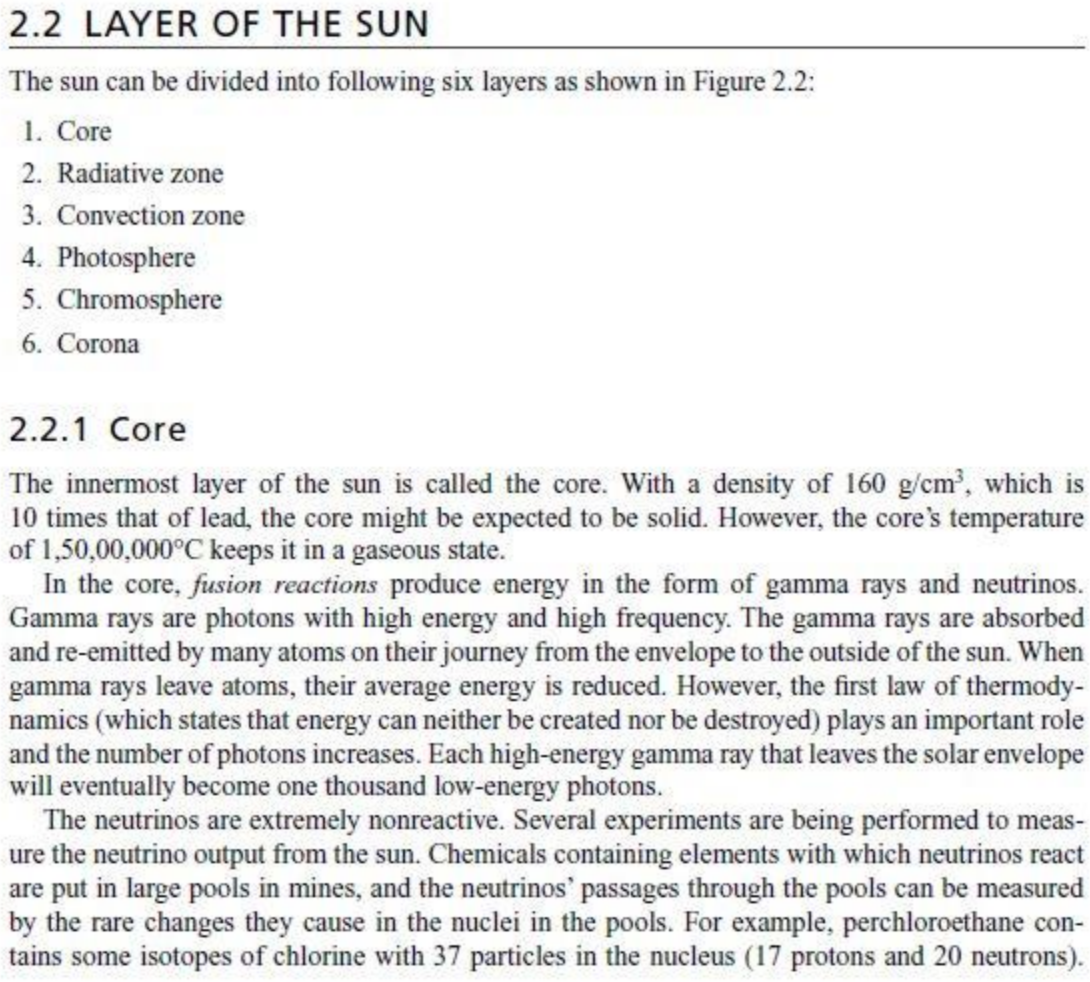
IAT-2 Solutions

1 a. With a neat sketch, explain the layers of the sun.



2.2 LAYER OF THE SUN

The sun can be divided into following six layers as shown in Figure 2.2:

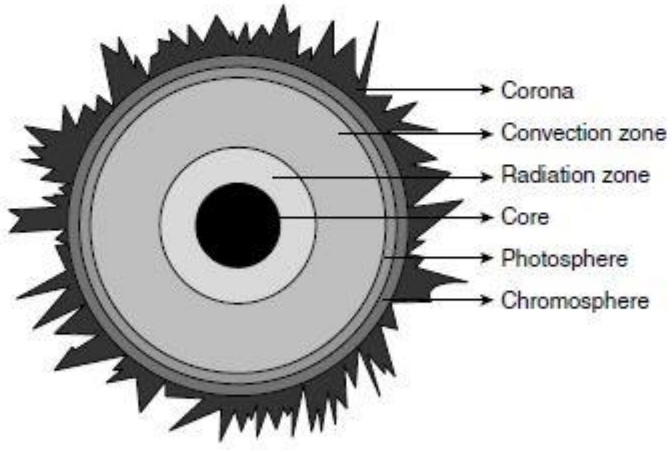
1. Core
2. Radiative zone
3. Convection zone
4. Photosphere
5. Chromosphere
6. Corona

2.2.1 Core

The innermost layer of the sun is called the core. With a density of 160 g/cm^3, which is 10 times that of lead, the core might be expected to be solid. However, the core's temperature of 1,50,00,000°C keeps it in a gaseous state.

In the core, *fusion reactions* produce energy in the form of gamma rays and neutrinos. Gamma rays are photons with high energy and high frequency. The gamma rays are absorbed and re-emitted by many atoms on their journey from the envelope to the outside of the sun. When gamma rays leave atoms, their average energy is reduced. However, the first law of thermodynamics (which states that energy can neither be created nor be destroyed) plays an important role and the number of photons increases. Each high-energy gamma ray that leaves the solar envelope will eventually become one thousand low-energy photons.

The neutrinos are extremely nonreactive. Several experiments are being performed to measure the neutrino output from the sun. Chemicals containing elements with which neutrinos react are put in large pools in mines, and the neutrinos' passages through the pools can be measured by the rare changes they cause in the nuclei in the pools. For example, perchloroethane contains some isotopes of chlorine with 37 particles in the nucleus (17 protons and 20 neutrons).



These Cl-37 molecules can take in neutrinos and become radioactive Ar-37 (18 protons and 19 neutrons). From the amount of argon present, the number of neutrinos can be calculated.

2.2.2 Solar Envelope

Outside of the core is the radiative envelope, which is surrounded by a convective envelope. The temperature is 4 million kelvin (7 million degrees F). The density of the solar envelope is much less than that of the core. The core contains 40% of the sun's mass in 10% of the volume, whereas the solar envelope has 60% of the mass in 90% of the volume. The solar envelope puts pressure on the core and maintains the core's temperature. The hotter a gas is, the more transparent it is.

The solar envelope is cooler and more opaque than the core. It becomes less efficient for energy to move by radiation, and as a result, heat energy starts to build up at the outside of the radioactive zone. The energy begins to move by convection in huge cells of circulating gas with several hundred kilometres in diameter. Convection cells nearer to the outside are smaller than the inner cells. The top of each cell is called a granule. These granules, when observed through a telescope, look like tiny specks of light. Variations in the velocity of particles in granules cause slight wavelength changes in the spectra emitted by the sun.

2.2.3 Photosphere

The photosphere is the zone from which the sunlight is both seen and emitted. The photosphere is a comparatively thin layer of low-pressure gasses surrounding the envelope. It is only a few hundred kilometres thick with a temperature of 6,000°C. The composition, temperature, and pressure of the photosphere are revealed by the spectrum of sunlight. When analysing the solar spectrum, William Ramsey discovered helium in 1896 and found that features of the gas did not belong to any gas known on earth. Hence, the newly discovered gas was named as helium in honour of Helios, the mythological Greek god of the sun.

2.2.4 Chromospheres

During an eclipse, a red circle can sometimes be seen outside the sun. This circle is called the chromospheres. Its red colouring is caused by the abundance of hydrogen. From the centre of the sun to the chromospheres, the temperature decreases proportionally as the distance from the core increases. The chromospheres' temperature, however, is 7,000 K, which is hotter than that of the photosphere. Temperatures continue to increase through the corona.

2.2.5 Corona

The outermost layer of the sun is called the corona or the crown. The corona is very thin and faint and is, therefore, very difficult to observe from the earth. Typically, we can observe the corona during a total solar eclipse or by using a coronagraph telescope, which simulates an eclipse by covering the bright solar disk. This outer layer is very dim—a million times dimmer than the photosphere and oddly enough, it is the hottest. At 10^6 K, it would seem that the heat would be

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1 b. Define (i) Hour angle (ii) Declination angle (iii) Latitude angle

2.3.1 Hour Angle (ω)

The hour angle is the angular distance between the meridian of the observer and the meridian whose plane contains the sun.

To describe the earth's rotation about its polar axis, the concept of the hour angle (ω) is used. As shown in Figure 2.3, the hour angle is zero at solar noon (when the sun reaches its highest point in the sky). At this time, the sun is said to be 'due south' (or 'due north', in the Southern Hemisphere) since the meridian plane of the observer contains the sun. The hour angle increases by 15° every hour. An expression to calculate the hour angle from solar time is,

$$\omega = 15 \times (t_s - 12); \text{ (in degrees)} \qquad (2.1)$$

Where, t_s is the solar time in hours.

Hour angle (ω) can be calculated simply as follows:

Since the earth makes one revolution on its axis in 24 h, then 15 minutes will be equal to 15/60 = 1/4 min

Therefore,

$$\omega = 1/4 \times t_m; \text{ (in degrees)} \qquad (2.2)$$

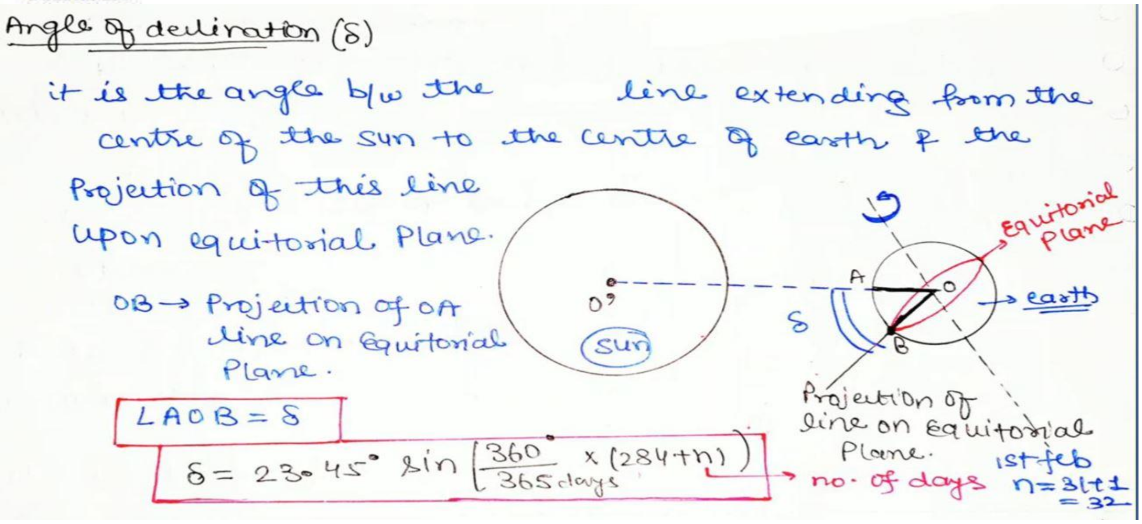
Where, t_m is the time in minutes after local solar noon. ω will be +ve if solar time is after solar noon. However, ω will be –ve if solar time is before solar noon as shown in Figure 2.4.

2.3.4 Latitude Angle (ϕ)

The latitude angle (ϕ) is the angle between a line drawn from a point on the earth's surface to the centre of the earth and the earth's equatorial plane. The intersection of the equatorial plane with the surface of the earth forms the equator and is designated as 0° latitude.

The earth's axis of rotation intersects the earth's surface at +90° S latitude (North Pole) and –90° latitude (South Pole). Any location on the surface of the earth can be then defined by the intersection of a longitude angle and a latitude angle.

Other latitude angles of interest are the Tropic of Cancer (+23.45° latitude) and the Tropic of Capricorn (–23.45° latitude). These represent the maximum tilts of the North and South Poles towards the sun. The other two latitudes of interest are the Arctic Circle (66.55° latitude) and Antarctic Circle (–66.5° latitude) representing the intersection of a perpendicular to the earth–sun line when the South and North Poles are at their maximum tilts towards the sun. The tropics represent the highest latitudes where the sun is directly overhead at solar noon, and the Arctic and Antarctic circles represent the lowest latitudes where there are 24 h of daylight or darkness. All of these events occur either at the summer or winter solstices.



Angle of declination (δ)

it is the angle b/w the line extending from the centre of the sun to the centre of earth & the Projection of this line upon equitorial Plane.

OB → Projection of OA line on Equitorial Plane.

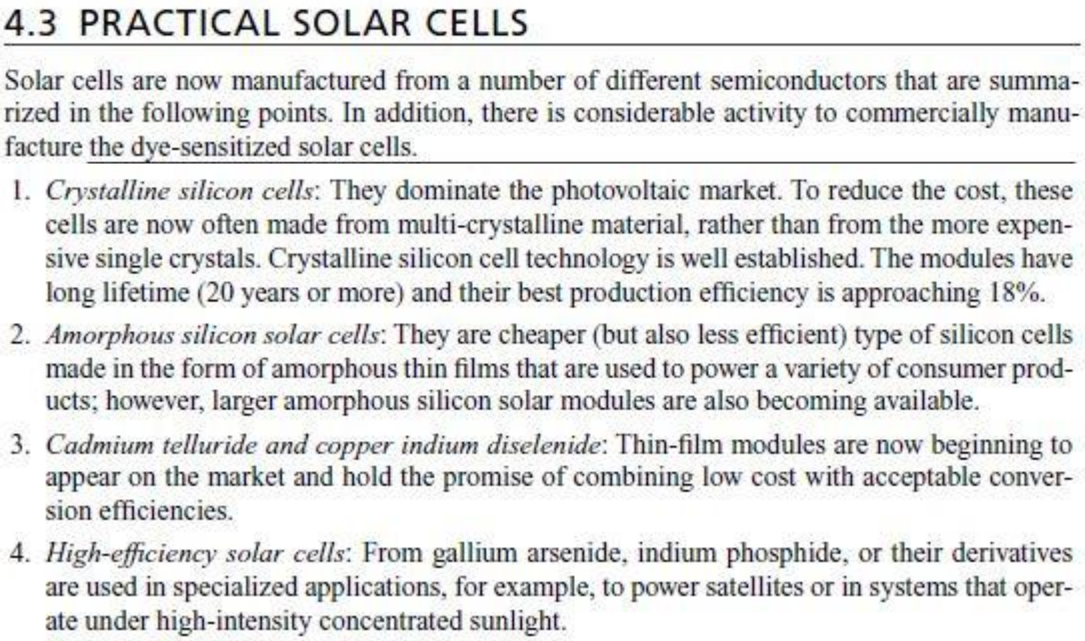
$\angle AOB = \delta$

$$\delta = 23.45^\circ \sin\left(\frac{360}{365\text{ days}} \times (284 + n)\right)$$

→ no. of days

1st feb n = 31+1 = 32

2 a. Explain the different types of practical solar cells.

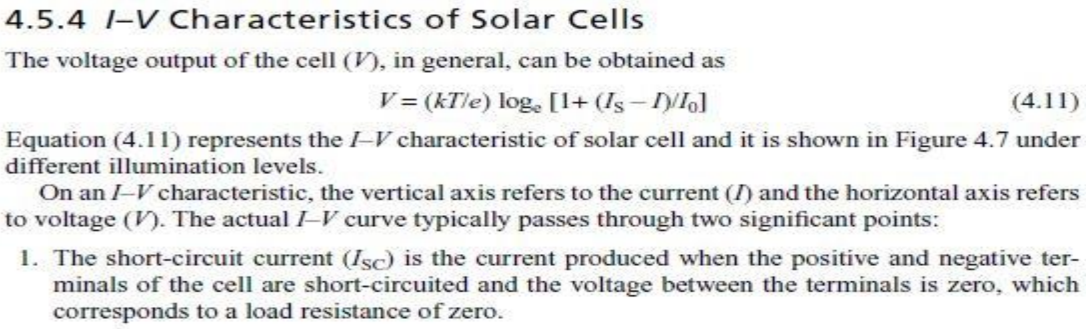


4.3 PRACTICAL SOLAR CELLS

Solar cells are now manufactured from a number of different semiconductors that are summarized in the following points. In addition, there is considerable activity to commercially manufacture the dye-sensitized solar cells.

1. *Crystalline silicon cells*: They dominate the photovoltaic market. To reduce the cost, these cells are now often made from multi-crystalline material, rather than from the more expensive single crystals. Crystalline silicon cell technology is well established. The modules have long lifetime (20 years or more) and their best production efficiency is approaching 18%.
2. *Amorphous silicon solar cells*: They are cheaper (but also less efficient) type of silicon cells made in the form of amorphous thin films that are used to power a variety of consumer products; however, larger amorphous silicon solar modules are also becoming available.
3. *Cadmium telluride and copper indium diselenide*: Thin-film modules are now beginning to appear on the market and hold the promise of combining low cost with acceptable conversion efficiencies.
4. *High-efficiency solar cells*: From gallium arsenide, indium phosphide, or their derivatives are used in specialized applications, for example, to power satellites or in systems that operate under high-intensity concentrated sunlight.

2 b. Plot the graph of a typical I-V characteristic of a solar cell. Show the relation between the output voltage and output current of a solar cell with the help of PV circuit models.



4.5.4 *I–V* Characteristics of Solar Cells

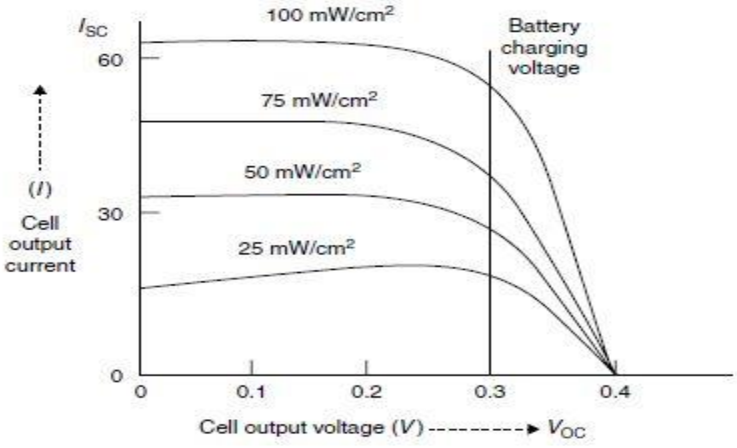
The voltage output of the cell (V), in general, can be obtained as

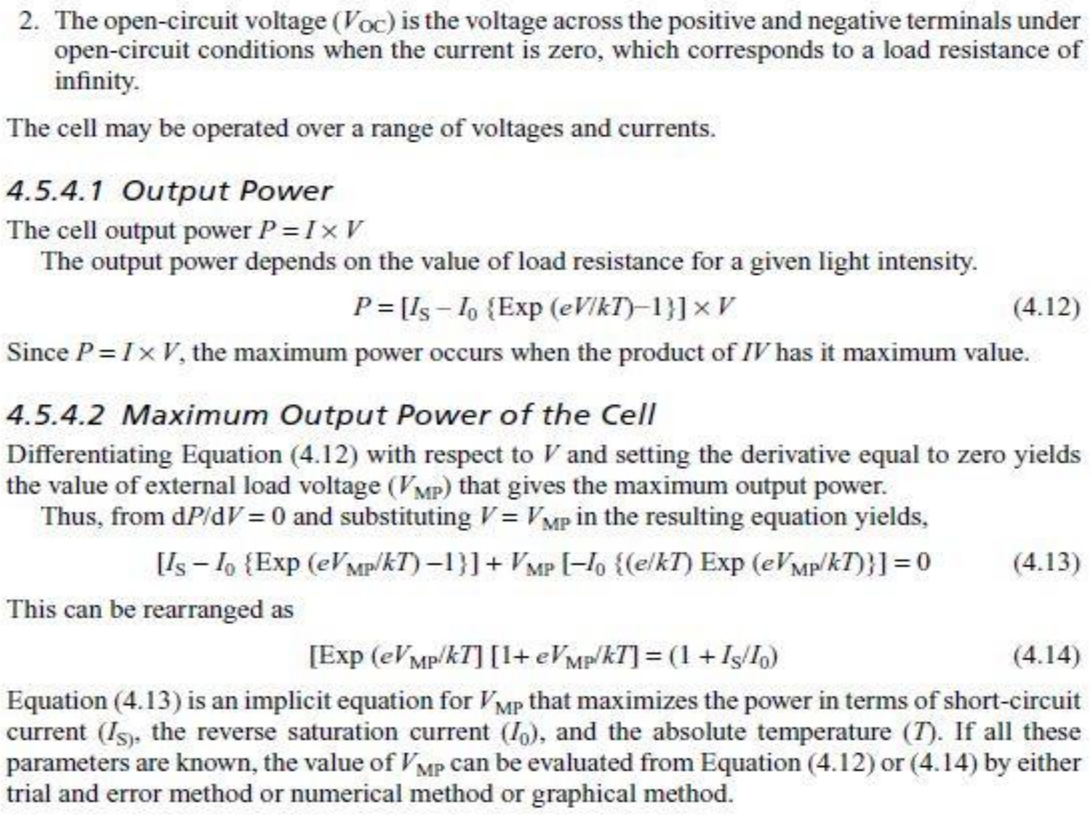
$$V = (kT/e)\log_e[1 + (I_S - I)/I_0] \tag{4.11}$$

Equation (4.11) represents the I–V characteristic of solar cell and it is shown in Figure 4.7 under different illumination levels.

On an I–V characteristic, the vertical axis refers to the current (I) and the horizontal axis refers to voltage (V). The actual I–V curve typically passes through two significant points:

1. The short-circuit current (I_{SC}) is the current produced when the positive and negative terminals of the cell are short-circuited and the voltage between the terminals is zero, which corresponds to a load resistance of zero.





2. The open-circuit voltage (V_{OC}) is the voltage across the positive and negative terminals under open-circuit conditions when the current is zero, which corresponds to a load resistance of infinity.

The cell may be operated over a range of voltages and currents.

4.5.4.1 Output Power

The cell output power $P = I \times V$

The output power depends on the value of load resistance for a given light intensity.

$$P = [I_S - I_0 \{\text{Exp}\ (eV/kT) - 1\}] \times V \qquad (4.12)$$

Since $P = I \times V$, the maximum power occurs when the product of IV has it maximum value.

4.5.4.2 Maximum Output Power of the Cell

Differentiating Equation (4.12) with respect to V and setting the derivative equal to zero yields the value of external load voltage (V_{MP}) that gives the maximum output power.

Thus, from $dP/dV = 0$ and substituting $V = V_{MP}$ in the resulting equation yields,

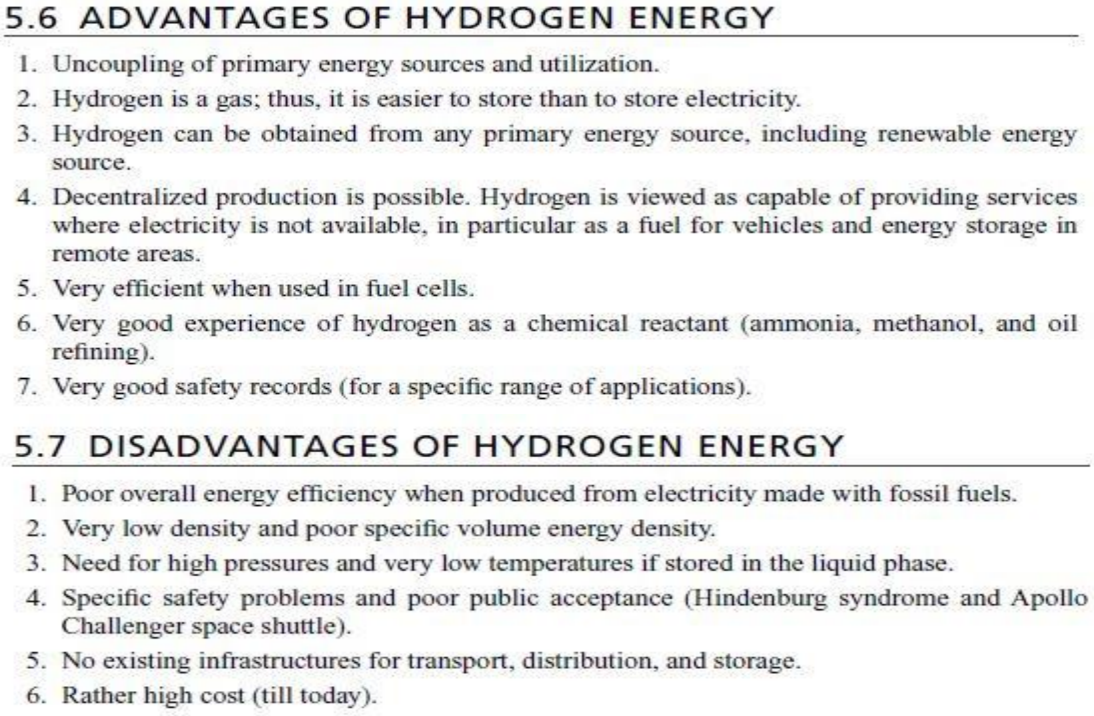
$$[I_S - I_0 \{\text{Exp}\ (eV_{MP}/kT) - 1\}] + V_{MP}\ [-I_0 \{(e/kT)\ \text{Exp}\ (eV_{MP}/kT)\}] = 0 \qquad (4.13)$$

This can be rearranged as

$$[\text{Exp}\ (eV_{MP}/kT]\ [1 + eV_{MP}/kT] = (1 + I_S/I_0) \qquad (4.14)$$

Equation (4.13) is an implicit equation for V_{MP} that maximizes the power in terms of short-circuit current (I_S), the reverse saturation current (I_0), and the absolute temperature (T). If all these parameters are known, the value of V_{MP} can be evaluated from Equation (4.12) or (4.14) by either trial and error method or numerical method or graphical method.

3 a. What are the advantages and disadvantages of hydrogen energy? Explain about applications of hydrogen energy.



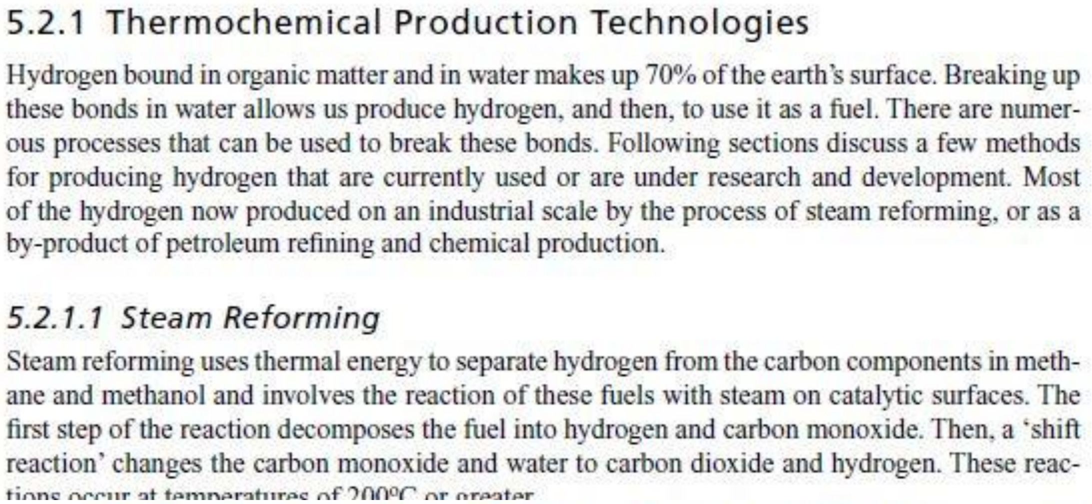
5.6 ADVANTAGES OF HYDROGEN ENERGY

1. Uncoupling of primary energy sources and utilization.
2. Hydrogen is a gas; thus, it is easier to store than to store electricity.
3. Hydrogen can be obtained from any primary energy source, including renewable energy source.
4. Decentralized production is possible. Hydrogen is viewed as capable of providing services where electricity is not available, in particular as a fuel for vehicles and energy storage in remote areas.
5. Very efficient when used in fuel cells.
6. Very good experience of hydrogen as a chemical reactant (ammonia, methanol, and oil refining).
7. Very good safety records (for a specific range of applications).

5.7 DISADVANTAGES OF HYDROGEN ENERGY

1. Poor overall energy efficiency when produced from electricity made with fossil fuels.
2. Very low density and poor specific volume energy density.
3. Need for high pressures and very low temperatures if stored in the liquid phase.
4. Specific safety problems and poor public acceptance (Hindenburg syndrome and Apollo Challenger space shuttle).
5. No existing infrastructures for transport, distribution, and storage.
6. Rather high cost (till today).

3 b. With all the necessary chemical equations, explain the following types of Thermo-chemical hydrogen production technologies (i) Steam Reforming; (ii) Partial oxidation; and (iii) biomass gasification and pyrolysis.

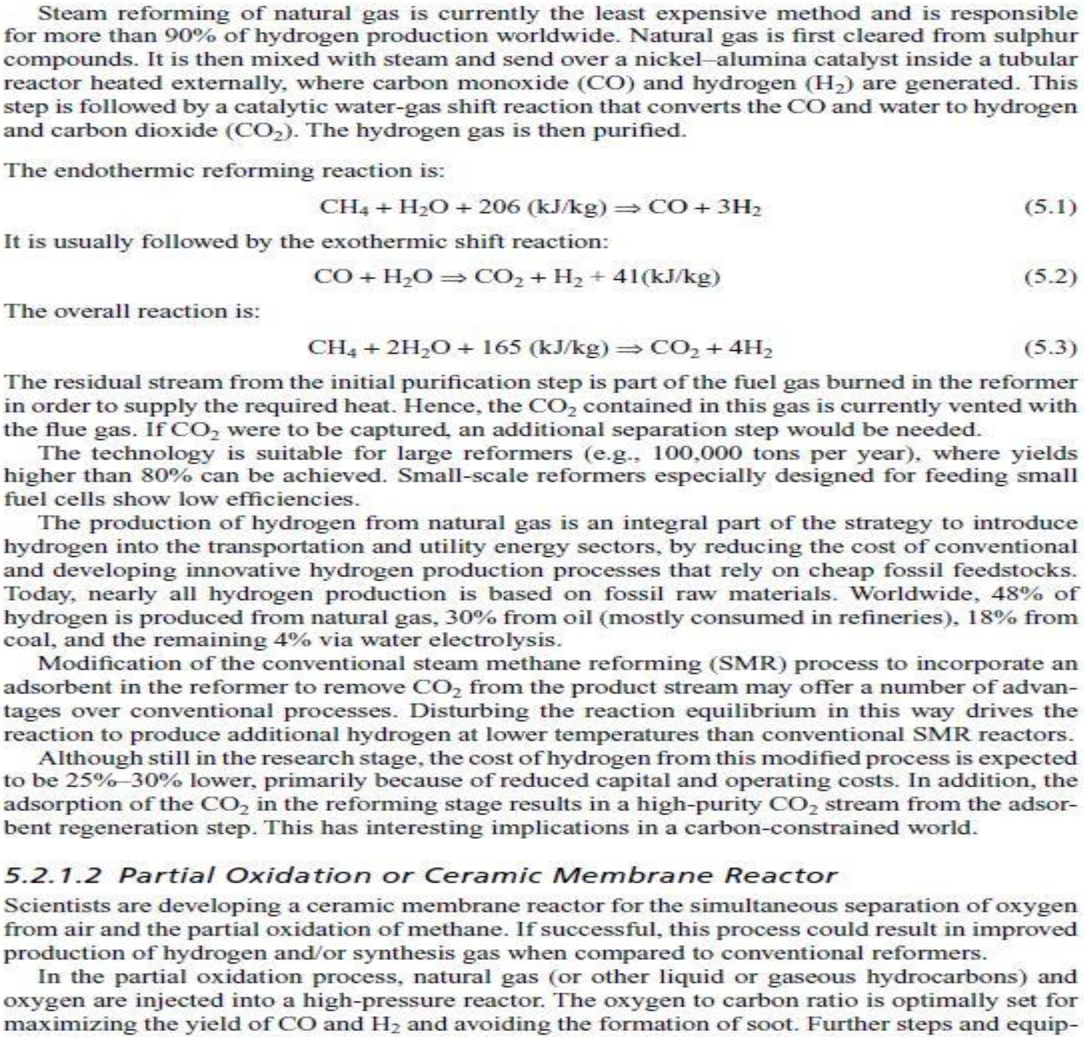


5.2.1 Thermochemical Production Technologies

Hydrogen bound in organic matter and in water makes up 70% of the earth's surface. Breaking up these bonds in water allows us produce hydrogen, and then, to use it as a fuel. There are numerous processes that can be used to break these bonds. Following sections discuss a few methods for producing hydrogen that are currently used or are under research and development. Most of the hydrogen now produced on an industrial scale by the process of steam reforming, or as a by-product of petroleum refining and chemical production.

5.2.1.1 Steam Reforming

Steam reforming uses thermal energy to separate hydrogen from the carbon components in methane and methanol and involves the reaction of these fuels with steam on catalytic surfaces. The first step of the reaction decomposes the fuel into hydrogen and carbon monoxide. Then, a 'shift reaction' changes the carbon monoxide and water to carbon dioxide and hydrogen. These reactions occur at temperatures of 200ºC or greater



Steam reforming of natural gas is currently the least expensive method and is responsible for more than 90% of hydrogen production worldwide. Natural gas is first cleared from sulphur compounds. It is then mixed with steam and send over a nickel–alumina catalyst inside a tubular reactor heated externally, where carbon monoxide (CO) and hydrogen (H_2) are generated. This step is followed by a catalytic water-gas shift reaction that converts the CO and water to hydrogen and carbon dioxide (CO_2). The hydrogen gas is then purified.

The endothermic reforming reaction is:

$$CH_4 + H_2O + 206\ (kJ/kg) \Rightarrow CO + 3H_2 \tag{5.1}$$

It is usually followed by the exothermic shift reaction:

$$CO + H_2O \Rightarrow CO_2 + H_2 + 41(kJ/kg) \tag{5.2}$$

The overall reaction is:

$$CH_4 + 2H_2O + 165\ (kJ/kg) \Rightarrow CO_2 + 4H_2 \tag{5.3}$$

The residual stream from the initial purification step is part of the fuel gas burned in the reformer in order to supply the required heat. Hence, the CO_2 contained in this gas is currently vented with the flue gas. If CO_2 were to be captured, an additional separation step would be needed.

The technology is suitable for large reformers (e.g., 100,000 tons per year), where yields higher than 80% can be achieved. Small-scale reformers especially designed for feeding small fuel cells show low efficiencies.

The production of hydrogen from natural gas is an integral part of the strategy to introduce hydrogen into the transportation and utility energy sectors, by reducing the cost of conventional and developing innovative hydrogen production processes that rely on cheap fossil feedstocks. Today, nearly all hydrogen production is based on fossil raw materials. Worldwide, 48% of hydrogen is produced from natural gas, 30% from oil (mostly consumed in refineries), 18% from coal, and the remaining 4% via water electrolysis.

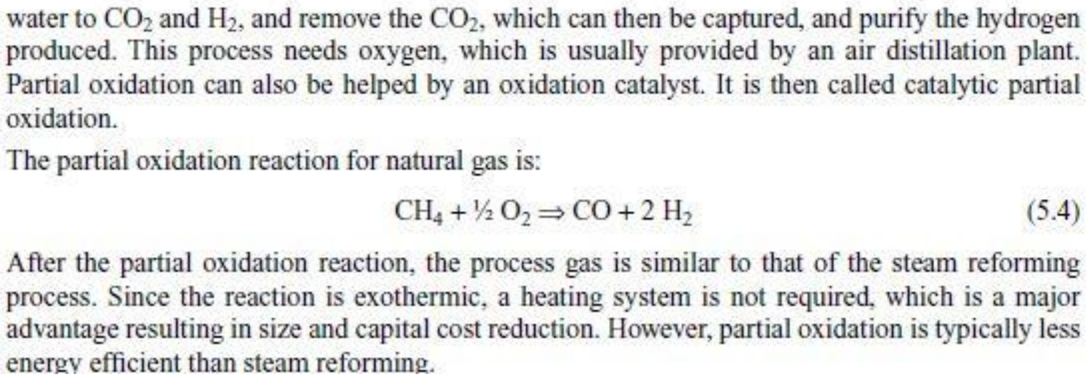
Modification of the conventional steam methane reforming (SMR) process to incorporate an adsorbent in the reformer to remove CO_2 from the product stream may offer a number of advantages over conventional processes. Disturbing the reaction equilibrium in this way drives the reaction to produce additional hydrogen at lower temperatures than conventional SMR reactors.

Although still in the research stage, the cost of hydrogen from this modified process is expected to be 25%–30% lower, primarily because of reduced capital and operating costs. In addition, the adsorption of the CO_2 in the reforming stage results in a high-purity CO_2 stream from the adsorbent regeneration step. This has interesting implications in a carbon-constrained world.

5.2.1.2 Partial Oxidation or Ceramic Membrane Reactor

Scientists are developing a ceramic membrane reactor for the simultaneous separation of oxygen from air and the partial oxidation of methane. If successful, this process could result in improved production of hydrogen and/or synthesis gas when compared to conventional reformers.

In the partial oxidation process, natural gas (or other liquid or gaseous hydrocarbons) and oxygen are injected into a high-pressure reactor. The oxygen to carbon ratio is optimally set for maximizing the yield of CO and H_2 and avoiding the formation of soot. Further steps and equip-



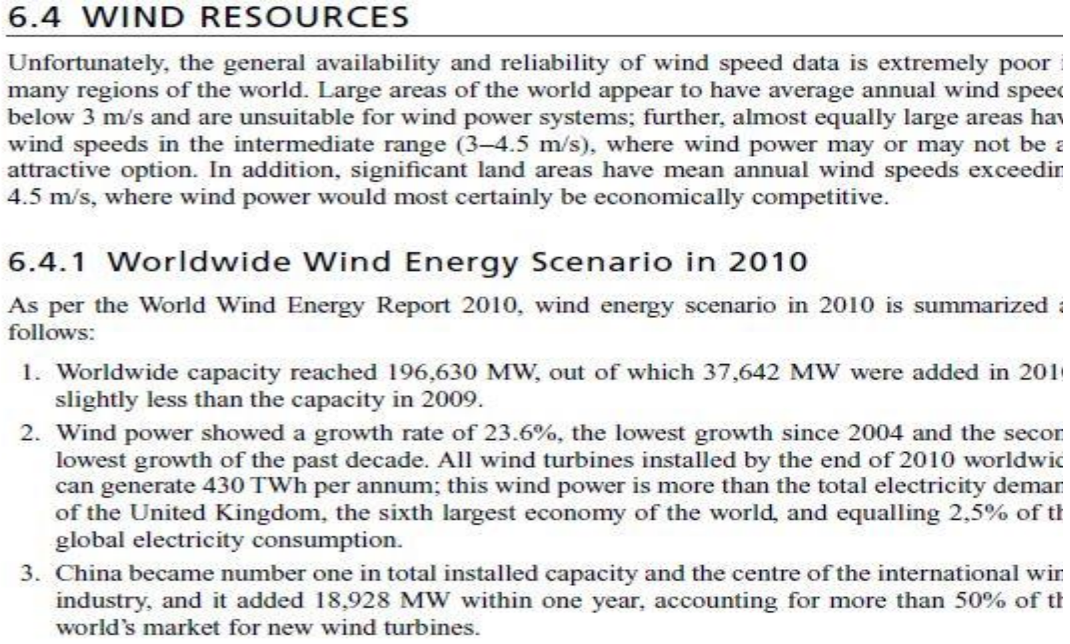
water to CO_2 and H_2, and remove the CO_2, which can then be captured, and purify the hydrogen produced. This process needs oxygen, which is usually provided by an air distillation plant. Partial oxidation can also be helped by an oxidation catalyst. It is then called catalytic partial oxidation.

The partial oxidation reaction for natural gas is:

$$CH_4 + \frac{1}{2}\,O_2 \Rightarrow CO + 2\,H_2 \tag{5.4}$$

After the partial oxidation reaction, the process gas is similar to that of the steam reforming process. Since the reaction is exothermic, a heating system is not required, which is a major advantage resulting in size and capital cost reduction. However, partial oxidation is typically less energy efficient than steam reforming.

4 a. Explain about wind resources.



6.4 WIND RESOURCES

Unfortunately, the general availability and reliability of wind speed data is extremely poor many regions of the world. Large areas of the world appear to have average annual wind spee below 3 m/s and are unsuitable for wind power systems; further, almost equally large areas hav wind speeds in the intermediate range (3–4.5 m/s), where wind power may or may not be attractive option. In addition, significant land areas have mean annual wind speeds exceedi 4.5 m/s, where wind power would most certainly be economically competitive.

6.4.1 Worldwide Wind Energy Scenario in 2010

As per the World Wind Energy Report 2010, wind energy scenario in 2010 is summarized follows:

1. Worldwide capacity reached 196,630 MW, out of which 37,642 MW were added in 201 slightly less than the capacity in 2009.
2. Wind power showed a growth rate of 23.6%, the lowest growth since 2004 and the secon lowest growth of the past decade. All wind turbines installed by the end of 2010 worldwi can generate 430 TWh per annum; this wind power is more than the total electricity deman of the United Kingdom, the sixth largest economy of the world, and equalling 2,5% of th global electricity consumption.
3. China became number one in total installed capacity and the centre of the international win industry, and it added 18,928 MW within one year, accounting for more than 50% of th world's market for new wind turbines.

4. Major decrease in new installations can be observed in North America and USA lost its number one position in total capacity to China.
5. Many Western European countries are showing stagnation, whereas there is strong growth in the number of Eastern European countries.
6. Germany keeps its number one position in Europe with 27,215 MW, followed by Spain with 20,676 MW.
7. The highest shares of wind power can be found in three European countries: Denmark (21%), Portugal (18%), and Spain (16%).
8. Asia accounted for the largest share of new installations (54,6%), followed by Europe (27,0%) and North America (16,7%).
9. Latin America (1,2%) and Africa (0,4%) still played only a marginal role in new installations.
10. Africa: North Africa represents still lion share of installed capacity, while wind energy plays hardly a role yet in Sub-Saharan Africa.
11. Nuclear disaster in Japan and oil spill in Gulf of Mexico will have long-term impact on the prospects of wind energy. Governments need to urgently reinforce their wind energy policies.
12. WWEA sees a global capacity of 600,000 MW as possible by 2015 and more than 1,500,000 MW by 2020.

6.4.2 Wind Energy in India

The Indian wind energy sector has an installed capacity of 14,158.00 MW (as on March 31, 2011). In terms of wind power installed capacity, India is ranked fifth in the world. Today, India is a major player in the global wind energy market.

The potential is far from exhausted. Indian Wind Energy Association has estimated that with the current level of technology, the 'on-shore' potential for utilization of wind energy for electricity generation is of the order of 65,000 MW. The unexploited resource availability has the potential to sustain the growth of wind energy sector in India in the years to come.

Wind in India are influenced by the strong south-west summer monsoon, which starts in May–June, when cool, humid air moves towards the land; further, the weak north-east winter monsoon, which starts in October, when cool, dry air moves towards the ocean. During March–August, the winds are uniformly strong over the whole Indian Peninsula, except the eastern peninsular coast. Wind speeds during November–March are relatively weak, although high winds are available during a part of the period on the Tamil Nadu coastline. A notable feature of the Indian programme has been the interest among private investors or developers in setting up of commercial wind power projects. The gross potential is 48,561 MW (source C-wet) and a total of about 14,158.00 MW of commercial projects have been established until March 31, 2011. The break-up of projects implemented in prominent wind potential states (as on March 31, 2011) is as given in Table 6.2.

Wind power potential has been assessed assuming 1% of land availability for wind farms requiring at 12 hectare/MW in sites having wind power density in excess of 200 W/m^2 at 50 m hub-height.

4 b. Discuss about parts of wind turbine.

6.5.4 Parts of a Wind Turbine

1. The nacelle contains the key components of the wind turbine, including the gearbox and the electrical generator.
2. The tower of the wind turbine carries the nacelle and the rotor. Generally, it is an advantage to have a high tower, since wind speeds increase farther away from the ground.
3. The rotor blades capture wind energy and transfer its power to the rotor hub.
4. The generator converts the mechanical energy of the rotating shaft to electrical energy.
5. The gearbox increases the rotational speed of the shaft for the generator.

6.5.4.1 Blade Count

The determination of the number of blades involves design considerations of aerodynamic efficiency, component costs, system reliability, and aesthetics. Noise emissions are affected by the location of the blades upwind or downwind of the tower and the speed of the rotor. Given that the noise emissions from the blades' trailing edges and tips vary by the fifth power of blade speed, a small increase in the tip speed can make a large difference. Wind turbines developed over the last 50 years have almost universally used either two or three blades. Aerodynamic efficiency increases with number of blades but with diminishing return. Increasing the number of blades from one to two yields a 6% increase in aerodynamic efficiency, whereas increasing the blade count from two to three yields only an additional 3% in efficiency. Further increasing the blade count yields minimal improvements in aerodynamic efficiency and sacrifices too much in blade stiffness as the blades become thinner.

Component costs that are affected by blade count are primarily for materials and manufacturing of the turbine rotor and drive train. Generally, the fewer the number of blades, the lower the material and manufacturing costs will be. In addition, the fewer the number of blades, the higher the rotational speed can be. This is because blade stiffness requirements to avoid interference with the tower limit how thin the blades can be manufactured, but only for upwind machines; deflection of blades in a downwind machine results in increased tower clearance. Fewer blades with higher rotational speeds reduce peak torques in the drive train, resulting in lower gearbox and generator costs.

The limitation on the available power in the wind means that the more the blades are, the lesser the power each can extract. A consequence of this is that each blade must also be narrower to maintain aerodynamic efficiency. The total blade area as a fraction of the total swept disc area is called the solidity, and aerodynamically, there is an optimum solidity for a given tip speed; the higher the number of blades, the narrower each one must be. In practice, the optimum solidity is low (only a few percentage) and this means that even with only three blades, each one must be very narrow. To slip through the air easily, the blades must be thin relative to their width, so the limited solidity also limits the thickness of the blades. Furthermore, it becomes difficult to build the blades strong enough if they are too thin, or the cost per blade increases significantly as more expensive materials are required.

For this reason, most large machines do not have more than three blades. The other factor influencing the number of blades is aesthetics: it is generally accepted that three-bladed turbines are less visually disturbing than one- or two-bladed designs.

6.5.4.2 Blade Materials

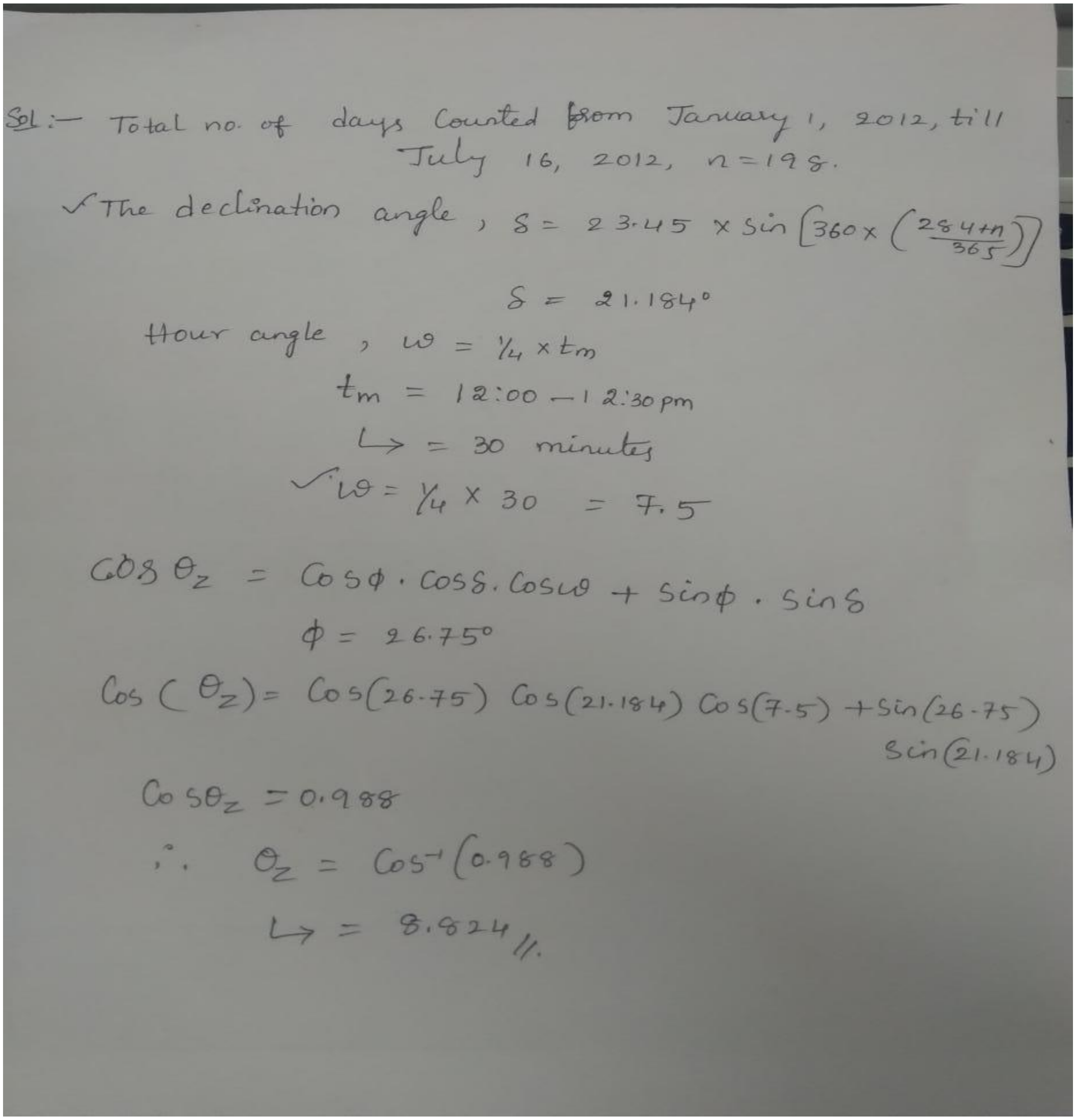
Wood and canvas sails were used on early windmills due to their low price, availability, and ease of manufacture. Small blades can be made from light metals such as aluminium. However, these materials require frequent maintenance. Wood and canvas construction limits the airfoil shape to a flat plate, which has a relatively high ratio of drag to force captured (low aerodynamic efficiency) when compared to solid airfoils. The constructions of solid airfoil designs require inflexible materials such as metals or composites. Some blades also have incorporated lightning conductors.

New wind turbine designs push power generation from the single megawatt range to upwards of 10 MW using very large blades. A large area effectively increases the tip-speed ratio of a turbine at a given wind speed, thus increasing its energy extraction. Computer-aided engineering software such as HyperSizer (originally developed for spacecraft design) can be used to improve blade design. The current production of wind turbine blades is as large as 100 m in diameter with prototypes in the range of 110–120 m. In 2001, an estimated 50,000,000 kg of fiberglass laminate were used in wind turbine blades.

An important goal of large blade systems is to control blade weight. Since blade mass scales as the cube of the turbine radius, loading due to gravity constrains systems with large blades. Proven fiberglass composite fabrication techniques are used in manufacturing blades in the 40–50 m range. Each technique use a glass fibre reinforced polymer composite materials constructed with different complexities. Perhaps the largest issue with more simplistic, open-mould, wet systems are the emissions associated with the volatile organics released. Pre-impregnated materials and resin infusion techniques avoid the release of volatiles by containing all reaction gases. However, these contained processes have their own challenges, namely the production of thick laminates necessary for structural components becomes more difficult. As the preform resin permeability dictates the maximum laminate thickness, bleeding is required to eliminate voids and insure proper resin distribution. One solution to resin distribution is a partially pre-impregnated fiberglass. During the evacuation, the dry fabric provides a path for airflow and, once heat and pressure are applied, resin may flow into the dry region resulting in a thoroughly impregnated laminate structure.

Epoxy-based composites have environmental, production, and cost advantages over other resin systems. Carbon fibre-reinforced spars for load bearing can reduce weight and increase stiffness. Using carbon fibres in 60 m turbine blades is estimated to reduce total blade mass by 38% and decrease the cost by 14% when compared to 100% fiberglass. Carbon fibres have the added benefit of reducing the thickness of fiberglass laminate sections and also solves the problems associated with resin wetting of thick lay-up sections. Wind turbines may also benefit from the general trend of increasing use and decreasing cost of carbon fibre materials.

5 a. Calculate Zeneith angle of the sun at Lucknow (26.75 degree N) at 12:30pm on July 16, 2012.



Sol :— Total no. of days Counted from January 1, 2012, till July 16, 2012, $n = 198$.

✓ The declination angle, $\delta = 23.45 \times \sin\left[360 \times \left(\frac{284+n}{365}\right)\right]$

$$\delta = 21.184^\circ$$

Hour angle, $\omega = \frac{1}{4} \times t_m$

$$t_m = 12{:}00 - 12{:}30\text{ pm}$$

$$\hookrightarrow = 30 \text{ minutes}$$

$$✓\ \omega = \frac{1}{4} \times 30 = 7.5$$

$$\cos\theta_z = \cos\phi \cdot \cos\delta \cdot \cos\omega + \sin\phi \cdot \sin\delta$$

$$\phi = 26.75^\circ$$

$$\cos(\theta_z) = \cos(26.75)\cos(21.184)\cos(7.5) + \sin(26.75)\sin(21.184)$$

$$\cos\theta_z = 0.988$$

$$\therefore\ \theta_z = \cos^{-1}(0.988)$$

$$\hookrightarrow = 8.824\ //.$$

5 b. List solar thermal energy applications.

2.5 SOLAR THERMAL ENERGY APPLICATIONS

Energy from the sun can be converted into usable form of energy for multi-purpose utilization as given in Figure 2.13 for the applications based on the controlled technology.

These technologies include passive and active systems.

2.5.1 Passive Systems

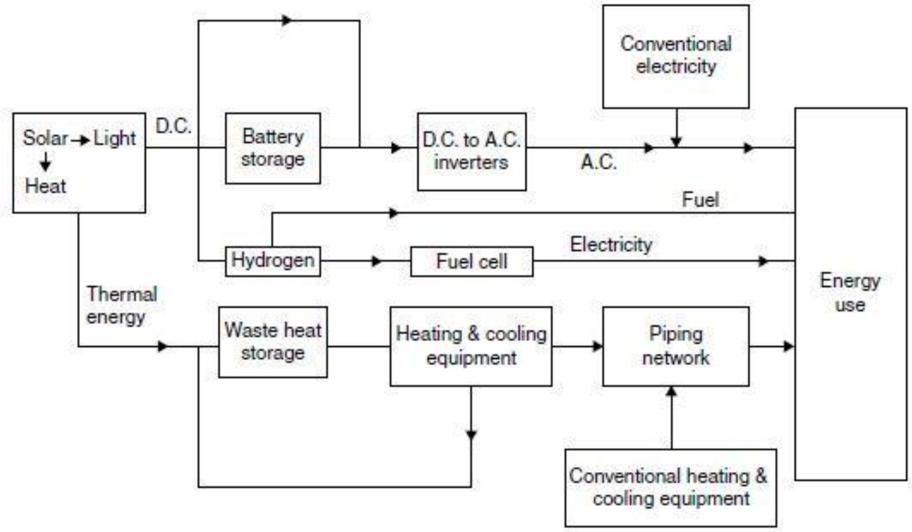
This system collects energy, without the need for pumps or motors, generally through the orientation, materials, and construction of a collector. These properties allow the collector to absorb, store, and use solar radiation. Passive systems are particularly suited to the design of buildings (where the building itself acts as the collector) and thermo siphoning solar hot water systems.

For new buildings, passive systems generally entail very low or no additional cost because they simply take advantage of the orientation and design of a building to capture and use solar radiation. In colder climates, a passive solar system can reduce heating costs by up to 40%, whereas in hotter climates, it can reduce the absorption of solar radiation and thus reduce cooling costs.

A passive solar system relies on natural sources to transfer heated water for domestic use, which is more prevalent in warmer climates with minor chance of freezing periods.

2.5.2 Active System

The most common active systems use pumps to circulate water or another heat absorbing fluid through solar collectors. These collectors are most commonly made of copper tubes bonded to



a metal plate, painted black, and encapsulated within an insulated box covered by a glass panel or 'glazing'. For pool heating and other applications where the desired temperature is less than 40°C, unglazed synthetic rubber materials are most commonly used.

An active pumped system can be either an open loop where the water is directly heated by the solar collector or closed loop where antifreeze or glycol mixture is heated before transferring its heat to the water by a heat exchanger. A popular design of the closed loop system is known as a drain back system. This freeze-proof design drains water back into a small holding tank when freezing temperatures occur.

2.5.3 Direct Thermal Applications

The sun's energy can be collected directly to create both high-temperature steam (greater than 100°C) and low-temperature heat (less than 100°C) for use in a variety of heat and power applications. Solar thermal collectors are, therefore, also classified as low-, medium-, and high-temperature collectors.

1. Low-temperature collectors are flat plates generally used to heat swimming pools.
2. Medium-temperature collectors are also usually flat plates but are used for heating water or air for residential and commercial use.
3. High-temperature collectors concentrate sunlight using mirrors or lenses and are generally used for electric power production.

These systems use mirrors and other reflective surfaces to concentrate solar radiation. Parabolic dish systems concentrate solar radiation to a single point to produce temperatures in excess of 1,000°C. Line-focus parabolic concentrators focus solar radiation along a single axis to generate temperatures of about 350°C. Central receiver systems use mirrors to focus solar radiation on a central boiler. The resulting high temperatures can be used to create steam either to drive electric turbine generators or to power chemical processes such as the production of hydrogen.

2.5.3.1 Low-temperature Solar Thermal Systems

It collects solar radiation to heat air and water for industrial applications including:

1. Space heating for homes, offices, and greenhouses
2. Domestic and industrial hot water
3. Pool heating
4. Desalination
5. Solar cooking
6. Crop drying

2.5.3.2 Domestic Water Heating

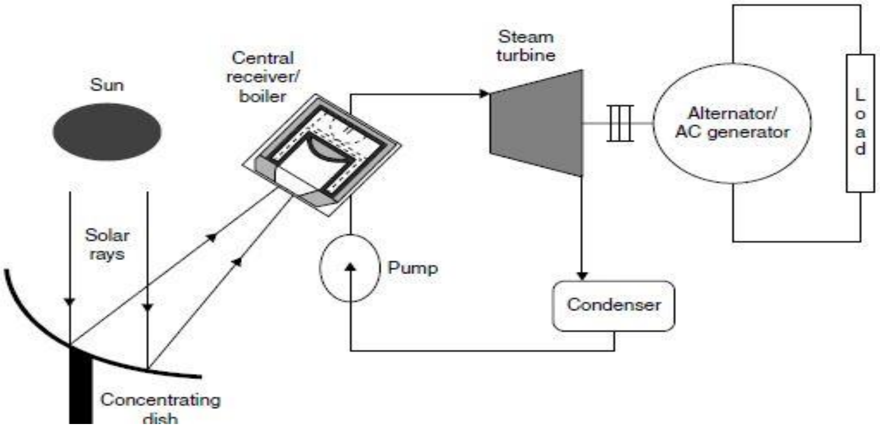
A solar domestic hot water system uses the sun's energy collected by a flat-plate solar collector and transfers the heat to water or another liquid flowing through the tubes. The system then draws upon this reservoir when hot water is needed. This system usually complements an existing elec-

2.5.4 Solar Electric Conversion and Applications

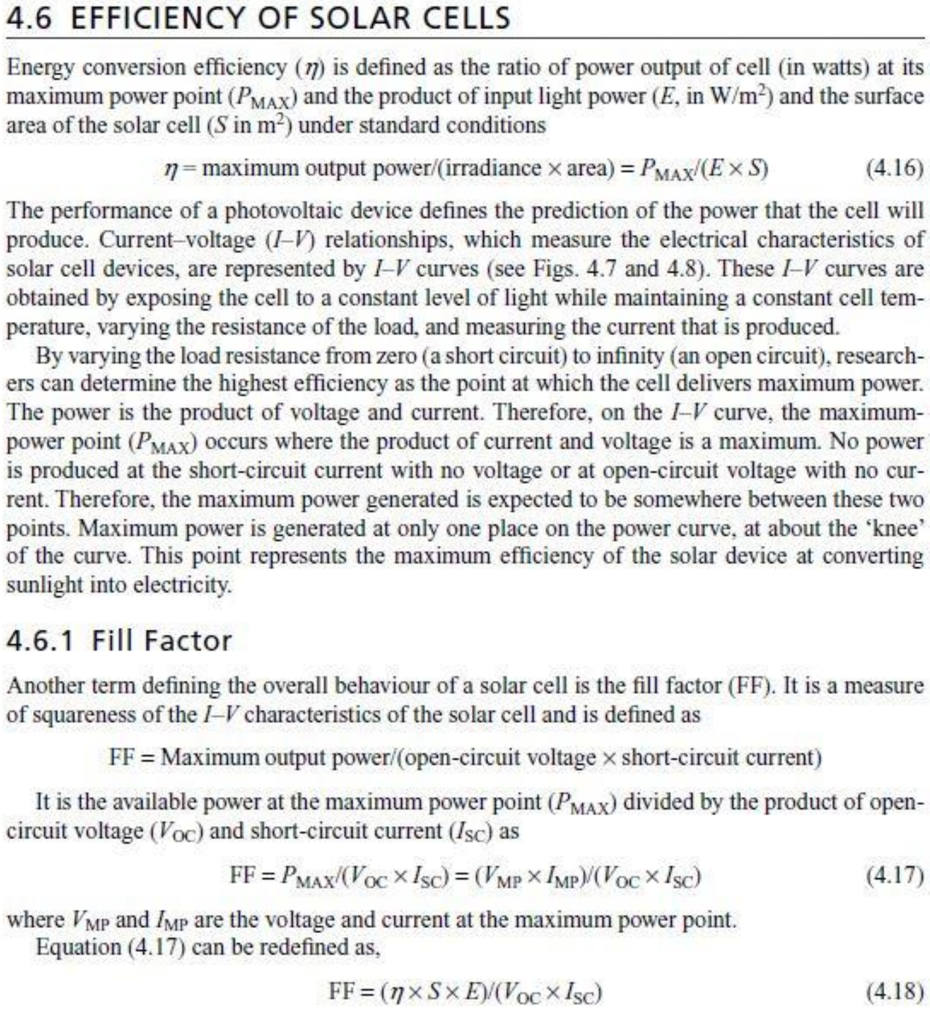
Energy from the sun is transformed into electricity through solar thermal, ocean thermal, photovoltaic, or wind conversion. A typical solar power conversion to electricity is shown in Figure 2.13a.

2.5.4.1 Solar Thermo–electro–mechanical Conversion (Heat to Power)

Solar thermal energy is concentrated and transferred to a working fluid for use either in a Rankine or in a Brayton cycle turbine generator. Most of the solar thermal energy development has been oriented towards obtaining heated fluid from a solar collector for direct heating applications. However, a more valuable form of energy as mechanical or electrical energy (both are equivalent in the thermodynamic sense) is sometimes desired either exclusively or in combination



6 a. Discuss about efficiency of solar cell and fill factor.



4.6 EFFICIENCY OF SOLAR CELLS

Energy conversion efficiency (η) is defined as the ratio of power output of cell (in watts) at its maximum power point (P_{MAX}) and the product of input light power (E, in W/m^2) and the surface area of the solar cell (S in m^2) under standard conditions

$$\eta = \text{maximum output power}/(\text{irradiance} \times \text{area}) = P_{MAX}/(E \times S) \qquad (4.16)$$

The performance of a photovoltaic device defines the prediction of the power that the cell will produce. Current–voltage (I–V) relationships, which measure the electrical characteristics of solar cell devices, are represented by I–V curves (see Figs. 4.7 and 4.8). These I–V curves are obtained by exposing the cell to a constant level of light while maintaining a constant cell temperature, varying the resistance of the load, and measuring the current that is produced.

By varying the load resistance from zero (a short circuit) to infinity (an open circuit), researchers can determine the highest efficiency as the point at which the cell delivers maximum power. The power is the product of voltage and current. Therefore, on the I–V curve, the maximum-power point (P_{MAX}) occurs where the product of current and voltage is a maximum. No power is produced at the short-circuit current with no voltage or at open-circuit voltage with no current. Therefore, the maximum power generated is expected to be somewhere between these two points. Maximum power is generated at only one place on the power curve, at about the 'knee' of the curve. This point represents the maximum efficiency of the solar device at converting sunlight into electricity.

4.6.1 Fill Factor

Another term defining the overall behaviour of a solar cell is the fill factor (FF). It is a measure of squareness of the I–V characteristics of the solar cell and is defined as

$$\text{FF} = \text{Maximum output power}/(\text{open-circuit voltage} \times \text{short-circuit current})$$

It is the available power at the maximum power point (P_{MAX}) divided by the product of open-circuit voltage (V_{OC}) and short-circuit current (I_{SC}) as

$$\text{FF} = P_{MAX}/(V_{OC} \times I_{SC}) = (V_{MP} \times I_{MP})/(V_{OC} \times I_{SC}) \qquad (4.17)$$

where V_{MP} and I_{MP} are the voltage and current at the maximum power point.

Equation (4.17) can be redefined as,

$$\text{FF} = (\eta \times S \times E)/(V_{OC} \times I_{SC}) \qquad (4.18)$$

6 b. Discuss about factors or guidelines for wind Turbine site selection.

6.5.2 Considerations and Guidelines for Site Selection

When looking for a place for a wind turbine, engineers consider factors such as wind hazards, characteristics of the land that affect wind speed, and the effects of one turbine on nearby turbines in wind farms. The following important factors need careful considerations:

1. *Hill effect*: When it approaches a hill, wind encounters high pressure because of the wind that has already built up against the hill. This compressed air rises and gains speed as it approaches the crest, or top of the hill. The installation of wind turbines on hilltops takes advantage of this increase in speed.
2. *Roughness or the amount of friction that earth's surface exerts on wind*: Oceans have very little roughness. A city or a forest has a great deal of roughness, which slows the wind.
3. *Tunnel effect*: The increase in air pressure undergoes when it encounters a solid obstacle. The increased air pressure causes the wind to gain speed as it passes between, for example, rows of buildings in a city or between two mountains. Placing a wind turbine in a mountain pass can be a good way to take advantage of wind speeds that are higher than those of the surrounding air.
4. *Turbulence*: Rapid changes in the speed and direction of the wind, often caused by the wind blowing over natural or artificial barriers are called turbulence. Turbulence causes not only fluctuations in the speed of the wind but also wear and tear on the turbine. Turbines are mounted on tall towers to avoid turbulence caused by ground obstacles.
5. *Variations in wind speed*: During the day, winds usually blow faster than they do at the night because the sun heats the air, setting air currents in motion. In addition, wind speed can differ depending on the season of the year. This difference is a function of the sun, which heats different air masses around earth at different rates, depending on the tilt of the earth towards or away from the sun.
6. *Wake*: Energy can neither be created nor destroyed. As wind passes over the blades of a turbine, the turbine seizes much of the energy and converts it into mechanical energy. The air coming out of the blade sweep has less energy because it has been slowed. The abrupt change in the speed makes the wind turbulent, a phenomenon called wake. Because of wake, wind turbines in a wind farm are generally placed about three rotor diameters away from one another in the direction of the wind, so that the wake from one turbine does not interfere with the operation of the one behind it.
7. *Wind obstacles*: Trees, buildings, and rock formations are the main obstacles in the installation of wind turbines. Any of these obstacles can reduce wind speed considerably and increase turbulence. Wind obstacles like tall buildings cause wind shade, which can considerably reduce the speed of the wind, and therefore, the power output of a turbine.
8. *Wind shear*: It is the differences in wind speeds at different heights. When a turbine blade is pointed straight upward, the speed of the wind hitting its tip can be, for example, 9 miles (14 km) per hour, but when the blade is pointing straight downward, the speed of the wind hitting its tip can be 7 miles (11 km) per hour. This difference places stress on the blades. Further, too much wind shear can cause the turbine to fail.

Choosing the right site for wind turbine is the most important decision. Further, the location plays a vital part in the performance and efficiency of a wind turbine. The following guidelines can be followed to evaluate site for the installation of wind turbines:

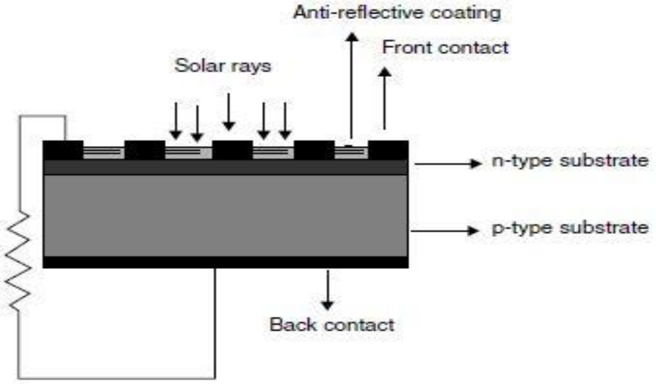
1. Turbines work best when on high and exposed sites. Coastal sites are especially good.
2. Town centres and highly populated residential areas are usually not suitable sites for wind turbines.
3. Avoid roof-mounted turbines as there is no guarantee that these devices will not damage property through vibration.
4. The farther the distance between the turbine and the power requirement, the more power will be lost in the cable. The distance of the cabling will also impact the overall cost of the installation.
5. Turbulence disrupts the air flow that can wear down the blades and reduces the lifecycle of the turbine. It is recommended that installing a turbine may be considered only when the distance between the turbine and the nearest obstacle is more than twice the height of the turbine, or when the height of the turbine is more than twice the height of the nearest obstacle.
6. Small turbines require an average wind speed of over 4.5 m/s to produce an efficient level of electricity.
7. If site is in a remote location, connecting wind turbine to the national grid will be very expensive and it may be worth considering an off-grid connection instead using battery storage.

7 a. Discuss about components of a solar cell system.

The basic elements of a solar cell is described in Figure 4.1.

The following are the basic elements:

1. *Substrate*: It is an unpolished p-type wafer referred to as p-region base material. The important parameters to be kept in mind while choosing a wafer for solar cells are its orientation, resistivity, thickness, and doping. Typical thickness of wafers used for solar cells is 180–300 μm. The typical resistivity values are in 1–2 Ωcm. The doping should be close to $5 \times 10^{15}/cm^3$ to $1 \times 10^{16}/cm^3$. The wafer can be single crystalline or multi-crystalline.
2. *Emitter*: The emitter formation involves the doping of silicon with pentavalent impurities such as phosphorus, arsenic, and antimony. However, for solar cell applications, phosphorus is the widely used impurity. The doping is done by the process of diffusion. The basic idea is to introduce the wafer in an environment rich in phosphorus at high temperatures. The phosphorus diffuses in, due to the concentration gradient, and it can be controlled by varying the time and temperature of the process. Commonly used diffusion technique makes use of POCl3 as the phosphorus source. The process is done at temperatures of 850°C to 1,000°C. The typical doping concentration will be of the order of $1\times10^{19}/cm^3$. The junction depths are in the range of 0.2–1 μm. This is also commonly known as *n*-region diffused layers
3. *Electrical contacts*: These are essential to a photovoltaic cell since they bridge the connection between the semiconductor material and the external electrical load. It includes
   - (a) *Back contact*: It is a metallic conductor completely covering back. The back contact of a cell is located on the side away from the incoming sunlight and is relatively simple. It usually consists of a layer of aluminium or molybdenum metal.
   - (b) *Front contact*: Current collection grid of metallic finger type is arranged in such a way that photon energy falls on n-region diffused layers. The front contact is located on the side facing the light source and is more complicated. When light falls on the solar cell, a current of electrons flow over the surface. If contacts are attached at the edges of the cell, it will not work well due to the great electrical resistance of the top semiconductor layer; only a small number of electrons will make it to the contact. To collect the maximum current, the contacts must be placed across the entire surface of a solar cell. This is done with a grid of metal stripes or fingers. However, placing a large grid, which is opaque, on the top of the cell shades active parts of the cell from the light source; as a result, this significantly reduces the conversion efficiency. To improve the conversion efficiency, the shading effect must be minimized.



   - (c) *Anti-reflective coatings*: Anti-reflective coatings are applied to reduce surface reflection and maximize cell efficiency in solar glass and silicon solar cell manufacturing. It helps to reduce the reflection of desirable wavelengths from the cell, allowing more light to reach the semiconductor film layer, increasing solar cell efficiency. When a thin-film nano-coating of anti-reflection coating of silicon dioxide (SiO_2) and titanium dioxide (TiO_2) is applied, there seems to be an increase in cell efficiencies by 3–4%.

7 b. Discuss about hydrogen energy storage.

5.3.1 Compressed Gas and Liquid Hydrogen Storage Tanks

Hydrogen has a very high energy content by weight (about three times more than gasoline), but it has a very low energy content by volume (liquid hydrogen is about four times less than gasoline). This makes hydrogen a challenge to store. Liquefied hydrogen is denser than gaseous hydrogen, and thus, it contains more energy in a given volume. Similar sized liquid hydrogen tanks can store more hydrogen than compressed gas tanks, but it takes energy to liquefy hydrogen. However, the tank insulation required to prevent hydrogen loss adds to the weight, volume, and costs of liquid hydrogen tanks.

5.3.2 Materials-based Storage

Hydrogen can be stored in materials by following different processes. It can be stored on the surfaces of solids (by adsorption process) or within solids (by absorption process).

In adsorption process, hydrogen attaches to the surface of a material either as hydrogen molecules (H_2) or hydrogen atoms (H). This is also referred to as surface adsorption storage.

In absorption process, hydrogen molecules dissociate into hydrogen atoms that are incorporated into the solid lattice framework. This is also known as intermetallic hydride storage. This method may make it possible to store larger quantities of hydrogen in smaller volumes at low pressure and at temperatures close to room temperature. Finally, hydrogen can be strongly bound within molecular structures, as chemical compounds containing hydrogen atoms in the form of compressed gas or cryogenic liquid.

5.3.3 Methods of Hydrogen Energy Storage

Based on the abovementioned processes, methods of hydrogen energy storage may be classified as follows:

5.3.3.1 Compression

The hydrogen can be compressed into containers or underground reservoirs. This is a relatively simple technology, but the energy density and efficiency (65%–70%) are low. Further, problems have occurred with the mechanical compression.

However, this is, at present, the most common form of hydrogen storage for the transport industry, with the hydrogen compressed to approximately 700 bar (the higher the storage pressure, the higher the energy density). However, the energy required for the compression is a major drawback.

5.3.3.2 Liquefied Hydrogen

The hydrogen can be liquefied by pressurising and cooling. Although the energy density is improved, it is still four times less than conventional petrol. Further, keeping the hydrogen liquefied is very energy intensive, as it must be kept below 20.27K

5.3.3.3 Metal Hydrides

Certain materials absorb molecular hydrogen such as nanostructured carbons and clathrate hydrate. By absorbing the hydrogen in these materials, it can be easily transported and stored. Once required, the hydrogen is removed from the parent material. The energy density is similar to that obtained for liquefied hydrogen. The extra material required to store the hydrogen is a major problem with this technique, as it creates extra costs and mass. This is still a relatively new technology, and therefore, with extra development, it could be a viable option, especially if the mass of material is reduced. Carbon-based absorption can achieve higher energy densities but it has higher costs and even lesser demonstrations. Both the metal-hydride and carbon-based absorption use thermal energy. This thermal heat could be got from the waste heat of other processes with HESS, such as the electrolyser or fuel cell, to improve overall efficiency.

Each storage technique is in the early stages of development, and hence, there is no optimum method, at present, with research being carried out in each area. Scientists are investigating several different kinds of materials, including metal hydrides, adsorbent materials, and chemical hydrides, in addition to identifying new materials with potential for favourable hydrogen storage attributes.

Hydrogen storage in materials offers great promise, but additional research is required to better understand the mechanism of hydrogen storage in materials under practical operating conditions and to overcome critical challenges related to it.