HOW A SOLAR (PHOTOVOLTAIC) CELL CONVERTS SOLAR ENERGY TO ELECTRICITY

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Most solar cells (photo-voltaic cells, or just pv-cells) are made of crystalline silicon. Silicon occurs naturally as silicates in many rock-forming minerals and in ordinary beach sand. However the silicon needed to make a pv-cell must be very pure and perfectly crystalline.

The silicon atom has four electrons in its outer, valence shell. In a crystal, all four of these electrons are used in forming co-valent bonds to neighbouring atoms. Most metal atoms, on the other hand, have only one or two outer electrons, and in the solid state these electrons are relatively free from their parent atoms, and can move through the crystal, as “conduction electrons”. Metals can therefore conduct electricity quite easily, while silicon is normally an insulator.

The interaction of light can, however, release some of silicon’s the bond-forming valence electrons, giving them enough energy to become conduction electrons: this is why silicon is sometimes called a semiconductor.

We have already seen that light travels as a wave – an electromagnetic wave. However, when it interacts with matter, its energy can be transferred only in fixed discrete amounts. These packages (or quanta) of electromagnetic energy are called photons. The amount of energy in a photon depends on the wavelength of the electromagnetic wave: the longer the wavelength the smaller the amount of energy in a photon. For example a photon of violet light (wavelength 400nm) has nearly twice the energy of a photon of red (700nm) light.

The solar spectrum, showing the portion where photons have sufficient energy to release conduction electrons in a silicon crystal.
The energy needed to release one conduction electron in a silicon crystal corresponds to the photon energy of electromagnetic waves with a wavelength of 1120 nm (1.12 microns), in the infra-red quite close to visible light. About 70% of the solar radiation is at wavelengths shorter than this, and so has photon energies sufficient to release conduction electrons in silicon. Each photon can release only one electron however, so if a photon has more than the required energy – and most do – then the excess must be wasted – transformed to heat (energy) in the crystal. This means that for a photon of say blue light, that has about twice the required energy, only half of its energy can be harnessed usefully. So, you might argue that solar→electric (or photo→voltaic) energy conversion is not very efficient – for this type of solar cell the theoretical maximum efficiency is about 25-30%. On the other hand, maybe this is not too important, since the “fuel” is free, and the environmental impact is minimal.

Now, releasing conduction electrons in the silicon crystal is only half the story – once produced, they must be made to flow as an electric current in a circuit: through appliances, to charge batteries, or to be fed into the electricity grid. This means creating a force on the newly released electrons to make them move through the crystal. This is achieved by cleverly altering the silicon ever so slightly, then sticking together layers of slightly different silicon to make what is called a p-n junction. The electrons are then attracted across the junction from the p side to the n side.

The crystal on the n side has a few atoms (about 1 per million) replaced with atoms having five electrons in the valence shell (e.g. phosphorus, arsenic or antimony). There are therefore more electrons than are needed for the co-valent bonding. On the p side the silicon is similarly “doped” with trivalent atoms e.g. aluminium or boron, so the bonding structure has electron “vacancies”. In the region of the p-n junction, some of the electrons drift naturally from the n side to fill vacancies on the p side. Since both the p and n materials started off electrically neutral, once this drift has occurred, the p material has excess negative charge (or potential), while the n material is left with a deficit of electrons, or net positive charge (potential). In other words, there is an electric potential difference and electric field across the p-n junction. When conduction electrons are released in the region of the junction, they find themselves in this field, and are repelled away from the negative charge/potential of the p silicon, towards the positive potential of the n silicon. If the solar cell is connected to an external circuit, then a current will flow in the circuit (remember that conventional current flows in the opposite direction from the electrons).
A typical pv-cell is about 5 cm in diameter, 1 mm thick, and has a potential difference of about 0.5 volt between its terminals. The maximum current is determined by the rate at which photons release conduction electrons. Usually 40 or 50 pv-cells are series connected to make a module with a total voltage of 20–25 volts. To increase the output current it is common to connect several such modules in parallel. The output is direct current (dc). The direct current is often used in small applications e.g. domestic solar systems. If alternating current (ac) is required e.g. to feed into the grid, an inverter must be added to the circuitry.

A domestic solar energy installation. Six modules are connected in parallel. Each module consists of about 40 photo-voltaic cells connected in series. The system charges batteries directly, and the house has a 12 volt dc network.