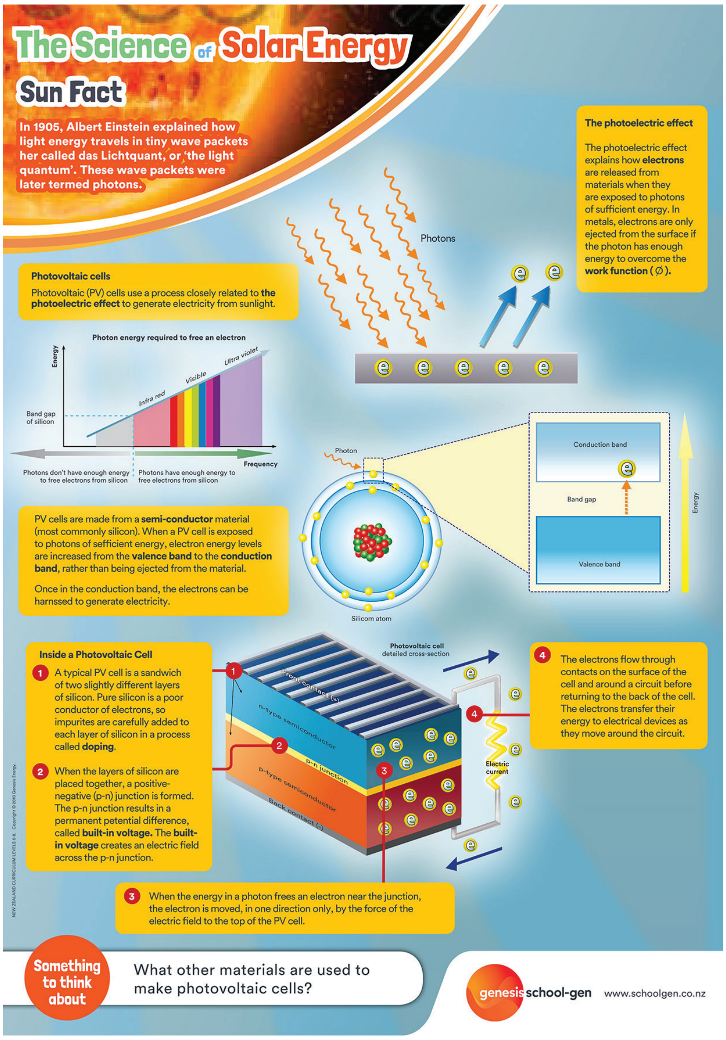
Schoolgen Poster 4 Teacher Guide

The Science of Solar Energy: Levels 6-8



About this Poster

This poster explains the science behind the technology of photovoltaic cells and how they transform the free energy of sunlight into renewable electricity.

The poster links science concepts (physical and material world strands) learnt in curriculum levels 4-5, particularly energy transformation, visible/invisible light spectrum, structure of the atom and simple electrical circuits to those at curriculum levels 6-8 in a senior science course (frequency and the electromagnetic spectrum, photons and the photoelectric effect, electronic components etc).

The poster also blends significant extension material linked to semiconductor/electronic technologies as a bridge to tertiary level physics, materials science and engineering courses.

Poster Discussion Questions

- How did Albert Einstein arrive at the idea of light as being composed of quantum packets of energy? (Nature of Science Strand)
- What does "quantum" mean and how did this radical idea change the course of physics? (Nature of Science Strand)
- What physical processes of the sun lead to the generation and radiation of solar energy?
- What is the essential difference between the photoelectric effect (as it is used in the strict historical sense) and the photovoltaic effect?
- How much energy is required to make PV modules compared to what they generate in their lifetime? Is it worth it?
- How are PV cells similar to electronic components such as diodes, LEDs, transistors?

Related Activity Links

- School-gen Solar Schools data
- <Photovoltaic technology factsheet>

Key Words & Glossary

Electron, conduction band, valence band, band-gap, photon, photoelectric, photovoltaic, frequency, quantum, energy, metal, work function, silicon, semiconductor, doping, p-n junction, built-in-voltage, electric field, force.

[Put into Table (Column 1 key words, column 2 definitions)]

Band-gap –
The energy gap between the valence and conduction bands. An electron must gain enough energy to jump across this gap and cannot exist within it.

Built-in Voltage –
A voltage that is formed across the p-n junction due to the electric field between fixed positive and negative charges on either side of the p-n junction left after mobile charges have diffused. Voltage = Electric Field x distance

Conduction band –
The range of energy levels which an electron can exist in above the valence band, separated by a band-gap. Electrons within this energy range are free to move away from their parent atoms and are able to transport energy through the material.

Diode –
An electronic component formed by a p-type and an n-type semi-conductor placed in contact with each other to form a junction. The electric field created at the junction only allows negative or positive charges to flow in one direction. LEDs and photovoltaic cells are types of diode.

Doping –
Doping is the process of adding small amounts of other elements into the crystal lattice of a pure element or compound to radically alter its electrical properties. Silicon, a Group IV element, is doped with Group III elements such as boron to form p-type silicon (see entry). When doped with Group V elements such as phosphorous, n-type silicon (see entry) is formed.

Electric Field –
The electric field is due to the built-in voltage (see entry for details). The electric field acts on free electrons that are released by photons, forcing them to move in one direction only (towards the top layer). Force = electron charge x electric field strength.

Electron –
Sub-atomic particle of negative charge that surrounds the positively charged nucleus of an atom. Electrons can be bound to their parent atom in electron shells, involved with bonding to neighbouring atoms or they can become free and mobile if they gain enough energy to escape the electrostatic attraction of the nucleus.

Energy –
Necessary for things to change, or events to happen. Energy can exist purely by itself as light, or it can be a varying property of matter (kinetic and potential energy). Energy always obeys the Conservation of Energy Law. A quantity measured in Joules.

Frequency –
the number of times a pattern or process is completely repeated in one second. The frequency of a wave is the number of times its crest or trough is repeated in one second. Units are Hertz (Hz), or per second (s-1). Frequency (f) is related to wavelength (   ) and wave velocity (v) by the wave equation v = f

Metal –
Substances that conduct electricity and heat well due to the abundance of free electrons which act as energy carriers. Metals have no band-gap so the electrons can move easily from the valence into the conduction band.

N-type silicon –
N (negative) type silicon has extra valence electrons due to doping with phosphorous (Group V element, 5 valence electrons) in the crystal lattice. Phosphorous has one more valence electron than that offered by adjacent silicon atoms. The overall charge of n-type silicon is zero/neutral due to equal amounts of protons (+) and electrons (-), but the negative charges (electrons) are mobile.

P-type silicon –
P (positive) type silicon has fewer valence electrons due to doping with aluminium atoms (Group III element, 3 valence electrons). Al only forms bonds with 3 of the 4 offered by the adjacent Si atoms. The overall charge of p-type silicon is zero/neutral due to equal amounts of protons (+) and electrons (-), but the positive charges are mobile.

p-n junction –
A positive-negative junction formed by the joining together of p-type and n-type semi-conductors (see entries). This can be thought of as a sandwich with the top and bottom layers being relatively conductive, and the filling being relatively insulating. The filling contains an electric field that only allows electrons to flow up the field-lines. This forms a one way gate for electrons (diode).

Photoelectric –
The tendency for materials to release electrons from their surface when they absorb incident photons. The absorbed photon must have enough energy to overcome the electrostatic binding of the electron to its parent atoms nucleus, or it will not be released.

Photon –
The smallest unit of light and other forms of radiant energy. The photon is indivisible and can be viewed as either a particle or a discrete wave. The energy of a photon increases with increasing frequency, and decreases with increasing wavelength. The energy (E) of a photon is equal to the frequency (f) multiplied by Planck's Constant (h).

Photovoltaic –
The tendency for materials to become electrically charged, thus generating voltage, when exposed to incident photons of sufficient energy. The photovoltaic effect is closely related to the photoelectric effect.

Quantum –
The smallest unit of energy or matter. A quantum entity cannot be divided into any smaller parts and has properties of both particle and wave.

Semiconductor –
A semiconductor material has electrical conductivity intermediate between an insulator and a conductor. A semiconductor has band-gap energy less than 4 electron Volts.

Silicon –
Element found abundantly in silicate compounds in the Earth's crust. Silicon is a poor conductor in its pure form but its electrical properties can be modified by the careful addition (doping) of small quantities of other elements such as aluminium and phosphorous. Sandwiches of doped silicon are the basis of most electronics including photovoltaic cells.

Valence band –
The range of energy levels which an electron can exist in below the conduction band, separated by a band-gap. Electrons within this energy range are bound to their parent atoms by electrostatic forces and

can take part in bonding with neighbouring atoms.

Work Function –
The minimum amount of energy required by a particular substance (metal or non-metal) to free an electron from its surface. The energy to free the electron may be gained through the absorption of a photon possessing sufficient energy.

New Zealand Curriculum & Assessment Links

Level 8 Science (Physical World)	**Physical inquiry and physics concepts:**	Investigate physical phenomena (in the areas of … electricity, light and waves, and atomic physics)
	Using Physics	Use physics ideas to explain a technological … application of physics and discuss related issues
NCEA Level 3: Physics	3.2 Demonstrate understanding of the application of physics to a selected context (photovoltaic cells).	
	3.3 Demonstrate understanding of wave systems (frequency and the wave equation).	
	3.5 Demonstrate understanding of nuclear and quantum physics (photoelectric effect, Planck's Law).	
	3.6 Demonstrate understanding of electrical systems (voltage-current relationships).	
Level 7 Science (Physical World)	**Physical inquiry and physics concepts**	investigate physical phenomena (in the areas of … electricity, electromagnetism, light and waves)
	Using Physics	Use physics ideas to explain a technological … application of physics
NCEA Level 2: Physics	2.2 Demonstrate understanding of physics relevant to a selected context (photovoltaic cells).	
	2.3 Demonstrate understanding of waves (electromagnetic spectrum, wave equation).	
	2.6 Demonstrate understanding of electricity & electromagnetism (diode voltage-current relationships).	
Level 6 Science (Physical World)	**Physical inquiry and physics concepts**	Investigate trends and relationships in physical phenomena (in the areas of … electricity, electromagnetism, light and waves)
	Using Physics	investigate how physics knowledge is used in a technological application
NCEA Level 1: Physics	1.2 Demonstrate understanding of the physics of an application (photovoltaic cells).	
	1.3 Demonstrate understanding of aspects of electricity & electromagnetism (Ohm's Law, series circuits, Power).	
	1.4 Demonstrate understanding of aspects of wave behaviour (electromagnetic spectrum, wave equation).	
Principles	Coherence (makes links, provides for coherent transitions, opens up pathways to further learning). Future Focus (exploring future focused issues such as sustainability)	