Photovoltaics or solar cells, as the name implies, converts light (photo) to electricity (voltaic). It relies on the fact that some materials, such as semiconductors have the ability to emit electrons upon exposure to light. First observed by Becquerel in 1839, it was mostly applied in solids, especially in the 1940s when crystalline silicon became available. Most of the scientific development on the use of solar energy to generate electricity came from space research programs.

How a Traditional (Crystalline Silicon) Solar Cell Works:

Upon exposure to sunlight, some of the photons are reflected, some will pass through, and some will be absorbed. Photons are absorbed in the bottom layer called the n-type where electrons will be excited to jump to the top layer called the p-type and will eventually be able to move to the top contact layer which has a function similar to an electrode. The top contact layer passes the electrons through an outside circuit generating current as it returns to the bottom contact layer.

The two main layers, p- and n-types are made of silicon with impurities intentionally embedded to produce an electrical field.
n-doping: 
Si has four valence electrons and so it can form four single bonds with neighboring atoms. However, if an impurity such as phosphorus (Group 5a) is added, the fifth valence electron is left unbonded. Although unbonded, the positively charged phosphorus nucleus holds it in place. But it does not take much energy for this electron to break free and become a loose electron. It becomes mobile throughout the whole structure looking for a hole (a spot in the structure that is deficient in electrons) to fall into. This introduction of a different atom into the structure is called doping. In the case of the addition of phosphorus, it is specifically called n-doping, producing an n-type layer (negative) into the structure.

p-doping: 
On the other hand, if a Group 3A element is inserted, only three bonds can be formed with silicon. An example is boron which has three valence electrons. As illustrated in the diagram above, because of the deficiency in electron, a "hole" is created, producing the p-type (positive) layer.

Now, when the two layers are put together, there will be a driving force for the "free" electrons in the n-type layer to go to the "holes" in the p-type layer. These "holes" can move freely throughout the structure because neighboring electrons will try to fill it in. An electric field is created in this p-n junction due to the electron-hole pairs. Upon exposure to light, the photons will supply the energy for the electrons in the n-type layer to break free and look for the holes in the p-type layer.

Silicon on its own is a very poor conductor. Doping is needed to make it conduct and have freely moving electrons!

Harnessing solar energy with photovoltaic cells has many advantages. There are no mechanical parts that can eventually wear out, it does not produce pollution during operation, there is very minimal maintenance required, it relies on the almost infinite supply of power coming from the sun, it can be implemented at the residential small scale to large-scale industrial level, and it is stand-alone so it can be easily installed in remote areas. However, the drawbacks are the limited supply of silicon and its cost of manufacturing, intermittent supply (day and night cycles) of energy from the sun, and the solar cells' relatively low efficiency. About 70% of energy from the sun is lost because either the photons do not have enough energy or have excess energy to affect the electron-hole pair. Thus some energy will either be reflected or will just go through.

To reduce the cost of manufacturing, efforts led to the development of thin film technology using amorphous (in contrast to crystalline) silicon and other blends of semiconductors like CdTe (cadmium and tellurium) and CIGS (copper indium gallium selenide). The main advantage of this second generation solar cells is the possibility of making long, continuous rolls that can be incorporated into laminates and roofing.

Printable Solar Cells: 
To avoid using these rare metals, another promising technology is the use of organic/plastic material or what is called organic photovoltaics or OPV. An organic polymer is used instead of a semiconductor in this third generation type of solar cells. An interpenetrated (mixed) network of electron-donor and electron-acceptor organic molecules serve as the substitute to the function of semiconductors used in the first and
second generation solar cells. The most studied electron donor molecules are P3HT and PCPDTBT with fullerene as electron-acceptor. It can be seen from their molecular structures shown below that the alternating single and double bonds allows for electron affinity and mobility. In addition, the networked configuration (also called bulk-heterojunction) allows for more contact area between the donor and acceptor molecules leading to higher efficiency.

The low cost and ease of manufacture offers OPVs or plastic solar cells many advantages. These are processed from solutions and no high temperature is required. This results in flexibility, because being liquid means they can be printed or coated into another base material made of either plastic or foil similar to the production of newspaper. This roll-to-roll fabrication leads to what is called printable solar cells made of lightweight materials.

So far, most of the organic polymers are synthesized in the lab. A compound called ruthenium polypyridyl complex has emerged as the polymer that yields the highest efficiency. Ruthenium is one of the rarest metals and its compounds may be toxic and carcinogenic. As such, scientists are now looking at natural molecules that will serve the same purpose.

Questions
1. In chemistry, impurities are often perceived as undesirable and methods are developed and utilized to obtain pure materials. In contrast, adding an impurity to silicon, called doping, makes it a better material. Explain.

2. Titanium oxide TiO$_2$ is a common ingredient in some household products. Give at least two examples. Do you think it would be possible to use these as coating for the solar cell?

3. Propose at least two ways on how to increase the voltage or electrical power of your dye-sensitized solar cell.

4. What do you think are the factors that can affect the long-term stability of dye-sensitized solar cells?

5. Compare the advantages and disadvantages of the three major types of solar cells: silicon-based, thin film organic photovoltaics (POVs) and dye-sensitized solar cells (DSC)?