years lifetime), etc. Emission of one kg of R-134a is roughly equivalent to emission of 1300 kg of CO₂ in 100 years, so GWP₁₀₀ of R-134a is 1300. Thus, the GWP of a greenhouse gas is an index relative to that of CO₂ to trap heat radiated from earth to space.

Ozone Depletion Potential (ODP): The ozone depletion potential is defined as an index that indicates the ability of refrigerants and other chemicals to destroy stratospheric ozone molecules based on a value of 1.0 for R11.

Solution : 25

Therefore, the rate of heat rejection per kW of net output = 1.865 kW.

Solution : 26

Therefore, the least power required to pump the heat continuously = 0.38 kW



2

Solar Energy Basics and Principles of Solar Radiation

LEVEL 1 Objective Questions

1. (d)
2. (b)
3. (b)
4. (b)
5. (d)
6. (a)
7. (a)
8. (b)
9. (b)
10. (c)
11. (c)
12. (d)
13. (b)
14. (a)
15. (b)
16. (b)
17. (b)
18. (d)

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LEVEL 2 Objective Questions

19. (c)
20. (d)
21. (b)
22. (a)
23. (c)
24. (b)
25. (c)
26. (b)
27. (b)
28. (d)
29. (d)
30. (a)
31. (c)
32. (a)
33. (c)
34. (c)

■■■■

LEVEL 3 Conventional Questions**Solution : 35**

$$\text{LAT} \simeq 1487.93 \text{ h}$$

(ii) Hour angle can be calculated as

$$\omega = 32.29^\circ$$

Solution : 36

$$I'_{sc} = 1354.92 \text{ W/m}^2$$

Solution : 37

$$\delta = 20.44^\circ$$

Solution : 38

$$\text{Hour angle} = +37.5^\circ$$

Solution : 39

$$\theta = 27.6^\circ$$

Solution : 40

$$\bar{S}_{\max} = 13.41 \text{ hours}$$

Solution : 41

$$\bar{H}_g = 0.6277 \times 28 = 17.58 \text{ MJ}$$



3

Solar Energy Collectors and Storage

LEVEL 1 Objective Questions

1. (b)
2. (c)
3. (d)
4. (a)
5. (d)
6. (b)
7. (d)
8. (a)
9. (b)
10. (b)

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LEVEL 2 Objective Questions

11. (d)
12. (d)
13. (b)
14. (d)
15. (a)
16. (c)
17. (c)
18. (d)
19. (c)
20. (d)
21. (d)
22. (a)
23. (a)
24. (c)
25. (b)
26. (c)
27. (b)

■ ■ ■ ■

LEVEL 3 Conventional Questions

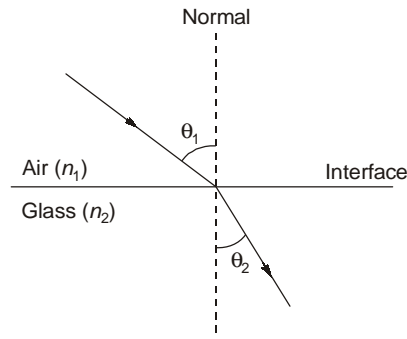
Solution : 28

$$\omega_s = 92.01$$

$$t_{\text{day}} = 12.27 \text{ hours}$$

Solution : 29

According to law,



$$\frac{\sin \theta_1}{\sin \theta_2} = \frac{n_2}{n_1}$$

$$\theta_2 = \sin^{-1} \left(\frac{n_1}{n_2} \times \sin \theta_1 \right)$$

where,

$$\rho = \frac{1}{2}(\rho_1 + \rho_2)$$

$$\rho_1 = \frac{\sin^2(\theta_2 - \theta_1)}{\sin^2(\theta_2 + \theta_1)} \text{ and } \rho_2 = \frac{\tan^2(\theta_2 - \theta_1)}{\tan^2(\theta_2 + \theta_1)}$$

Similarly,

$$\tau = \frac{1}{2}(\tau_1 + \tau_2)$$

$$\tau = (1 - \rho)^2 + \rho^2(1 - \rho)^2 + \rho^4(1 - \rho)^2 + \dots \infty$$

$$\tau = \frac{(1 - \rho)^2}{1 - \rho^2}$$

⇒

$$\tau = \frac{1 - \rho}{1 + \rho}$$

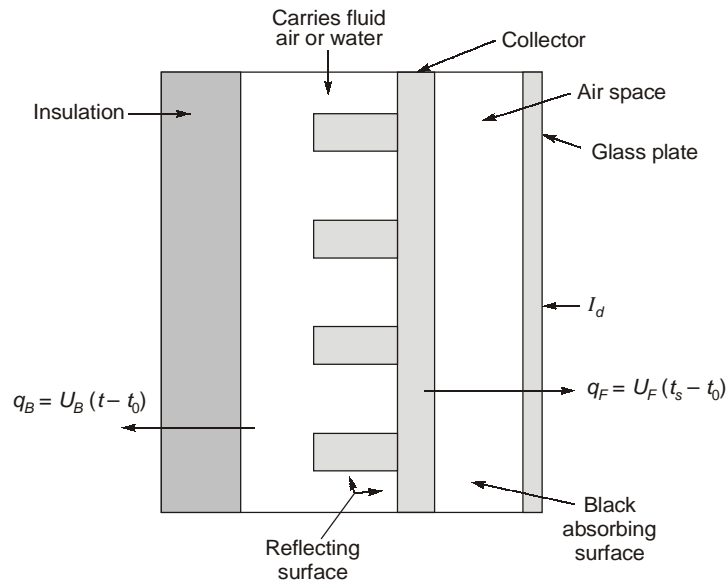
for

$$\tau_1 = \frac{1 - \rho_1}{1 + (2M - 1)\rho_1}$$

$$\tau_2 = \frac{1 - \rho_2}{1 + (2M - 1)\rho_2}$$

$$\tau = \frac{1}{2}(\tau_1 + \tau_2)$$

$$\tau = \frac{1}{2}(\tau_1 + \tau_2) = 0.84$$

Solution : 30

Heat loss occurs from

- (1) Cover plate (Q_B)
- (2) Back side (Q_F)
- (3) Sides of collector box (Negligible)

Let U_F and U_B be the overall heat transfer coefficient from plate to ambient from front side, and from fluid to ambient from back side.

t_0 , t_s , t = Ambient, plate surface and fluid temperature

Consider an elemental plate surface area dA over which the temperature of the fluid rises by dt , we have:

$$\dot{m}Cdt = \frac{U_o A_o}{A} dA(t_s - t) - U_B dA(t - t_0)$$

where

\dot{m} = mass flow rate of carrier fluid

C = specific heat

A = collector surface area

A_o = Extended surface area on the side of fluid

and Collector efficiency = $\frac{\text{Heat collected/ Area}}{\text{Solar intensity}}$

Solution : 31

$$\Rightarrow I'_{sc} \simeq 1389 \text{ W/m}^2$$



4

Solar Photovoltaic System

LEVEL 1 Objective Questions

1. (c)
2. (a)
3. (a)
4. (d)
5. (b)
6. (c)
7. (a)
8. (c)
9. (a)
10. (a)

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LEVEL 2 Objective Questions

11. (b)
12. (c)
13. (c)
14. (d)
15. (b)
16. (c)
17. (b)
18. (d)

■ ■ ■ ■

LEVEL 3 Conventional Questions

Solution : 20

$$N = 12.8 \approx 13$$

Minimum number of modules

Solution : 21

As per the photoelectric effect,

$$I = I_{sc} - I_o \left[\exp\left(\frac{eV}{kT}\right) - 1 \right]$$

for V_{oc} , the current supply, $I = 0$

$$0 = I_{sc} - I_o \left[\exp\left(\frac{eV}{kT}\right) - 1 \right]$$

where,

$$e = 1.602 \times 10^{-19} \text{ J/V}$$

Dark-current, I_o

$$\Rightarrow I_o = \frac{I_{sc}}{\left[\exp\left(\frac{eV}{kT}\right) - 1 \right]} = 5.502 \times 10^{-8} \text{ A/m}^2$$

For Pmax conditions,

$$P = V \times I$$

After solving,

$$V_m = 0.519 \text{ V}$$

Similarly,

$$I_m = 237.6 \text{ A/m}^2$$

$$P_m = I_m \cdot V_m = 123.3 \text{ W/m}^2$$

$$F.F. = \frac{I_m \cdot V_m}{I_{sc} \cdot V_{oc}} = 0.822$$

$$(P_{\max})_{\text{actual}} = 1.233 \text{ W}$$

Solution : 22

Causes of low efficiency of a solar cell: The efficiency of a photovoltaic cell is 15% only. The major losses which lead to the low efficiency of the cell are:

1. As the temperature of the cell rises due to solar radiation, leakage across the cell increases. Consequently, power output, relative to solar energy input, decreases. For silicon, the output decreases by 0.5% per °C.
2. The excess energy of active photons given to the electrons beyond the required amount to cross the band gap cannot be recovered as useful electric power. It appears as heat, about 33 per cent, and is lost.
3. The electric current (generated) flows out of the top surface by a mesh of metal contacts provided to reduce series resistance losses. These contacts cover a definite area which reduces the active surface and proves an obstacle to incident solar radiation.

Solution : 23

Solar cells can be classified on the basis of:

1. Cell size;
2. Thickness of active material;
3. Type of junction structure;
4. Type of active material.

1. Cell size: The size of the silicon solar cell can be divided into four groups;

- (i) Round single crystalline having 100 mm diameter;
- (ii) Square single crystalline having area of 100 cm²,
- (iii) 1000 mm × 1000 mm square multicrystalline, and
- (iv) 125 mm × 125 mm square multicrystalline.

Larger size solar cells are used in terrestrial applications. Due to brittleness property of the silicon, area of silicon solar cells is limited.

2. Thickness of active material: Such solar cells are of two types:

- (i) Bulk material cell, and
- (ii) Thin film cell.

Bulk material single crystal and multicrystalline cells are most successful for terrestrial applications.

Thin film cells are not commercially successful.

3. Type of junction structure: These cells are classified as:

- (i) p-n homojunction cell,
- (ii) p-n heterojunction cell,
- (iii) p-n multijunction cell, and
- (iv) Metal semiconductor Schottky junction.

4. Type of active material: Such cells are classified as:

- (i) Single, crystal silicon cell,
- (ii) Multicrystalline silicon cell,
- (iii) Amorphous silicon cell,
- (iv) Gallium arsenide cell.



LEVEL 1 Objective Questions

1. (d)
2. (a)
3. (a)
4. (c)
5. (a)
6. (c)
7. (b)
8. (d)
9. (c)
10. (c)
11. (a)
12. (a)
14. (d)
15. (c)
16. (b)
17. (b)
18. (c)

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LEVEL 2 Objective Questions

19. (a)
20. (d)
21. (a)
22. (d)
23. (b)
24. (a)
25. (d)
26. (b)
27. (b)
28. (b)
29. (c)
30. (d)
31. (d)
32. (c)
33. (c)

■ ■ ■ ■

LEVEL 3 Conventional Questions

Solution : 34

- (i) $U_H = 16.565 \text{ m/sec}$
 (ii) $P_{\text{total}} = 14.005 \text{ MW}$
 (iii) $(P_{\text{turbine}})_{\text{max}} = 8.305 \text{ MW}$
 $(EP)_{\text{gen}} = 7.059 \text{ MW}$
 $N = 37.569 \text{ rpm}$

Solution : 35

- (1) Power available at turbine rotor = 2205.86 W
 (2) Power in the wind at outlet = 198.52 W
 (3) Power developed by turbine = 2007.3 W
 (4) Coefficient of performance (C_p) = 91%

Solution : 36

Maximum power extracted by turbine = 75.5 W/m²

Solution : 37

Axial induction factor is given by

Since value of a cannot be 1's

$$\text{Axial induction factor } (a) = 1/3$$

$$a = \frac{1}{3}$$

Solution : 38

$$P_w = 441.45 \text{ W}$$

Solution : 39

Basic components of wind energy conversion system (WECS)

- **Wind turbines** (Aeroturbines) convert the energy of moving air into rotary mechanical energy. These turbines requires pitch and yaw controls for proper operation.
- A **mechanical interface** consisting of a step up gear and a suitable coupling transmits the rotary mechanical to an **electrical generator**. The output of this generator is connected to the road or power grid as the application demands.
- A **controller** serves purposes of sensing:
 - (i) Wind speed,
 - (ii) Wind direction, shafts speed and torques at one or more points,
 - (iii) Output power and generator temperature,
 - (iv) Appropriate control signals for matching the electrical output to the wind energy input and
 - (v) Protect the system from extreme conditions brought about by strong winds, electrical faults etc.

Solution : 40

Advantages and disadvantages of wind energy conversion systems (WECS): the advantages and disadvantages of wind energy conversion system as follows:

Advantages:

1. Wind energy, a renewable energy source, can be tapped free of fuel cost.
2. The wind turbine generation (WTG) produces electricity which is environmentally friendly.
3. Wind power generation is cost effective.
4. It is economically competitive with other modes of power generation.
5. Quite reliable.
6. Electric power can be supplied to remote inaccessible areas.

Disadvantages:

1. As the wind speed is variable, wind energy is irregular, unsteady and erratic.
2. Wind turbine design is complex.
3. Wind energy systems requires storage batteries which contribute to environmental pollution.
4. Wind energy systems are capital intensive and need government support.
5. Wind energy has low energy density and normally available at only selected geographical locations away from cities and load centers.
6. For wind farms (which are located in open areas away from load centres), the connection to state grid is necessary.
7. 'Large units' have less cost per kWh, but require capital intensive technology. In contrast 'small units' are more reliable but have higher capital cost per kWh.



6

Biomass Energy

LEVEL 1 Objective Questions

1. (c)
2. (c)
3. (a)
4. (c)
5. (d)
6. (c)
7. (d)
8. (b)
9. (c)
10. (a)

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LEVEL 2 Objective Questions

11. (d)
12. (b)
13. (d)
14. (b)
15. (c)
16. (c)
17. (c)
18. (a)
19. (d)
20. (c)

■■■■

LEVEL 3 Conventional Questions**Solution : 21**

Total amount of slurry produced per day = $10 \times 2 = 20$ kg

Solution : 22

$$\dot{m} = 144 \text{ kg/h}$$

Solution : 23**Environmental benefits/effects of biomass/biofuels**

Following are the benefits/effects of biomass/biofuels:

1. Biomass can pollute air when it is burned but less than those of fossil fuels.
2. Burning biofuels do not produce pollutants like sulphur, that results in acid rain.
3. When biomass crops are grown, nearly equivalent amount of CO_2 is captured through photosynthesis.

Solution : 24**Application of biogas in petrol engines:**

- Biogas can be used in petrol engines after initial starting of the engine on petrol. It needs about 550 litres of gas per kWh to run a petrol engine.
- Engine can also run a dual fuel engine either on biogas or petrol. It has the advantage that the engine can run on petrol if the biogas is not available or vice-versa.

Application of biogas in "Diesel engines":

- Biogas can be better used in diesel engines (as a dual fuel engine).
- It is more convenient to use biogas since it has high self ignition temperature of about 730°C .

Application of using biogas in engines:

1. It has ample flexibility of operation.
2. A uniform gas-air mixture is available in multicylinder engines.
3. Clean combustion reduces the wear of engine parts.
4. Lubricating oil consumption is reduced.
5. Emissions of CO are greatly reduced.
6. NO_x emissions are also reduced.

Solution : 25**Factors affecting generation of biogas**

The generation of biogas is affected by the following factors:

1. Temperature,
2. Loading rate,
3. Solid concentration,
4. pH value,
5. Retention period,
6. Toxic substances.

1. **Temperature:** The anaerobic fermentation process is temperature dependent. The process of the digestion and gasification proceeds at the highest rate when the temperature lies between 35°C – 38°C .

2. **Loading rate:** "Loading rating" is the weight of volatile solids fed to a digester per day. It depends upon the plant capacity and also the retention period.
3. **Solid concentration:** Normally, 7 to 9 parts of solid in 100 parts of the slurry is considered ideal.
 - It is recommended that 4 parts of the cattle dung to be mixed with 5 parts of water.
4. **pH Value:** pH denotes the acidity and alkalinity of the substrate. The pH less than 7 is called 'acidic' and pH more than 7 is called 'alkaline' and pH solution of 7 is called 'neutral'.
5. **Retention period:** It is the time period for which fermentable material resides inside the digester. This period ranges from 30 days to 50 days depending upon the climatic conditions.
 - Generally it is observed that maximum gas production takes place within 'first four weeks' and it tapers off gradually.
6. **Nutrients concentration:** The major nutrients required by the bacteria in the digester are C, H₂, O₂, N₂, P and S. To maintain proper balance of nutrients an extra raw material, rich in P and N₂, should be added along with cattle dung to obtain maximum gas production.
7. **Toxic substance:** The presence of ammonia, pesticides, detergents and heavy metals are considered as toxic substances to micro-organisms, since their presence reduces fermentation rate.

Solution : 26

Main components of a biogas plant

The main components of a biogas plant are enumerated and briefly described below:

1. Digester,
 2. Gas holder,
 3. Inlet,
 4. Outlet,
 5. Slurry mixing tank;
 6. Gas outlet pipe;
 7. Stirrer.
1. **Digester:** A digester is also called 'fermentation tank' and is mostly embedded partly or fully in the ground. It is generally cylindrical in shape and is made of bricks. It holds the slurry for a sufficiently long time to complete the digestion.
 2. **Gas holder:** Its function is to keep the gas for subsequent use. The gas connection for use is taken from the top of the gas holder. In some designs of biogas plants, it may be separable from the digester whereas in other designs it may be an integral part of the digester.
 3. **Inlet:** An inlet is provided to add the mixture of dung and water to the digester, and is slope.
 4. **Outlet:** The provision of an outlet is made to take out the digester portion of slurry.
 5. **Slurry mixing tank:** This tank carries out mixing of the dung with water or induction in the digester, through the inlet.
 6. **Gas outlet pipe:** It is used for taking out gas from the gas holder and is connected to its top. The other end of the pipe is connected with the device using biogas.
 7. **Stirrer:** The stirrers are provided in biogas plants of large size for stirring the slurry for fermentation inside the fermentation chamber to ensure the normal production of gas.



7

Tidal Energy and Fuel Cells

LEVEL 1 Objective Questions

1. (b)
2. (b)
3. (c)
4. (c)
5. (c)
6. (d)
7. (c)
8. (b)
9. (d)
10. (a)

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LEVEL 2 Objective Questions

11. (d)
12. (c)
13. (b)
14. (c)
15. (b)
16. (b)
17. (a)
18. (b)
19. (b)
20. (a)

■■■■

LEVEL 3 Conventional Questions

Solution : 21

Average power generated = 50.4 MW

Average annual energy generation = 2.2×10^8 kWh

Solution : 22

$$(\dot{M}_{\text{methanol}})_{\text{required}} = 19.32 \text{ g/s} = 69.264 \text{ kg/h}$$

$$(\dot{M}_{\text{O}_2})_{\text{required}} = \frac{100}{165.644} \times 48 = 28.98 \text{ g/s} = 104.32 \text{ kg/h}$$

$$(\Delta Q)_{\text{actual}} = 43.549 \text{ kJ/sec (kW)}$$

$$\eta_{\text{conv.}} = \frac{\Delta G^\circ}{\Delta H^\circ} = 0.697 \approx 69.7\%$$

$$\Delta W_{\text{max}} = (\eta_{\text{conv.}})_{\text{max.}} \times \Delta H^\circ = 165.732 \text{ kJ/mol}$$

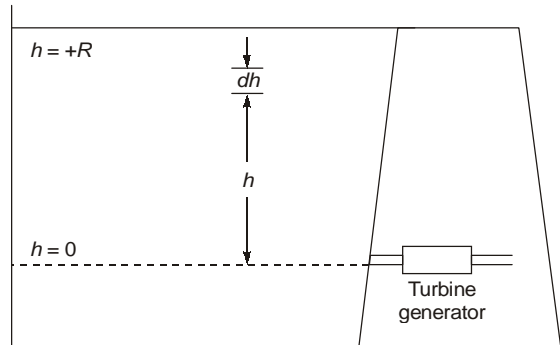
Solution : 23

Tidal range (amplitude), 'R' and certain head 'h' at given time during the flow from ocean to basin, the differential work done (dW) is equal to change in potential energy.

$$dW = dmgh \quad \dots(1)$$

$$dm = -\rho A dh \quad \dots(2)$$

$$W_{\text{emp}} = \int_R^0 dW = \int_R^0 -\rho A gh \times dh$$



$$W_{\text{emp}} = \frac{\rho g A R^2}{2} \text{ Joule}$$

Hence,

$$W_{\text{emp}} \propto R^2$$

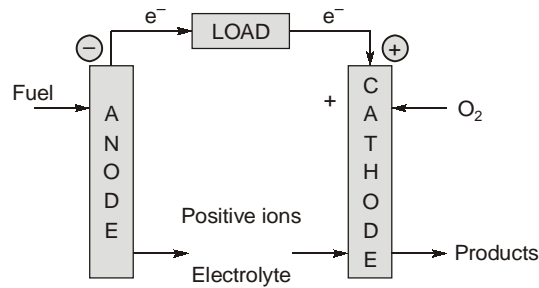
$$P_{\text{avg}} = 818.817 \text{ MW}$$

Solution : 24

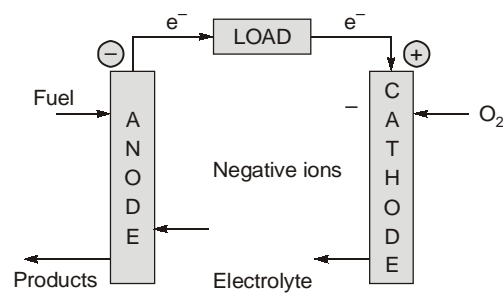
In a fuel cell, the type of reactions taking place is determined by the fuel and oxidizer combination, by the composition of the electrolyte, and the materials and the catalytic effect of cathode and the anode surfaces.

The three different types of fuel-cell reaction are –

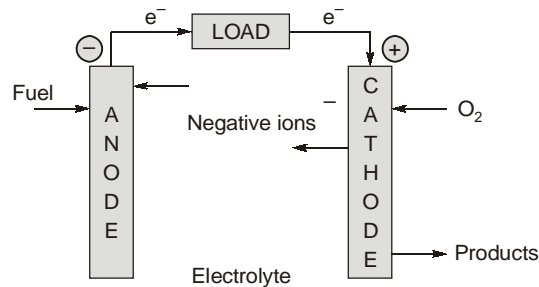
(1) Type A



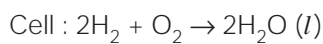
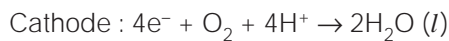
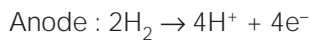
(2) Type B



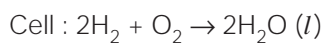
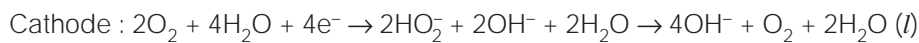
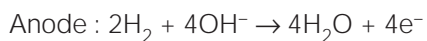
(3) Type C



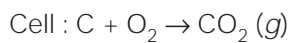
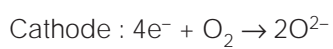
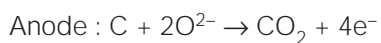
Hydrogen-oxygen fuel cell reactions, (Type A)



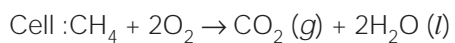
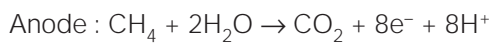
for (Type C)



Carbon-Oxygen fuel cell, Type B



Methane - oxygen fuel cell —



Solution : 25

Power generated = 368.5 MW

