1. **What are primary and secondary energy sources?**

(a) Primary resources

These include resources embodied in nature prior to undergoing any human-made conversions or transformations. This only involves extraction or capture. Examples of primary energy resources are coal, crude oil, sunlight, wind, running rivers, vegetation and radioactive material like uranium etc.

(b) Secondary Resources

The energy resources supplied directly to consumer for utilization after one or more steps of transformation are known as secondary or usable energy, e.g. electrical energy, thermal energy (in the form of steam or hot water), refined fuels or synthetic fuels such as hydrogen fuels, etc.

2. **What are conventional and non-conventional energy sources?**

(a) Conventional Energy resources

The energy resources which are being traditionally used, for many decades and were in common use around oil crisis of 1973, are called conventional energy resources, e.g. fossil fuels, nuclear and hydro resources.

(b) Non-conventional Energy resources

These are considered for large-scale use after the oil crisis of 1973, are called nonconventional energy sources, e.g. solar, wind, biomass, etc.

3. **Which is the cleanest of all fuels? Give reasons**

The cleanest of all fossil-based fuels, natural gas is plentiful and flexible. It is increasingly used in the most efficient power generation technologies, such as, Combined Cycle Gas Turbine (CCGT) with conversion efficiencies of about 60 percent.

4. **Explain the laws of thermodynamics.**

The first law of thermodynamics can be stated as, "when a system undergoes a thermodynamic cycle then the net heat supplied to the system from the surroundings is equal to net work done by the system on its surroundings."

The SECOND law of thermodynamics

Kelvin-Planck Statement – "It is impossible to construct an engine, which while operating in a cycle produces no other effect except to extract heat from a single reservoir and do equivalent amount of work."

Clausius Statement - "It is impossible for a self-acting machine working in a cyclic process unaided by any external agency, to convey heat from a body at a lower temperature to a body at a higher temperature."

5. What are the forms and sources of energy? List some reasons, why nonconventional sources are preferred?

Sources of Energy

A. Based on usability of Energy
   Primary resources and Secondary Resources
B. Based on traditional use
   Conventional and Non-conventional
C. Based on Long term availability
   Non-Renewable and Renewable
D. Based on Commercial Application
   Commercial Energy Resources and Non-Commercial Energy resources
E. Based on Origin
   (a) Fossil fuels energy
   (b) Nuclear energy
   (c) Hydro energy
   (d) Solar energy
   (e) Wind energy
   (f) Biomass energy
   (g) Geothermal energy
   (h) Tidal energy
   (i) Ocean thermal energy
   (j) Ocean wave energy

Common forms of energy are Electrical Energy, Mechanical Energy, Thermal Energy and Chemical Energy.

Nonconventional sources are preferred because

a. Non-conventional sources are available in nature free of cost.
b. They produce no or very little pollution. Thus by and large they areenvironment friendly.
c. They are inexhaustible.
d. They have low gestation period.

6. Distinguish between renewable and non-renewable energy sources.

Non-renewable Resources

Energy resources which are finite and do not get replenished after their consumption, are called non-renewable e.g. fossil fuels, uranium, etc. They are likely to deplete with time.

Renewable Resources

Renewable energy is energy obtained from sources that are essentially inexhaustible. Examples of renewable resources include wind power, solar power, geothermal energy, tidal power and hydroelectric power. The most important feature of renewable energy is that it can be harnessed without the release of harmful pollutants.

7. **Classify the energy resources based on commercial application with examples.**

Commercial Energy Resource

The energy sources that are available in the market for a definite price are known as commercial energy. By far the most important forms of commercial energy are electricity, coal and refined petroleum products. Commercial energy forms the basis of industrial, agricultural, transport and commercial development in the modern world. In the industrialized countries, commercialized fuels are predominant sources not only for economic production, but also for many household tasks of general population.

Non-commercial Energy

The energy sources that are not available in the commercial market for a price are classified as non-commercial energy. Non-commercial energy sources include fuels such as firewood, cattle dung and agricultural wastes, which are traditionally gathered, and not bought at a price, used especially in rural households. Non-commercial energy is often ignored in energy accounting. Examples of non-commercial energy are: firewood, agro waste in rural areas, solar energy for water heating, animal power for transport, irrigation and crushing of sugarcane, etc.

8. **What do you mean by global warming? Give some reason of it.**

The presence of CO_2 in the atmosphere is not undesirable altogether. It is required for the growth of vegetation. However, any further increase in the concentration of CO_2 from present level will upset the temperature balance and would cause further warming of globe, which may have disastrous consequences.

Global warming is being caused mainly due to ever-increasing emission of CO_2 because of burning of fossil fuels for energy in industry. Other sources have comparatively lesser contribution. CH_4 and N_2O are produced due to agricultural practices such as application of fertilizer, management of livestock and their manure.

9. **Explain the greenhouse effect. Mention some of the greenhouse gasses.**

Carbon dioxide (CO_2) envelope presentaround the globe in the atmosphere behaves similar to a glass pane and forms a big global green house. This tends to prevent the escape of heat from earth, which leads to global warming. This phenomenon is known as greenhouse effect. Apart from CO_2, other gases behaving similar to CO_2 include methane, nitrous oxide (N_2O), hydrofluorocarbons (HFCs), chlorofluorocarbons (CFCs), hydro chlorofluorocarbons (HCFC), sulphur hexafluoride, ozone and water vapor. These gases are known as greenhouse gases (GHG).

10. **List various non-conventional energy resources. Give their availability, relative merits and their classification.**

a. Solar Energy
b. Wind Energy

c. Biomass Energy
d. Geothermal Energy
e. Ocean Tidal Energy
f. Ocean wave Energy
g. Ocean Thermal Energy Conversion

11. Discuss the main features of various types of renewable and non-renewable energy sources and explain the importance of non-conventional energy sources in the context of global warming.

12. What do you understand by green power?

The term "green power" is used to describe sources of energy which are considered environment friendly, non-polluting; and therefore, may provide a remedy to the systemic effects of certain forms of pollution, and global warming.

13. What is meant by renewable energy sources?

Renewable energy is energy obtained from sources that are essentially inexhaustible. Examples of renewable resources include wind power, solar power, geothermal energy, tidal power and hydroelectric power. The most important feature of renewable energy is that it can be harnessed without the release of harmful pollutants.

14. What do you understand by commercial energy?

The energy sources that are available in the market for a definite price are known as commercial energy. By far the most important forms of commercial energy are electricity, coal and refined petroleum products. Commercial energy forms the basis of industrial, agricultural, transport and commercial development in the modern world.

15. What are the advantages and limitations of non-conventional energy sources?

Advantages

- Non-conventional sources are available in nature free of cost.
- They produce no or very little pollution. Thus by and large they are environment friendly.
- They are inexhaustible.
- They have low gestation period i.e. less time required for setting up the power plants.

Limitations

- In general, the energy is available in dilute form from these sources.
- Though available freely in nature the cost of harnessing energy from nonconventional sources is generally high.
- Uncertainty of availability: the energy flow depends on various natural phenomena beyond human control.
- Difficulty in transporting this form of energy.
- Difficulty in storage.

16. What is the percentage share of fossil fuels in total energy consumption of the world?

About 82 per cent of the world's energy supply comes mainly from fossil fuels.
Fossil Fuels
Coal – 19.4 %
Oil – 35.8 %
Gas – 25.8%

17. What percentage of primary energy requirement is met by coal in India?
Coal – 19.4 %

18. Discuss the main feature of non-conventional energy sources.

- Non-conventional sources are available in nature free of cost.
- They produce no or very little pollution. Thus by and large they are environment friendly.
- They are inexhaustible.
- They have low gestation period i.e. less time required for setting up the power plants.

19. Discuss different renewable sources of energy with special reference to Indian context.

a. Solar Energy
b. Wind Energy
c. Biomass Energy
d. Geothermal Energy
e. Ocean Tidal Energy
f. Ocean wave Energy
g. Ocean Thermal Energy Conversion

20. What are the advantages and disadvantages of conventional energy sources?

Advantages
a. Cost: At present these are cheaper than non-conventional sources.
b. Security: As storage is easy and convenient; by storing certain quantity, the energy availability can be ensured for certain period.
c. Convenience: These sources are very convenient to use as technology for their conversion and use is universally available.

Disadvantages
1. Fossil fuels generate pollutants. Main pollutants generated in the use of these sources are CO, CO2, NOx, SOx, particulate matter and heat. These pollutants degrade the environment, pose health hazards and cause various other problems. CO2 is mainly responsible for global warming also.

2. Coal is also a valuable petro-chemical and is used as raw material for various chemical, pharmaceuticals and paints, etc. industries. From long-term point of view it is desirable to conserve coal for future needs.

3. There are safety and technical issues with nuclear energy. Major problems associated with nuclear energy are as follows:
(a) The waste material generated in nuclear plants has radioactivity of dangerous level; it remains above safe limit for a long period of time and thus is a health hazard. Its safe disposal, which is essential to prevent radioactive pollution, is a challenging task. Also the disposed radioactive waste is required to be guarded for a long period (till its radioactivity level comes down to a safe limit) in order to prevent against going in wrong hands.
(b) Possibility of accidental leakage of radioactive material from reactor (as happened in Chernobyl, former USSR in April 1986)
(c) Uranium resource, for which the technology presently exists, has limited availability.
(d) Sophisticated technology is required for using nuclear resources. Only few countries possess the required expertise to use nuclear energy.

4. Hydroelectric plants are cleanest but large hydro-reservoirs cause following problems:
(a) As large land area submerges into water, it leads to deforestation
(b) Causes ecological disturbances such as earthquakes
(c) Affects wild life
(d) Causes dislocation of large population and their rehabilitation problems

21. What do you understand by greenhouse effect and what are its consequences? How is it caused?

Carbon dioxide (CO_2) envelope presentaround the globe in the atmosphere behaves similar to a glass pane and forms a big global green house. This tends to prevent the escape of heat from earth, which leads to global warming. This phenomenon is known as greenhouse effect.

22. Which is the cleanest of all fuels and what is its heating value?

Natural Gas – 50 MJ/Kg

23. What do you understand by energy conservation? Explain its various aspects.

Energy conservation implies reduction in energy consumption by reducing losses and wastage by employing energy efficient means of generation and utilization of energy. There are three important aspects of energy conservation:
a. Economic Aspect
b. Environmental aspect

c. Conservation of Non-renewable energy assets

24. Define solar constant and its application in solar radiation geometry.

Solar Constant, is defined as the energy received from the sun per unit time, on a unit area of surface perpendicular to the direction of propagation of the radiation, at the earth's mean distance from the sun.

(WRC) has adopted a value of solar constant as 1367 W/m^2 (1.940 cal/cm^2 min, 432Btu/ft^2 hr or 4.921 MJ/m^2 hr). This has been accepted universally as a standard value of solar constant.

25. Define solar irradiance.

The terrestrial radiation expressed as energy per unit time per unit area (i.e. W/m^2) is known as Solar Irradiation.

26. Define the terms: laltitude angle, incident angle, zenith angle, solar azimuth angle, declination angle, and hour angle.

Latitude or Angle of Latitude (ϕ): The latitude of a location on earth's surface is the angle made by radial line, joining the given location to the centre of the earth, with its projection on the equator plane.

Angle of Incidence (θi)**:** It is the angle between sun's ray incident on the plane surface (collector) and the normal to that surface.

Zenith Angle (θz)**:** It is the angle between sun's ray and perpendicular (normal) to the horizontal plane.

Solar Azimuth Angle (γs)**:** It is the angle on a horizontal plane, between the line due south and the projection of sun's ray on the horizontal plane.

Declination (δ): It is defined as the angular displacement of the sun from the plane of earth's equator.

Hour Angle (ω): The hour angle at any moment is the angle through which the earth must turn to bring the meridian of the observer directly in line with sun's rays.

27. Derive an expression for solar day length.

At sunrise the sunrays are parallel to the horizontal surface. Hence the angle of incidence, $\theta_i = \theta_z = 90^\circ$, the corresponding hour angle, ω_s can be found as below:

$$\cos\theta_i = 0 = \cos\phi\cos\delta\cos\omega_s + \sin\delta\sin\phi$$

$$\omega_s = \pm\cos^{-1}(-\tan\phi\tan\delta)$$

The positive value corresponds to sunrise while the negative to sunset.

Therefore, the hour angle between sunrise and sunset is given by:

$$2\omega_s = 2\cos^{-1}(-\tan\phi\tan\delta)$$

Since 15° of hour angle is equivalent to one-hour duration, the duration of sunshine hours, t_d or daylight hours is given by:

$$t_d = (2/15)\cos^{-1}(-\tan\phi\tan\delta) \text{ hours}$$

28. Write short notes on beam and diffuse radiation.

Beam radiation:
Solar radiation propagating in a straight line and received at the earth surface without change of direction, i.e., in line with sun is called beam or direct radiation.

Diffuse radiation:
Solar radiation scattered by aerosols, dust and molecules is known as diffuse radiation. It does not have a unique direction.

29. Explain the construction and principle of operation of a sunshine recorder.

A sunshine recorder measures the sunshine hours in a day.

It essentially consists of glass sphere (about 10 cm in diameter) mounted on its axis parallel to that of earth, within a spherical section (bowl). The bowl and glass sphere is arranged in such a way that sun's rays are focused sharply at a spot on a card held in a groove in the bowl. The card is prepared from special paper bearing a time scale. As the sun moves, the focused bright sunshine burns a path along this paper. The length of the trace thus obtained on the paper is the measure of the duration of the bright sunshine. Three overlapping pairs of grooves are provided in the spherical segment to take care of the different seasons of the year.

30. How does the collection of solar energy is affected by tilting a flat plate collector with respect to ground?

Tilting a flat plate solar collector affects solar energy collection by optimizing the angle at which it intercepts sunlight, thereby maximizing the amount of solar radiation absorbed and converted into heat.

The optimal tilt angle for a flat plate collector depends on the location's latitude and the desired application (e.g., heating water, space heating).

- Generally, a tilt angle equal to the latitude maximizes annual solar energy collection.
- However, for winter heating, a slightly steeper tilt angle (greater than the latitude) can be beneficial, while for summer applications, a shallower tilt angle (less than the latitude) can be more efficient.

31. How does sun tracking helps in energy collection by a flat plate solar collector?

Sun tracking in flat plate solar collectors improves energy collection by maximizing the angle of incidence between incoming sunlight and the collector, resulting in higher efficiency and energy output.

32. What are the basic features required in an ideal pyranometer?

A precision pyranometer is designed to respond to radiation of all wavelengths and hence measures accurately the total power in the incident spectrum. It contains a thermopile whose sensitive surface consists of circular, blackened, hot junctions, exposed to the sun and cold junctions are completely shaded.

33. Define concentration ratio of a solar collector.

Concentration ratio (CR): It is defined as the ratio of the area of aperture of the system to the area of the receiver. The aperture of the system is the projected area of the collector facing (normal) the beam.

34. What are the main advantages of flat plate solar collector?

A flat plate collector is simple in construction and does not require sun tracking. Therefore, it can be properly secured on a rigid platform and thus becomes mechanically stronger than those requiring flexibility for tracking purpose. As the collector is installed outdoors and exposed to atmospheric disturbances (rain, storm, etc.), the flat plate type is more likely to withstand harsh outdoor conditions. Also because of simple stationary design, a flat plate collector requires little maintenance.

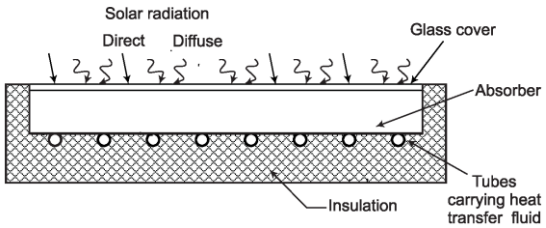
35. Describe the flat plate collector with the help of a suitable diagram.

A flat plate collector is placed at a location in a position such that its length aligns with

line of longitude and suitably tilted towards south to have maximum collection.

The basic elements in most of these collectors are:

(i) Transparent cover (one or two sheets) of glass or plastic. Thickness is 4 mm to 5 mm. It is transparent to incoming radiation (short wavelength) and largely opaque to reflected radiation (longer wavelength) creating greenhouse effect.
(ii) Blackened absorber plate usually made of copper or steel sheets of thickness 0.2 mm to 1 mm. The width of plate is usually 5 to 12 cm.
(iii) Copper tubes or channels with diameter 1 cm to 1.5 cm. Heat is transferred to heat transfer liquid circulating in the tube from the absorber plates.
(iv) weather tight, insulated container to enclose the components.
(v) Heat transfer liquid is usually water or water with ethylene glycol as anti-freezing agent.



36. What is approximate value of concentration ratio obtained from a CPC collector?

For Concentrating Plate Collectors, the Cr value varies from 1 to 1000.

37. Name three collectors requiring one axis sun tracking.

Three types of solar collectors that typically require one-axis sun tracking are parabolic trough collectors (PTCs), linear Fresnel collectors, and CPCs (Compound Parabolic Concentrators).

38. What range of temperature a parabolical dish collector may attain?

Maximum 2000^0 C

39. What range of CR is realizable from a central tower receiver collector?

CR value - 300

40. Discuss the principle of a solar collector. How collector coating can be used to improve the performance of a collector?

Principle of a Solar Collector:

Absorption:
Solar collectors, like flat plate or concentrating collectors, utilize a dark-colored absorber plate to capture solar radiation.

Heat Transfer:
The absorbed solar energy heats the absorber plate, which then transfers this heat to a fluid (water, air, or other heat transfer medium) flowing through the collector.

Applications:
The heated fluid can be used for various applications, including heating water, space heating, and even electricity generation in some cases.

Collector coating helps in

Increased Absorption:
These coatings are designed to absorb a high percentage of incoming solar radiation while reflecting or transmitting a high percentage of the infrared radiation emitted by the absorber plate at its operating temperature.

Reduced Heat Loss:
By minimizing the emission of infrared radiation, selective coatings help to reduce heat losses from the collector, leading to higher overall efficiency and higher temperatures.

41. What is the basic difference between an active and passive solar heating system?

The primary difference between active and passive solar heating systems lies in their reliance on mechanical or electrical components: active systems use pumps, fans, and controls to circulate heat, while passive systems rely on natural processes like convection and conduction for heat transfer.

42. Compare advantages and disadvantages of concentrating type collector over flat plate collector

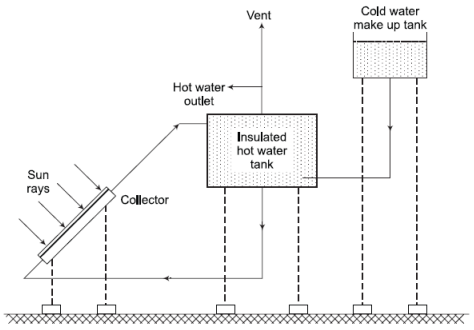
In concentrating type solar collectors, solar radiation is converged from large area into smaller area using optical means. Beam radiation, which has a unique direction and travels in a straight line, can be converged by reflection or refraction techniques. Diffuse radiation however, has no unique direction and so does not obey optical principles. Therefore, diffuse component cannot be concentrated. Thus, concentrating type solar collectors mainly make use of beam radiation component (plus very little diffuse component coming directly over absorber), while non-concentrating (flat plate) collectors absorb both beam as well as diffuse radiation, which is a distinct advantage of flat plate collector.

43. Explain the construction and working of the pyro heliometer with a diagram.

The normal incidence pyranometer uses a long collimator tube to collect beam radiation whose field of view is limited to a solid angle of 5.5° (generally) by appropriate diaphragms inside the tube. The inside of the tube is blackened to absorb any radiation incident at angles outside the collection solid angle. At the base of the tube a wire wound thermopile having a sensitivity of approximately 8 mV/W/m2 and an output impedance of approximately 200 W is provided. The tube is sealed with dry air to eliminate absorption of beam radiation within the tube by water vapor. A tracker is needed if continuous readings are desired.

44. With neat sketch explain the working of solar water heating system.

The details of most common type of solar water heater are shown in schematic diagram shown in the Figure. A tilted flat plate solar collector with water as heat transfer fluid is used. A thermally insulated hot water storage tank is mounted above the collector. The heated water of the collector rises up to the hot water tank and replaces an equal quantity of cold water, which enters the collector. The cycle repeats, resulting in all the water of the hot water tank getting heated up. When hot water is taken out from hot water outlet, the same is replaced by cold water from cold-water make up tank fixed above the hot water tank. The scheme is known as passive heating scheme, as water is circulated in the loop naturally due to thermos-siphon action.



45. Define solar constant and surface azimuthal angle?

Solar Constant, is defined as the energy received from the sun per unit time, on a unit area of surface perpendicular to the direction of propagation of the radiation, at the earth's mean distance from the sun.

Surface Azimuth Angle, is the angle in horizontal plane, between the line due south and the horizontal projection of normal to the inclined plane surface.

46. What do you understand by the heating value of a fuel?

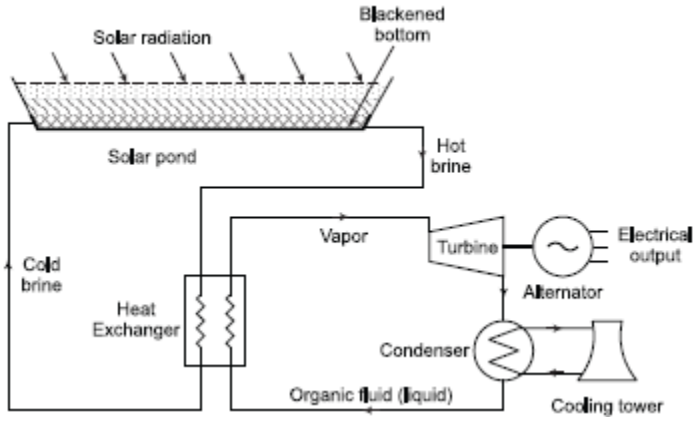
The heating value, also known as calorific value, of a fuel is the amount of heat energy released when a specific quantity of that fuel is completely burned. It's a measure of a fuel's energy content and is typically expressed in units like megajoules per kilogram (MJ/kg).

47. What are the different types of solar energy based on its application?

Solar energy applications are broadly categorized into photovoltaic (PV) systems for electricity generation and solar thermal systems for heat applications, with further subcategories like concentrating solar power (CSP) and passive/active solar designs.

48. With the help of block diagrams explain the operations of solar pond.

A non-convective solar pond serves the purpose of a large flat plate collector as well as long term thermal storage and can provide sufficient heat for the entire year. The black bottom serves as absorber and the layer of still water above it is used as insulator rather than normal glazing and air space. In a large area pond approximately 1–2 m deep, vertical gradient of salt concentration is maintained such that most concentrated and dense solutions are at the bottom. The salt concentration varies from 20–30 per cent at the bottom to almost zero at the top. Left to itself, the salt concentration gradient will disappear over a period of time because of upward diffusion of the salt. In order to maintain it, fresh water is added at the top of the pond through a horizontal diffuser, while slightly saline water is run off. At the same time concentrated brine is added at the bottom of the pond. The amount of salt required for this purpose is about 50 kg/m2-day, which is a large quantity when considered on an annual basis. For this reason, normally the salt is recycled by evaporating the saline water run-off from the surface in an adjoining evaporation tank.



49. Explain the construction and working of the pyranometer with a diagram.

A precision pyranometer is designed to respond to radiation of all wavelengths and hence measures accurately the total power in the incident spectrum. It contains a thermopile whose

sensitive surface consists of circular, blackened, hot junctions, exposed to the sun and cold junctions are completely shaded. The temperature difference between the hot and cold junctions is the function of radiation falling on the sensitive surface. The sensing element is covered by two concentric hemispherical glass domes to shield it from wind and rain. This also reduces the convection currents. A radiation shield surrounding the outer dome and coplanar with the sensing element, prevents direct solar radiation from heating the base of the instrument.

50. What is the main advantage of using a glass cover in a box type cooker?

A glass cover consisting of two layers of clear window glass sheets serves as the box door. The glass cover traps heat due to greenhouse effect. Maximum air temperature obtained inside the box is around 140–160 °C. This is enough for cooking the boiling type food slowly in about 2–3 hours.

51. How can solar thermal energy be converted into electrical energy?

Solar thermal energy can be converted into electrical energy using systems that concentrate sunlight to heat a fluid, which then powers a turbine connected to a generator, producing electricity.

Concentrating Solar Power (CSP):
CSP systems use mirrors or lenses to focus sunlight onto a receiver, which heats a fluid (like water, oil, or molten salts) to a high temperature.

Heat Transfer:
The heated fluid is then used to produce steam, which drives a turbine.

Turbine and Generator:
The turbine, in turn, spins a generator, converting the mechanical energy of the turbine into electrical energy.

52. What are major advantages and disadvantages of a solar PV system?

Solar photovoltaic (PV) systems convert solar energy directly into electrical energy. Major advantages of solar PV systems over conventional power systems are:

- It converts solar energy directly into electrical energy without going through thermal-mechanical link. It has no moving parts.
- Solar PV systems are reliable, modular, durable and generally maintenance free.
- These systems are quiet, compatible with almost all environments, respond instantaneously to solar radiation and have an expected life span of 20 years or more.
- It can be located at the place of use and hence no or minimum distribution network is required, as it is universally available.

Major disadvantages of solar PV systems are:

- At present the costs of solar cells are high, making them economically uncompetitive with other conventional power sources.
- The efficiency of solar cells is low. As solar radiation density is also low, large area of solar cell modules are required to generate sufficient useful power.
- As solar energy is intermittent, some kind of electrical energy storage is required, to ensure the availability of power in absence of sun. This makes the whole system more expensive.

53. What are the advantages and disadvantages of direct energy conversion system over the conventional power generation system?

Direct energy conversion systems, which bypass mechanical stages and directly convert energy forms into electricity, offer potential advantages like high efficiency and reduced complexity, but also face challenges like high operating temperatures and limited scalability compared to conventional power generation methods.

Advantages of Direct Energy Conversion Systems:
High Efficiency:
Reduced Complexity:
Compactness:

Disadvantages of Direct Energy Conversion Systems:
High Operating Temperatures:
Limited Scalability:
High Cost:
Material Limitations: The materials used in direct energy conversion systems must be able to withstand high temperatures and harsh environments, which can be a challenge.
Efficiency Challenges:

54. Describe the principle of solar photovoltaic energy conversion.

Photon Absorption:
When a photon with sufficient energy is absorbed in the depletion region of a p-n junction, it generates an electron-hole pair.

Separation of Charge Carriers:
Due to the built-in electric field in the depletion region (directed from the n-type to the p-type), electrons are swept towards the n-type region and holes towards the p-type region.

Accumulation of Charge:
The movement of charge carriers results in:
– An excess of positive charge (holes) in the p-type region.

– An excess of negative charge (electrons) in the n-type region.

Voltage Generation:
The accumulation of charges across the p-n junction creates a voltage difference across the terminals.

Flow of Current:
When a load is connected across the terminals, an electric current flows through the external circuit, generating power.

55. What do you understand by energy payback period?

The length of time during which a solar cell generates the same amount of energy that it has consumed during its production is known as Energy payback period.

56. Describe the classification of solar cells based on the type of active material used.

Single Crystalline Silicon Cell
Mult crystalline Silicon Cell
Amorphous Silicon cell
Gallium Arsenide Cell
Organic PV Cell

57. What are direct and indirect gap materials?

In direct band gap materials, the minima of conduction band, EC and the maxima of valance band, EV exist at the same value of electron momentum.

In indirect band gap materials, the conduction band minima do not exist exactly above the maxima of valance band in the energy ‑ momentum diagram.

58. Explain the I-V characteristics of a solar cell and define fill factor. What is the significance of fill factor?

$$I = I_o\left\{\exp\left(\frac{V}{V_T}\right)-1\right\} \tag{6.29}$$

where I_o is reverse saturation current, V_T is known as voltage equivalent of temperature and is given as:

$$V_T = \frac{kT}{q}$$

where, k is Boltzmann's constant (in J/K), T is temperature in Kelvin and q is charge of an electron in coulombs.

Closeness of the characteristics to the rectangular shape is a measure of quality of the cell. Ideal cell would have a perfect rectangular characteristic. Therefore, 'fill factor', FF which indicates the quality of cell, is defined as the ratio of the peak power to the product of open circuit voltage and short circuit current, i.e.,

$$FF = \frac{V_m I_m}{V_{oc} I_{sc}} \tag{6.33}$$

59. What do you understand by energy payback period?

The length of time during which a solar cell generates the same amount of energy that it has consumed during its production is known as Energy payback period.

60. In the context of PV define cell, module, and array?

- **A solar PV cell** is a specially designed photovoltaic (PV) junction diode that generates electricity when exposed to sunlight. It operates at a typical voltage level of 0.5 V to 0.9 V per cell.
- **A solar PV module** is formed by interconnecting an appropriate number of solar cells to obtain a workable voltage and reasonable power output. Typical voltage levels of solar modules are 12 V, 24 V, or 48 V, depending on the application.
- **A solar PV array** is a large assembly of interconnected solar panels designed for large-scale power generation.