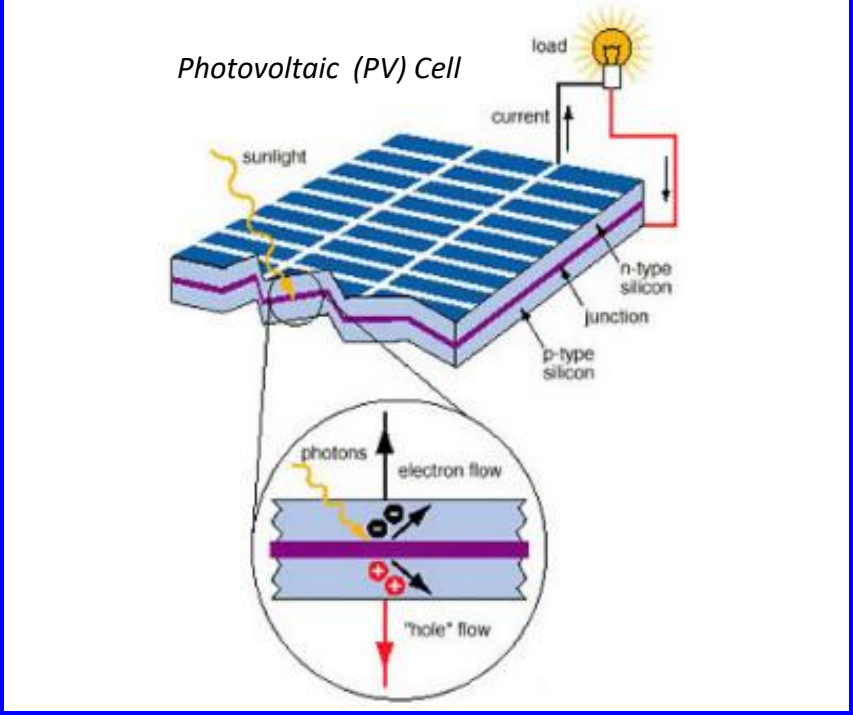
Solar Energy and Solar Cells

Introduction to Engineering - E10
San Jose State University

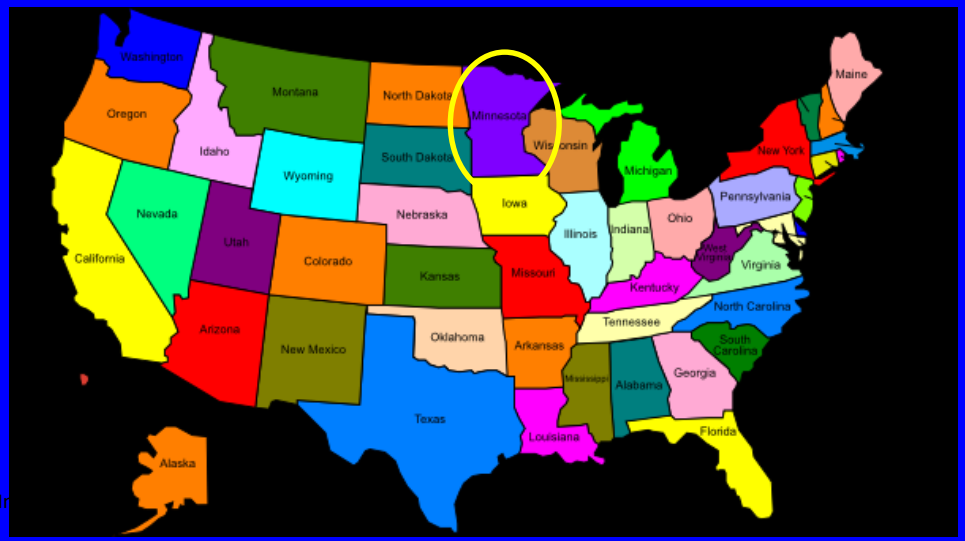
How does it work?



A **photovoltaic cell** (PV **cell**) is a semiconductor that converts visible light (sun energy) into a flow of electrons producing electricity, direct current (DC)

Average power from the sun striking the Earth's surface, assuming 10% efficiency = **17 W/m²**

Considering the total US electricity consumption, we would need a land area about the size of Minnesota (87,000 mile²). This is roughly about 30 times of the available roof space. So we need Solar fields (farms)



Solar Power

Single cell

Photovoltaic (PV) Cell

Single panel

Solar field

Product Features

- **Power** (Pmax) : 25**W**
- Maximum power voltage (Vpm) : **18 V**
- Maximum Power Current: **1.39 A**
- Cost: **$38**

Provide usable power when needed, ideal for powering your RVs, ATV, marine boats and electronic equipment.

An **iPhone charger** delivers 5 Watts (5 volts at 1000 mA)

- Lightweight and water-resistant.
- Overcharge protection.
- Compatible with any USB Device
- Power 5W, $25

Nellis Airforce Base, in southern Nevada

- Built in April 2007 by SunPower Corporation in San Jose
- Cost $100 million

Capacity: 14 MW or 30 GWh/yr

- 72,000 solar panels on 140 acres land
- Supplies 30% of power requirement by the Base with 12,000 workers and 7,215 residents.

Largest Solar Farm in the US

Solar Star

The 579 MW Solar Star power plant was completed in 2015. Located in Rosamond, California, this solar power plant uses 1.7 million solar panels made by SunPower and spreads over 13 square km (3,200 acres). It will deliver enough electricity to power the equivalent of approximately 255,000 homes. Tracks the sun, 25% more efficient

Topaz Solar Farm in San Luis Obispo County in California, went on line in Nov. 2014. Produces 550 MW of power using 9 million panels, enough to provide power for 160,000 homes.

Ken Youssefi Introduction to Engineering – E10

Desert Sunlight Solar Farm in Riverside County in California, went on line in Jan. 2015. Produces 550 MW of power , enough to provide power for 160,000 homes.

World largest Solar Field

Tengger Desert Solar Park – capacity 1500 MW – China

The MW solar power was installed in Zhongwei, Ningxia is the world's largest solar array by far. Know as the "Great Wall of Solar" in China, June 2017. It covers 27 km^2 (10 square miles). Could roughly provide electricity for half of the households in San Jose.

Kurnool Ultra Mega Solar Park – 1000 MW – India

It was operational by May 2017, generating 1000 MW. 5000 acers of land. It has 4 million solar panels (315 Watt/panel)

World largest Solar Field

Datong – capacity 1000 MW – China

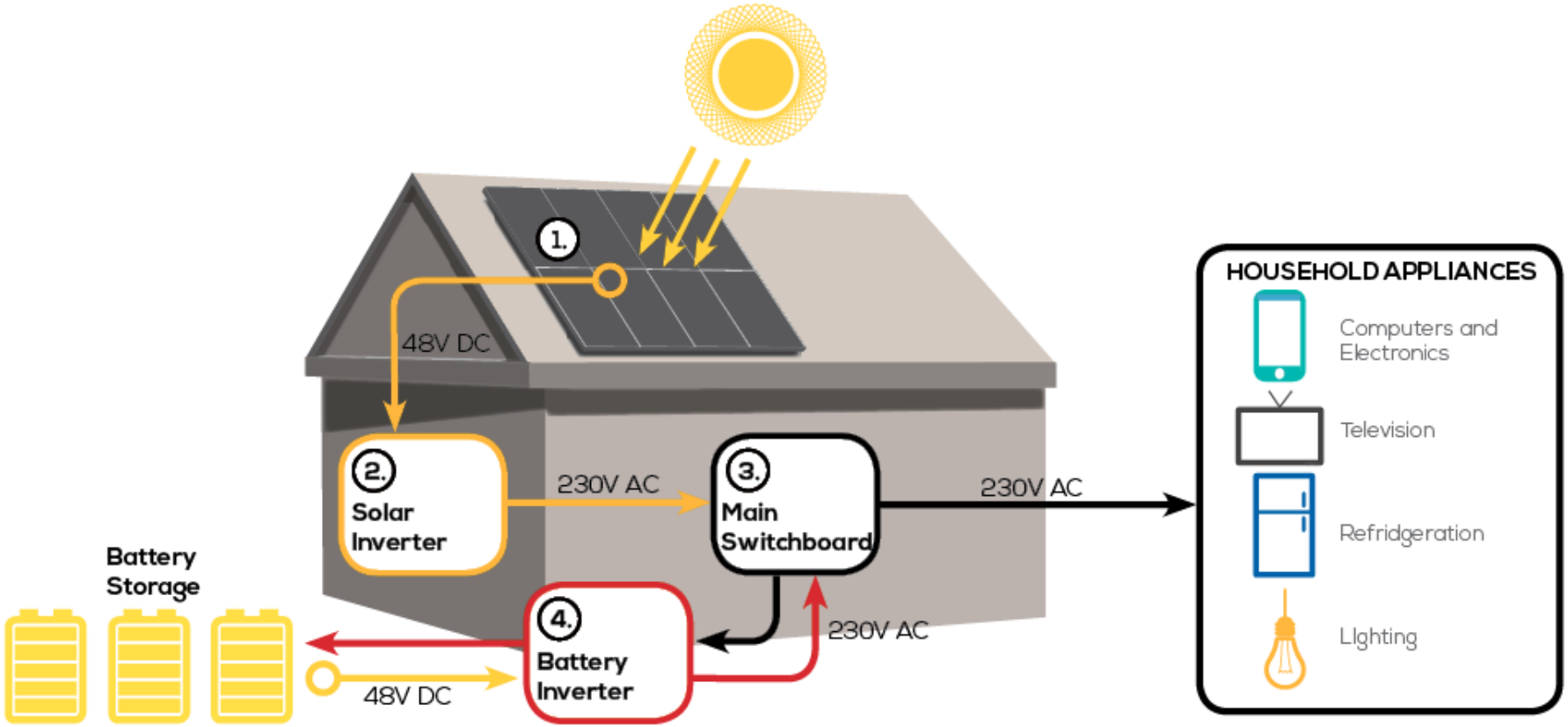
Longyangxia – capacity 850 MW – China

It went online in Feb 2017. It has 4 million solar panels, 10 square miles.

Solar Electricity for Homes

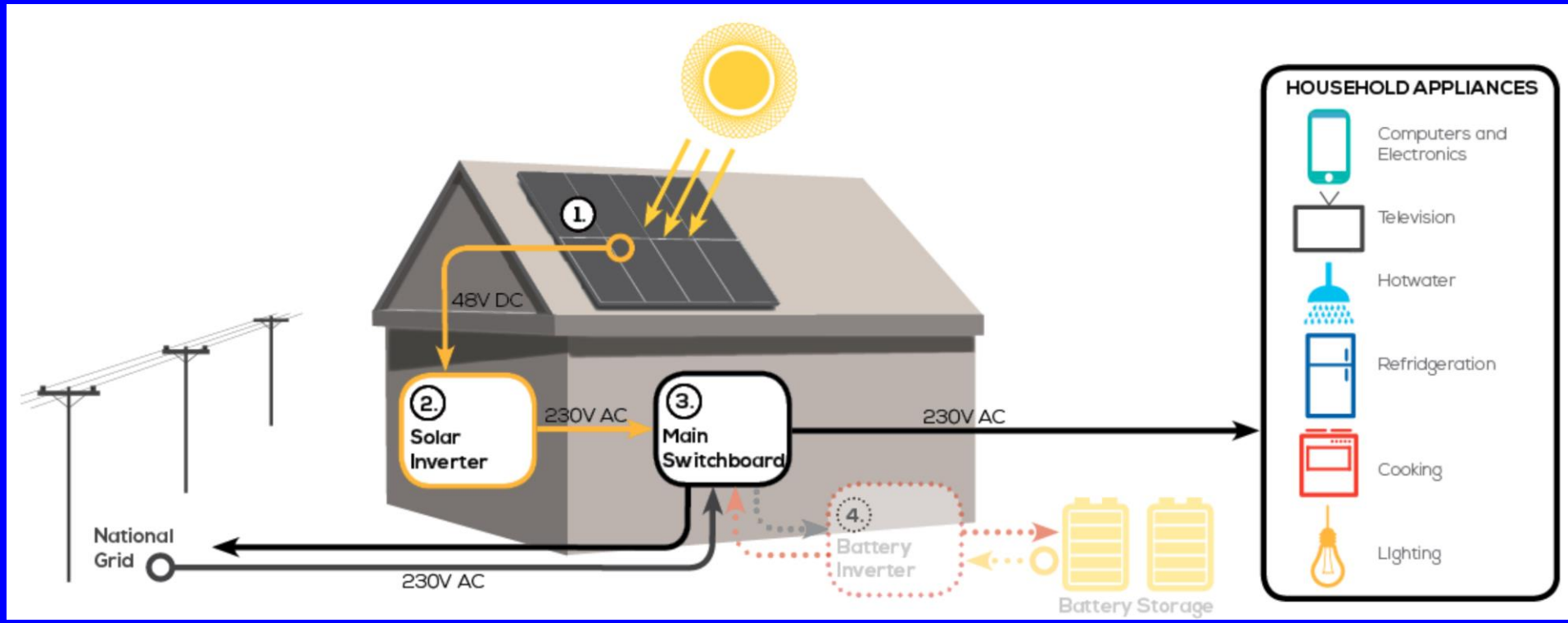
While the science of converting sunshine into electricity is complex, the idea is pretty simple. Solar electricity is generated by a group of solar modules called an array that's installed on your roof or in your yard. When sunlight falls on the solar modules, a DC electrical current is created instantly. The DC electricity is fed into an inverter that changes it to standard AC electricity - the same kind your home already uses.

Off the grid layout with batteries



1. Solar PV panels mounted on your roof or near your house capture energy from the sun and convert this energy into DC electricity
2. A Solar Inverter converts this DC electricity into 230V AC electricity.
3. The main switchboard takes electricity from the solar inverter or battery inverter and sends it to power your home.
4. The battery inverter is two way and can take surplus electricity from the main switchboard and convert in into DC electricity to be stored in batteries or demand is their convert stored DC electricity from the batteries into AC electricity to power your house.

Grid and batteries combination



San Jose is ranked 3rd per capita in total installed Solar PV capacity, April 2019

Population: Honolulu (1st), .4 million, San Diego (2nd), 1.41 million, San Jose, 1.02 million

Solar Energy

- **Every <u>hour</u>**, enough sunlight energy reaches Earth to meet the world's energy demand for a **<u>whole year</u>.**

- The amount of energy from the Sun that reaches Earth annually is **$4x10^{18}$** Joules.

- The amount of energy consumed annually by the world's population is about **$3\ x10^{14}$** J.

A major drawback of most renewable energy sources is the ***high cost***. To spur a huge rise in use, prices must come down and ***efficiencies*** must go up (better technology)

Typical efficiencies for commercial applications: 15% - 20%

Panasonic company has the most efficient, 25.6%

Factors Affecting Efficiency

- Sunlight consists of a spectrum of wavelengths – semiconductor materials cannot respond to the full spectrum
- Impurities can cause the charge to "recombine" and therefore not generate electricity
- As much as 30% of light is reflected from the surface of the cell (only absorbed light can produce electricity)
- Efficiency goes down as the cell gets hotter

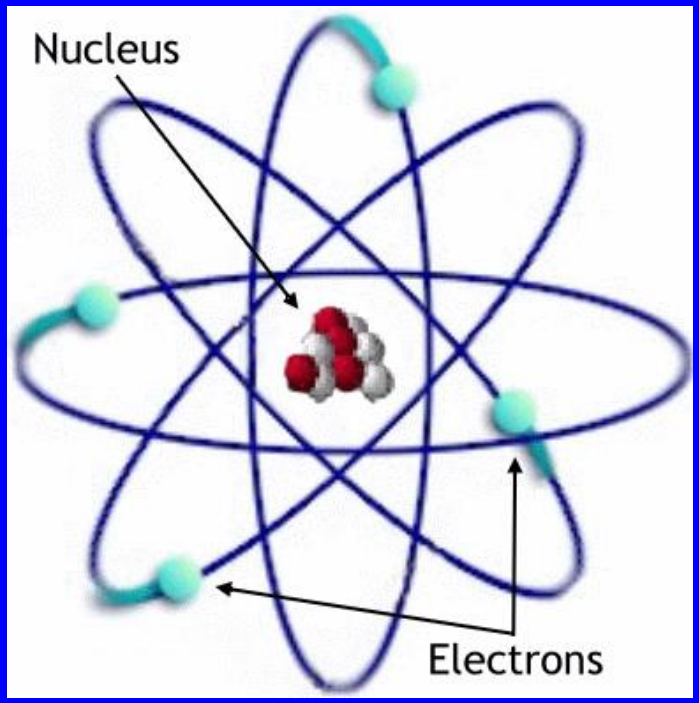
Other Factors Affecting Efficiency

- Angle of incidence of the sun
- Cloud cover
- Shading (even a small amount of shading reduces output dramatically)
- Dirt, snow, or other impurities on cell surface

Atoms

An atom is composed of 3 particles:

Protons - carrying positive charge
Neutrons - charge neutral
Electrons - carrying negative charge



- Nucleus consists of Protons and neutrons, and electrons orbit around the nucleus
- The number of protons and electrons are the same, therefore an atom, as a whole, is electrical charge neutral.
- Different materials have different number of particles in their atoms.

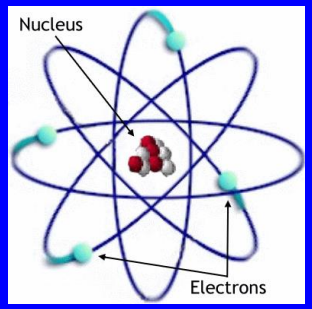
Atoms

- Every atom has a certain number of electrons, protons and neutrons.
- If the atom has the same number of electrons and protons it is balanced and stable.
- Positively charged atom has more protons and negatively charged atom has more electrons; a "charged" atom is called an "ion“.

For example, ***Carbon*** *has 6 electrons and 6 protons. It is found in abundance in the sun, stars, comets, atmospheres of most planets, and the food we eat. Coal is made of carbon; so are diamonds.*

Electricity is created when electrons can be made to move from one atom to another.

Conductors & Insulators



Insulators

Insulators are materials that ***hold their electrons very tightly*** (high bonding force). Electrons do not move through them very well.

Rubber, plastic, cloth and glass are good insulators and have very high resistance.

Conductors & Insulators

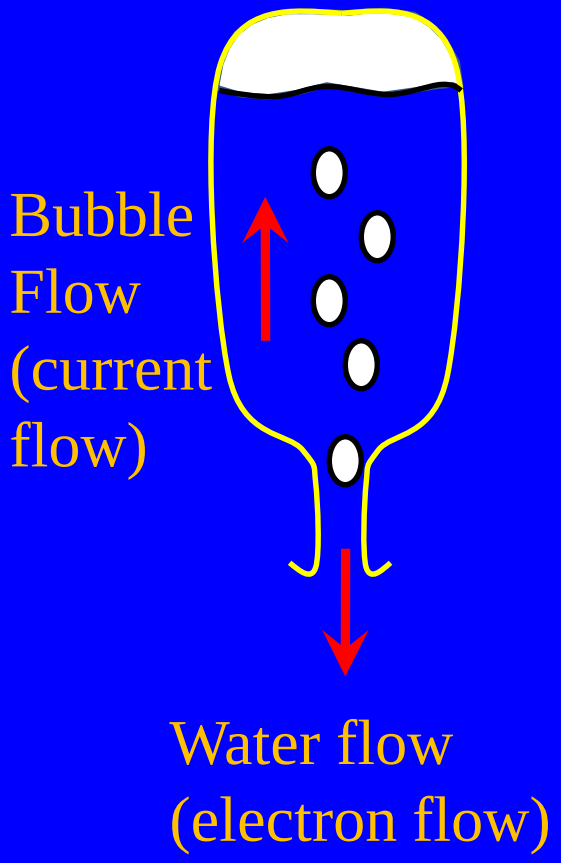
Conductors

Other materials have some ***loosely held electrons***, which move through them very easily. These are called ***conductors***.

Most metals – like copper, aluminum or steel – are good conductors.

Electric Current

- Electric current is the flow of positive charge. 1 Amp = 1 Coulomb per second.
- Electric current is an effect of the flow of free electrons which carries negative charge. (6.28 x 10^{18} electrons = -1 Coulomb).
- Positive charge flow (current) and negative charge flow (electron flow) are the same in magnitude but in the opposite direction.
- By convention, current flow is used in analyzing circuits. Electron flow is used ONLY for describing the physical behavior of electric conduction of materials.



Clicker Question 1

What type of electric charge does an atom carry?

(a) Positive charge
(b) Negative charge
(c) Neutral
(d) Radiation charge
(e) Magnetic charge

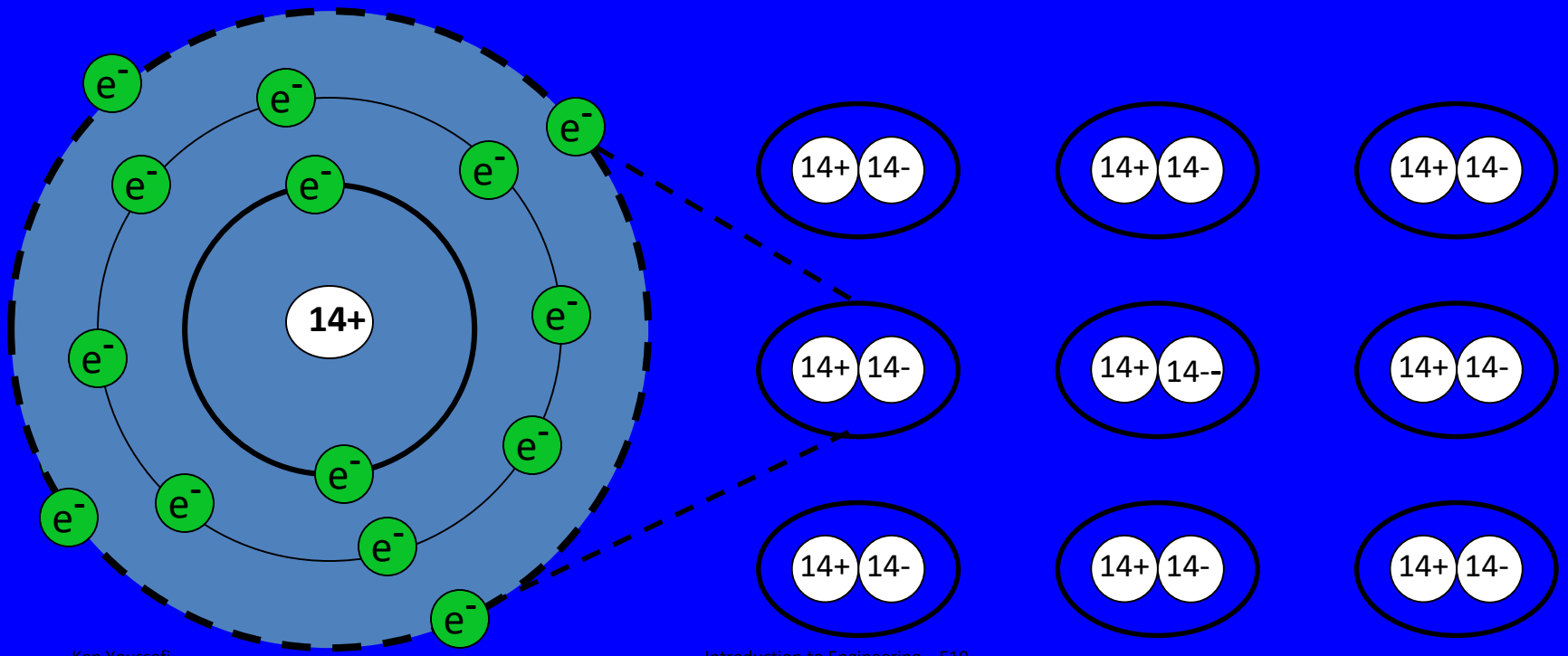
Clicker Question 2

What type of electric charge does the nucleus of an atom carry?

(a) Positive charge
(b) Negative charge
(c) Neutral
(d) Radiation
(e) Magnetic

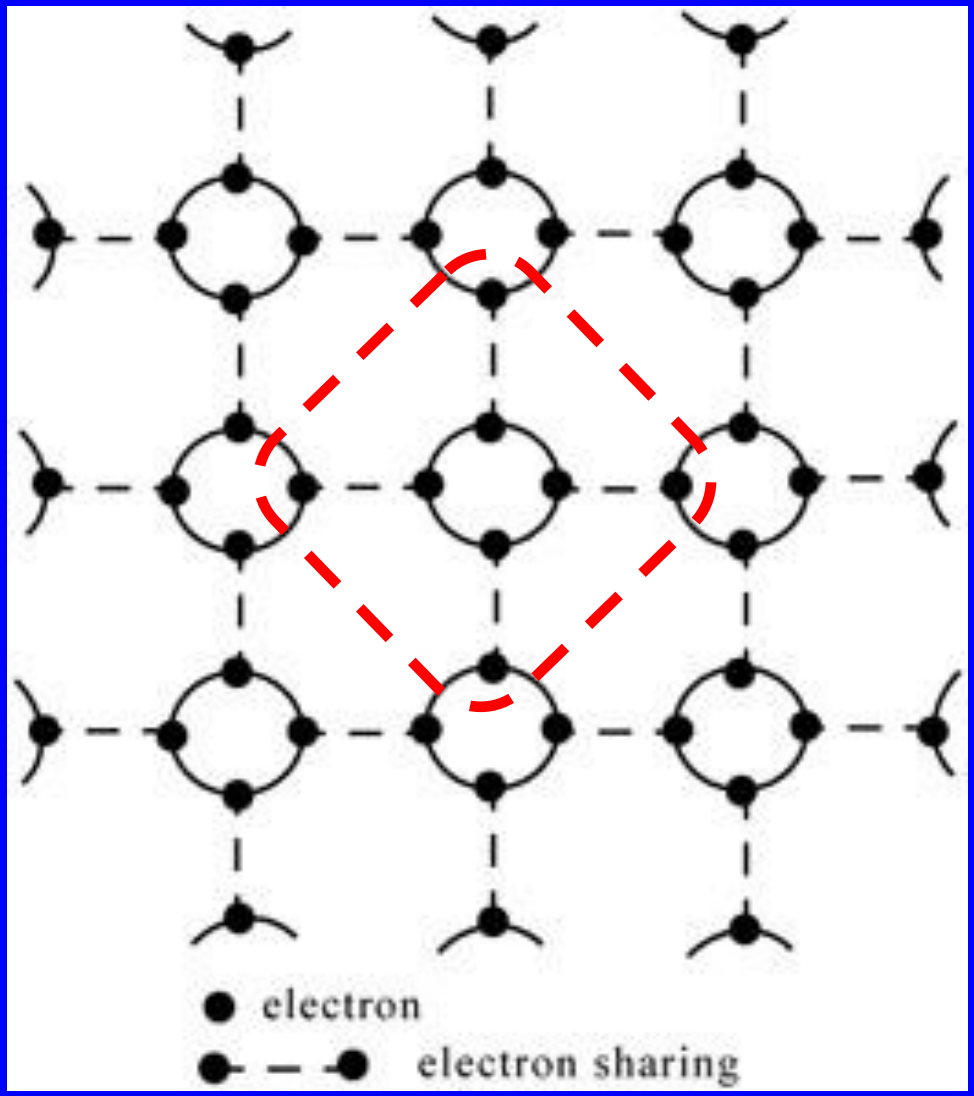
Silicon atom has 14 electrons and 14 protons.

The outer 4 electrons, together with the 4 from their adjacent atoms, form "**octets**" which is a stable structure. Electrons don't "wander off" (i.e., free) from this structure.

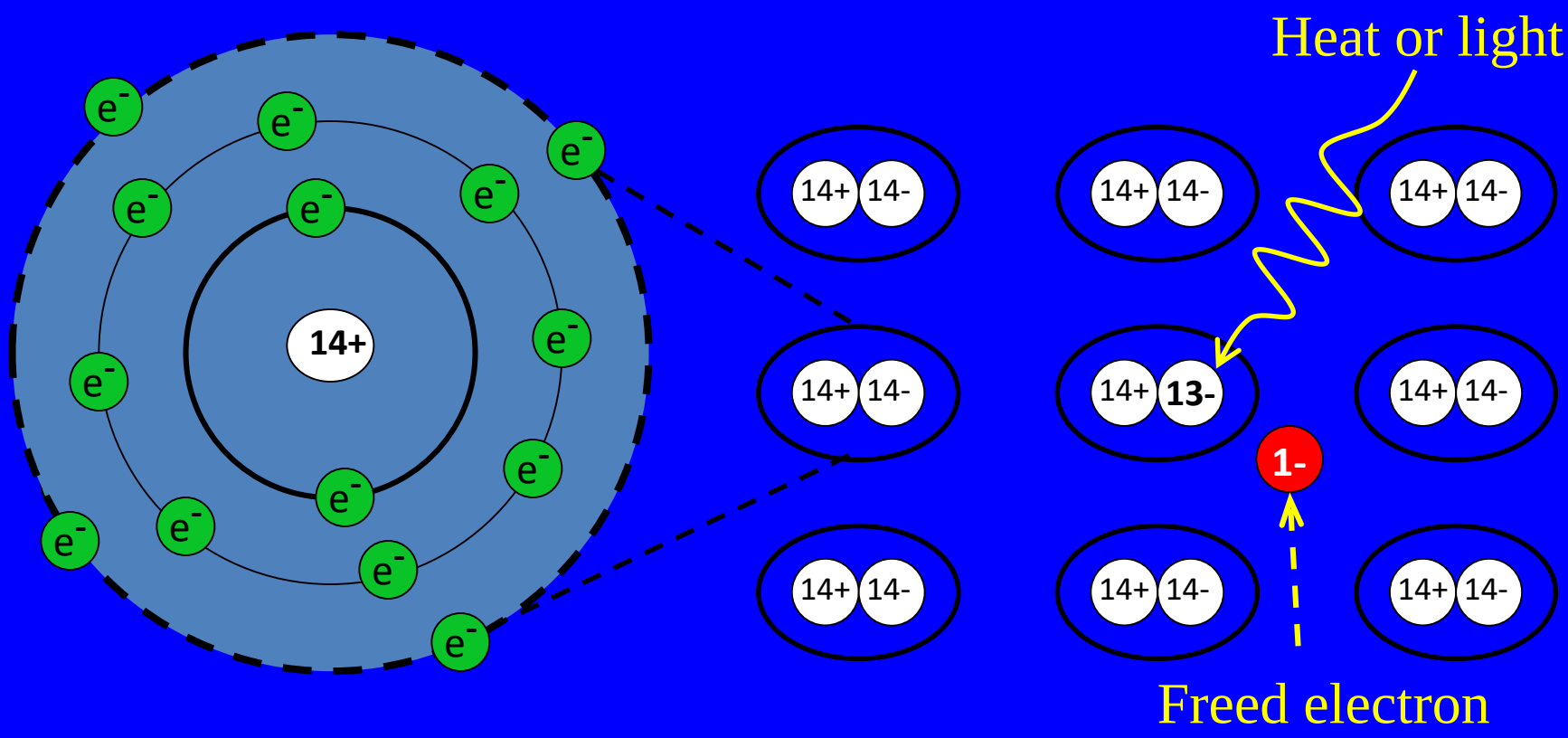


Octet structure

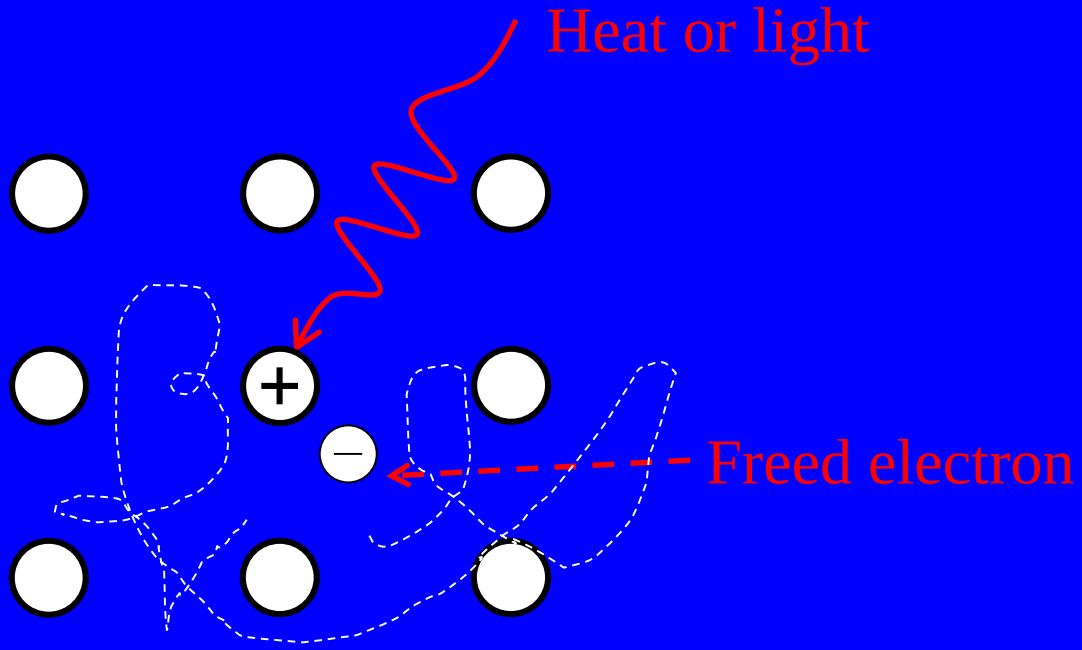
(Only outer orbit electrons are shown)



Sunlight strikes a piece of Silicon, the solar energy knocks and frees electrons from their atom structure (the octets structure)



For simplicity, we only show the charge of free electrons (-1) and the corresponding positive charges (14-13= +1) at the nucleus.

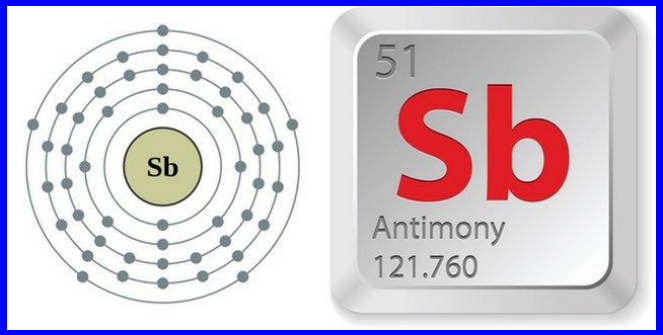


The freed electrons randomly move within the material. This random motion of charge cannot be utilized for power generation. In order to utilize the energy from the sun, this flow of charges must be directed in one direction.

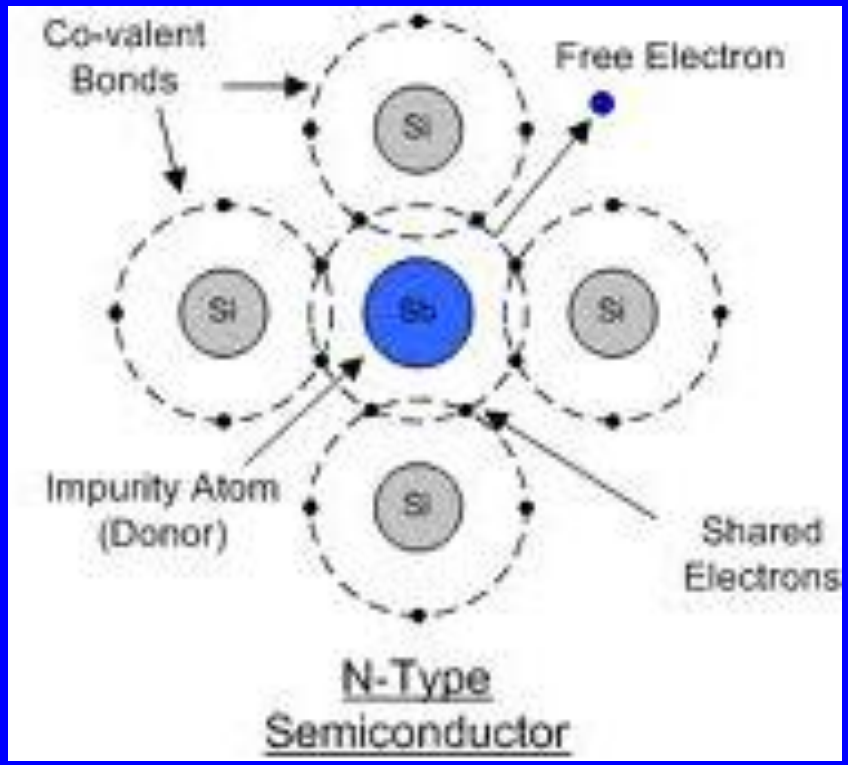
N-type (Negative Type) Semiconductor

A small amount of impurity (doping) such as Phosphorus, arsenic, or antimony is mixed into a Silicon base.

These loosely bonded electron helps with conducting current. The conductivity is not nearly as good as a true conductor. That's why it is called a "semiconductor".



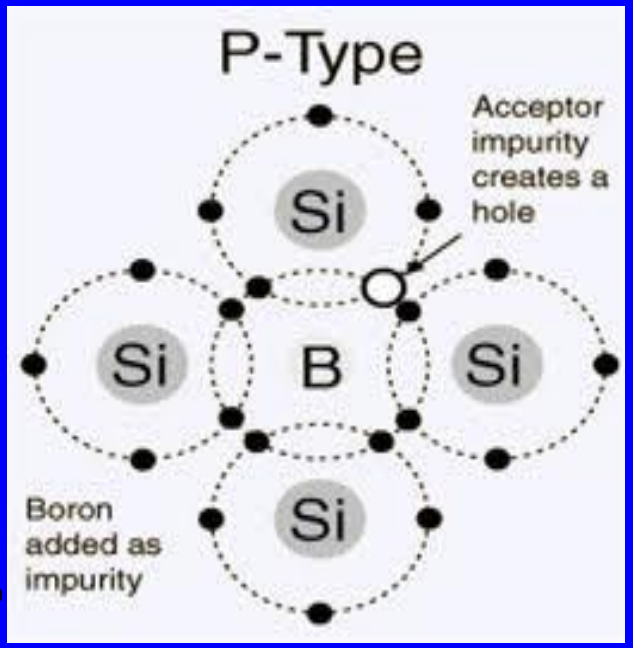
Antimony has 5 outer orbit electrons. Therefore, when bonded with Silicon, there is <u>one electron extra</u> to form the stable octet configuration.

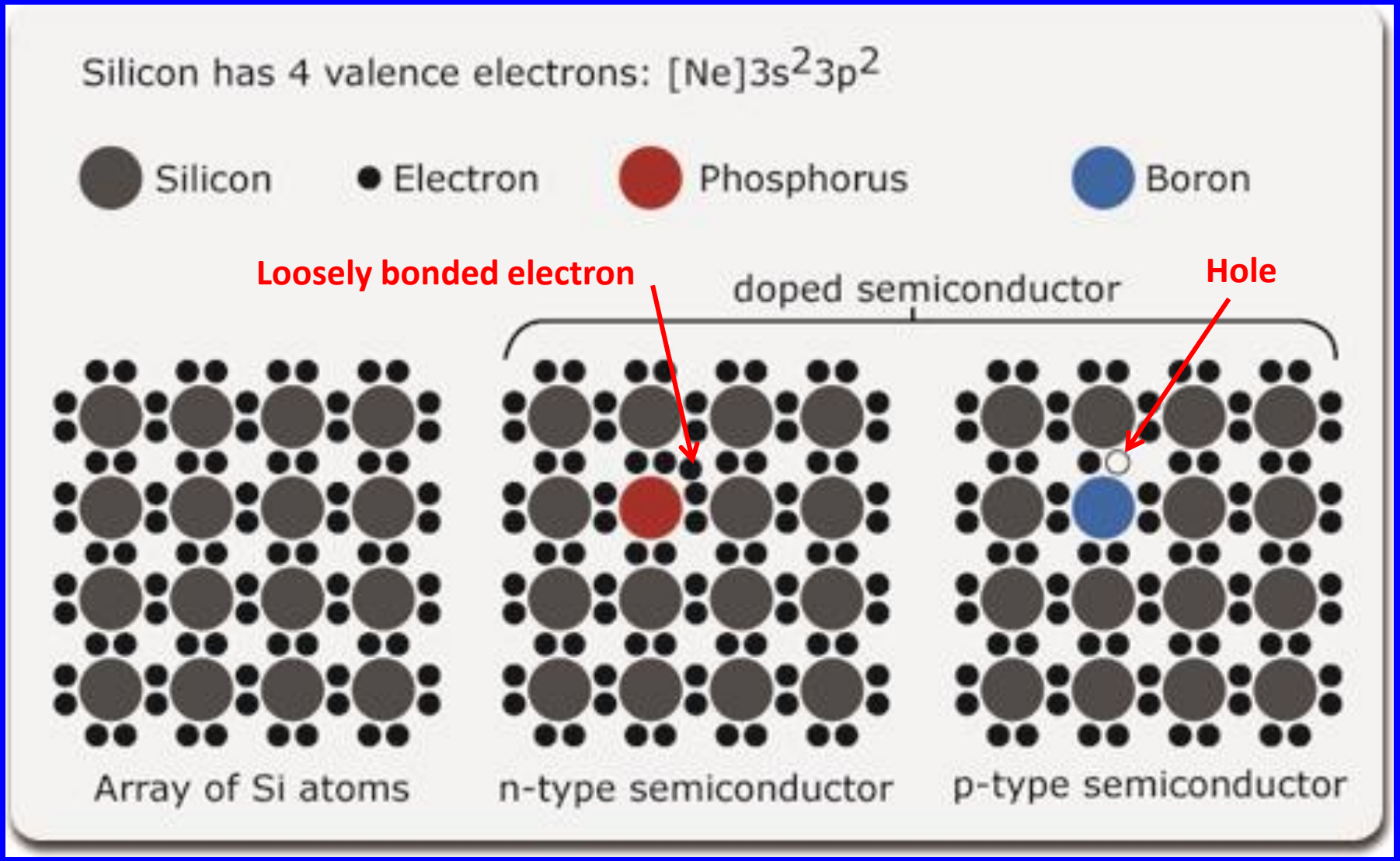


P-type (Positive Type) Semiconductor

A small amount of impurity such as boron, aluminum or gallium is mixed into a Silicon base. Boron has 3 outer orbit electrons. Therefore, when bonded with Silicon, it is one electron **short** to form the stable octet configuration. This type materials can, on the other hand, easily accept one electron.

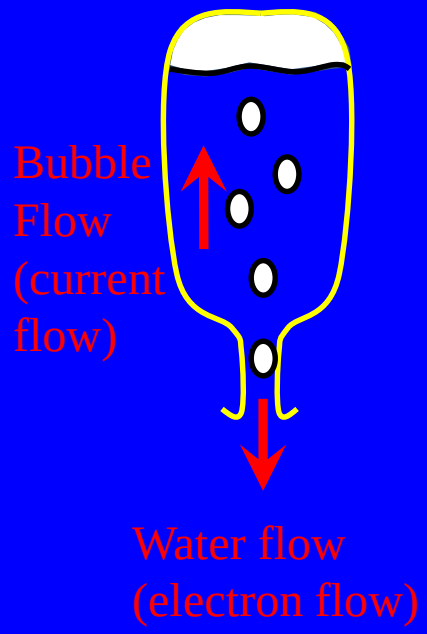
For simplicity, this characteristic of 'easily accepting electron' is represented by a "**hole**" with a positive charge and a corresponding negative charge at the nucleus.




Silicon has 4 valence electrons: [Ne]3s2 3p2
Silicon
Electron
Phosphorus
Boron
Loosely bonded electron
doped semiconductor
Hole
Array of Si atoms
n-type semiconductor
p-type semiconductor

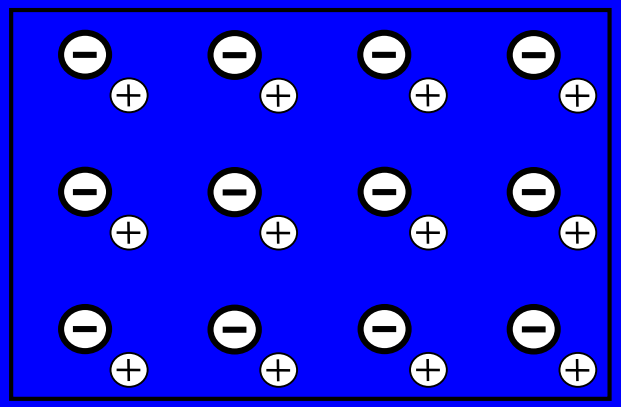
- **N-type materials** conduct electric current (supports movement of charge) by the free electrons ----- just like metal but with fewer free electrons than that in metal.

- **P-type materials** conduct electric current (supports movement of charge) by electric "holes". When electrons jump from hole to hole in one direction, the holes appear moving in the opposition direction. Similar to the situation when you turn a filled water bottle upside down; as the water moves downward (electrons), the bubbles (holes) moves up.

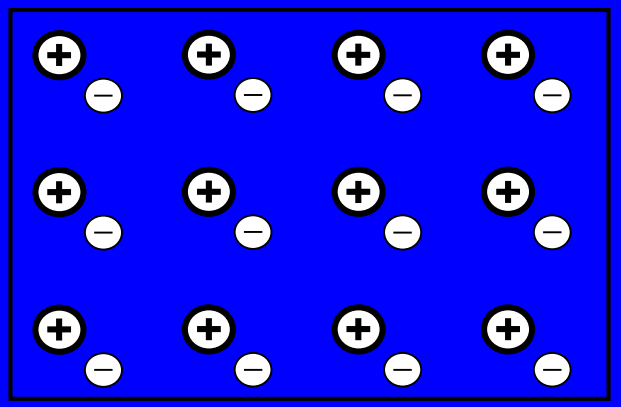


Interesting things happen when you put an N-type material in contact with a P-type material.

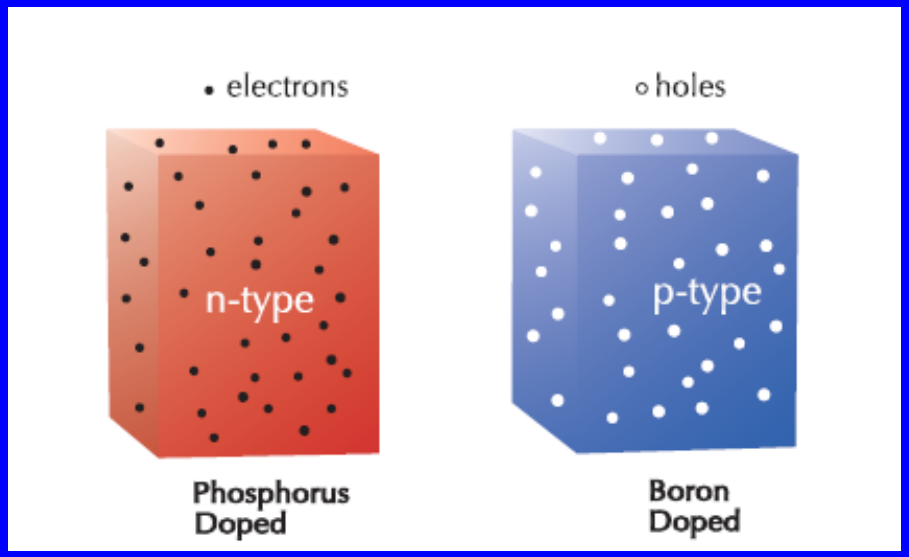
Before making the contact:

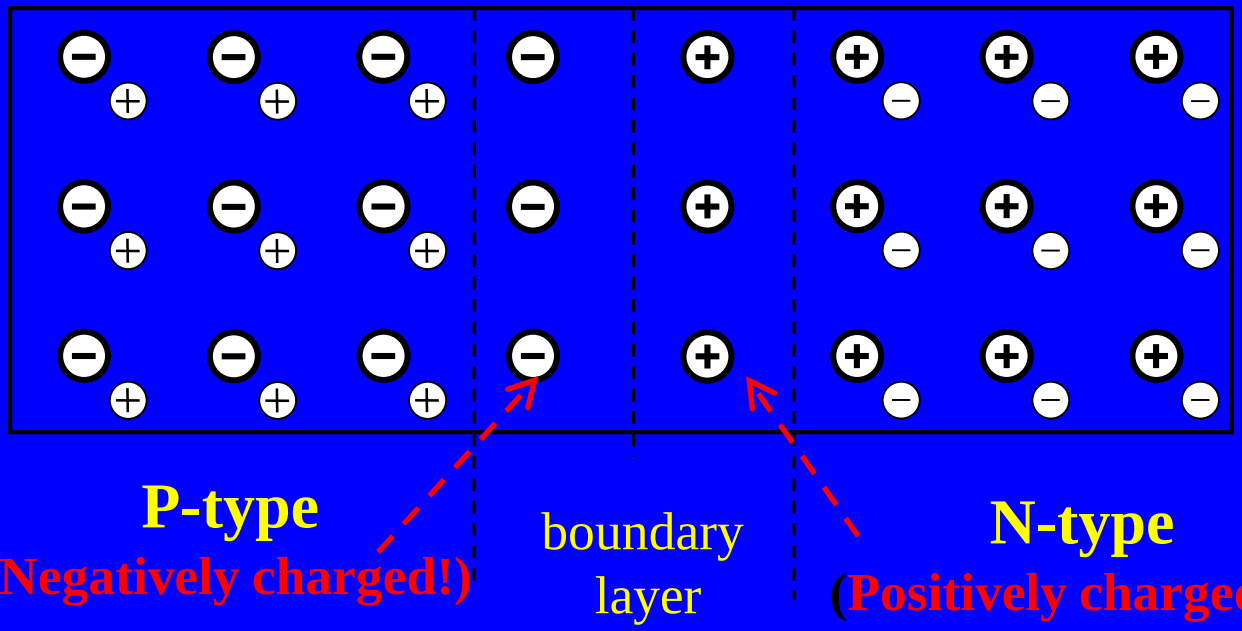


P-type (neutral)



N-type (neutral)



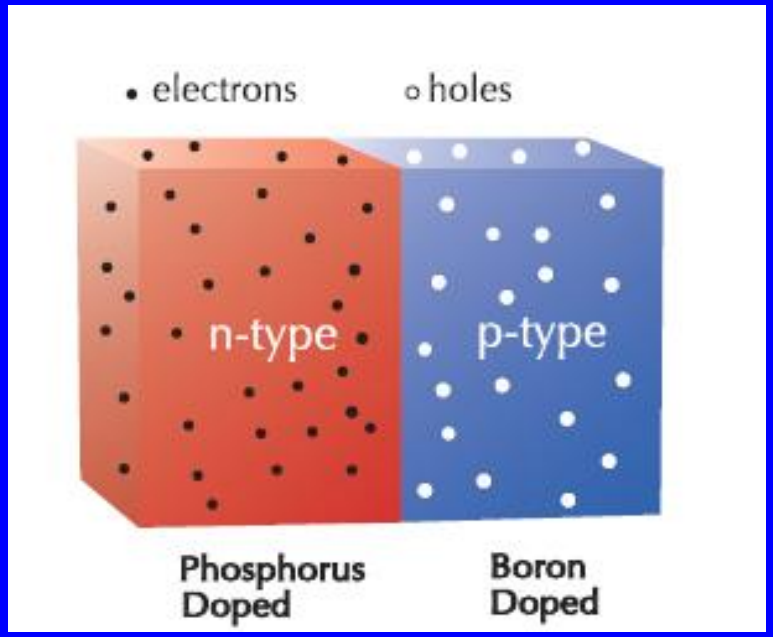


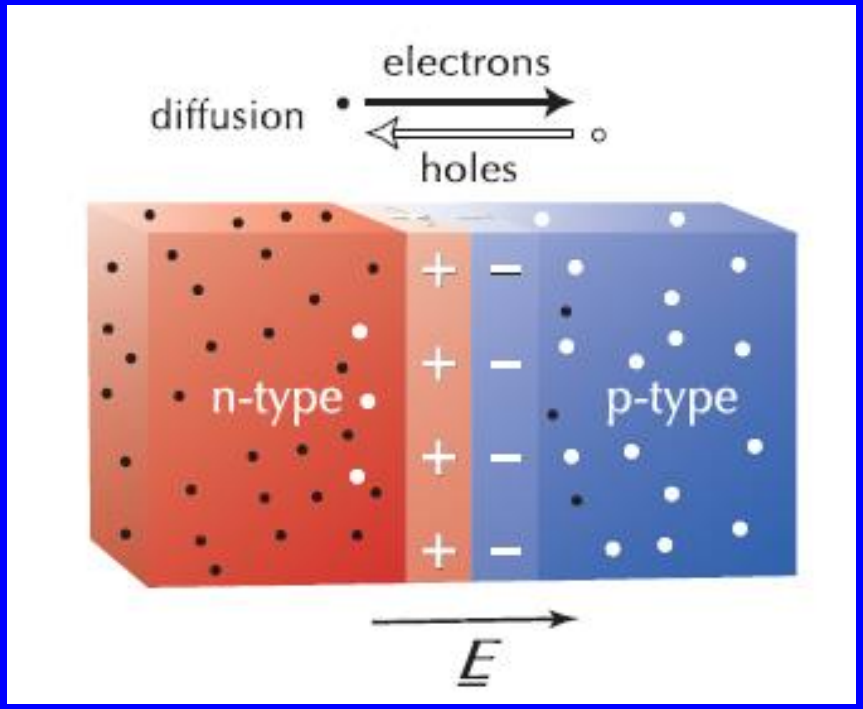
In the boundary layer, the free electrons in the N-type materials combine with the holes in the P-type. Consequently, the **P-type side** of the boundary layer is **negatively charged** and **N-type** side is **positively charged**.

Negative charge in P-type material prevents the free electrons in the rest of the N-type material to continue to migrate into the P-type. (Negative charge repels negative charged free electrons.)

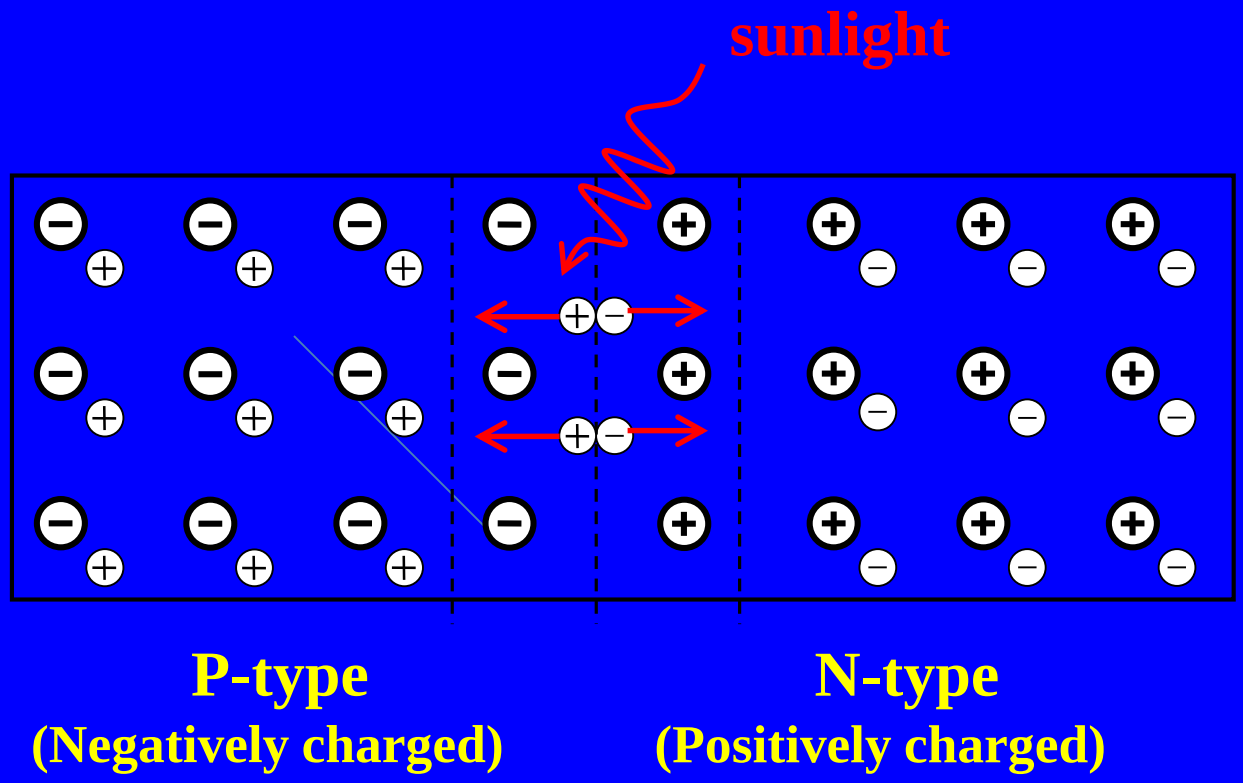
The boundary layer is called **PN junction** or depletion region.

n-type and p-type materials brought together.



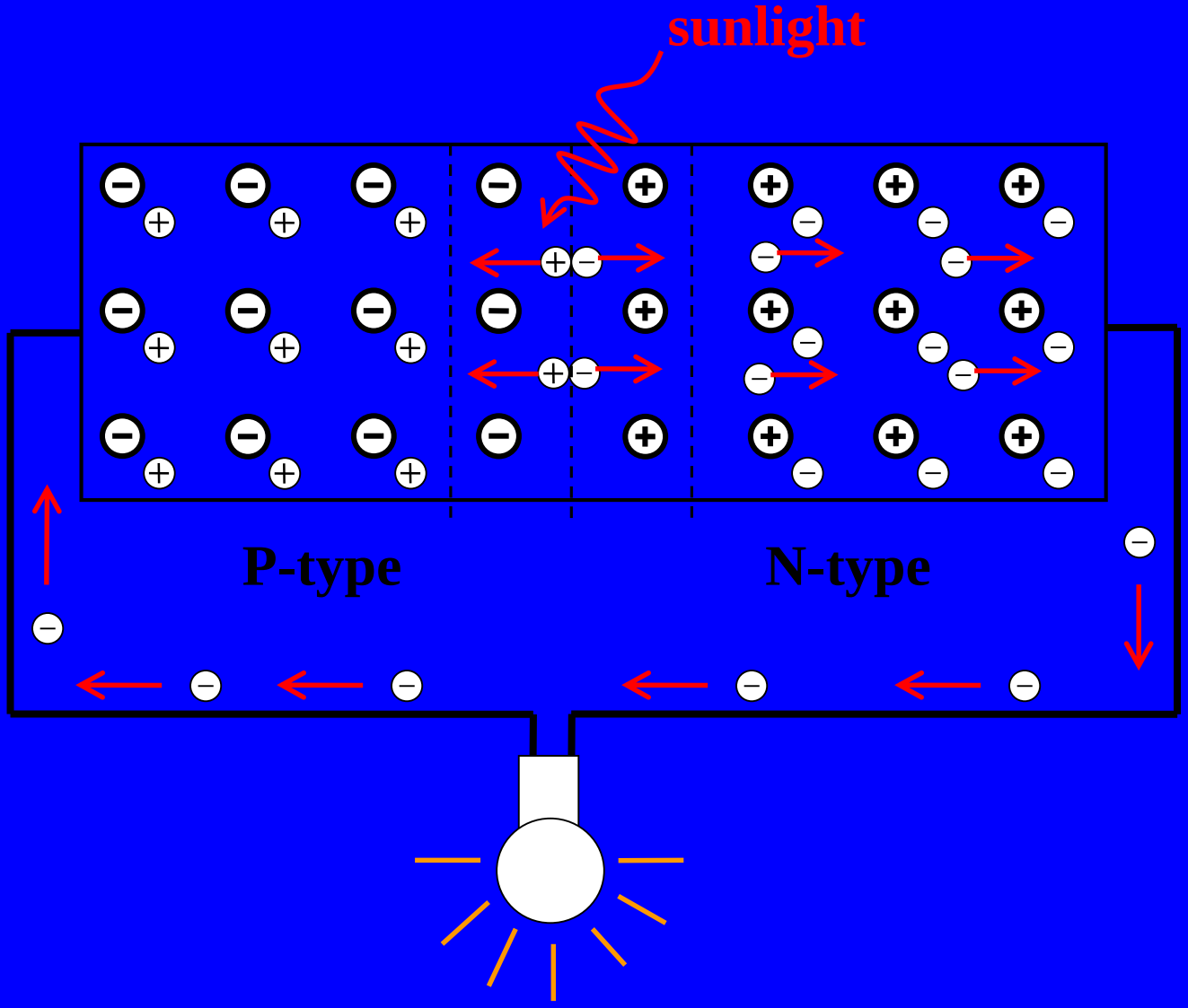


Diffusion establishes “built-in” electric field.



When sunlight strikes atoms in the P-N Junction and knocks out more electrons (and creates corresponding holes), the free electrons are expelled by the negative charge on the P-type side and hence move towards the N-type side.

If a load is connected across the cell, electric current is formed and the energy is transmitted to the load.



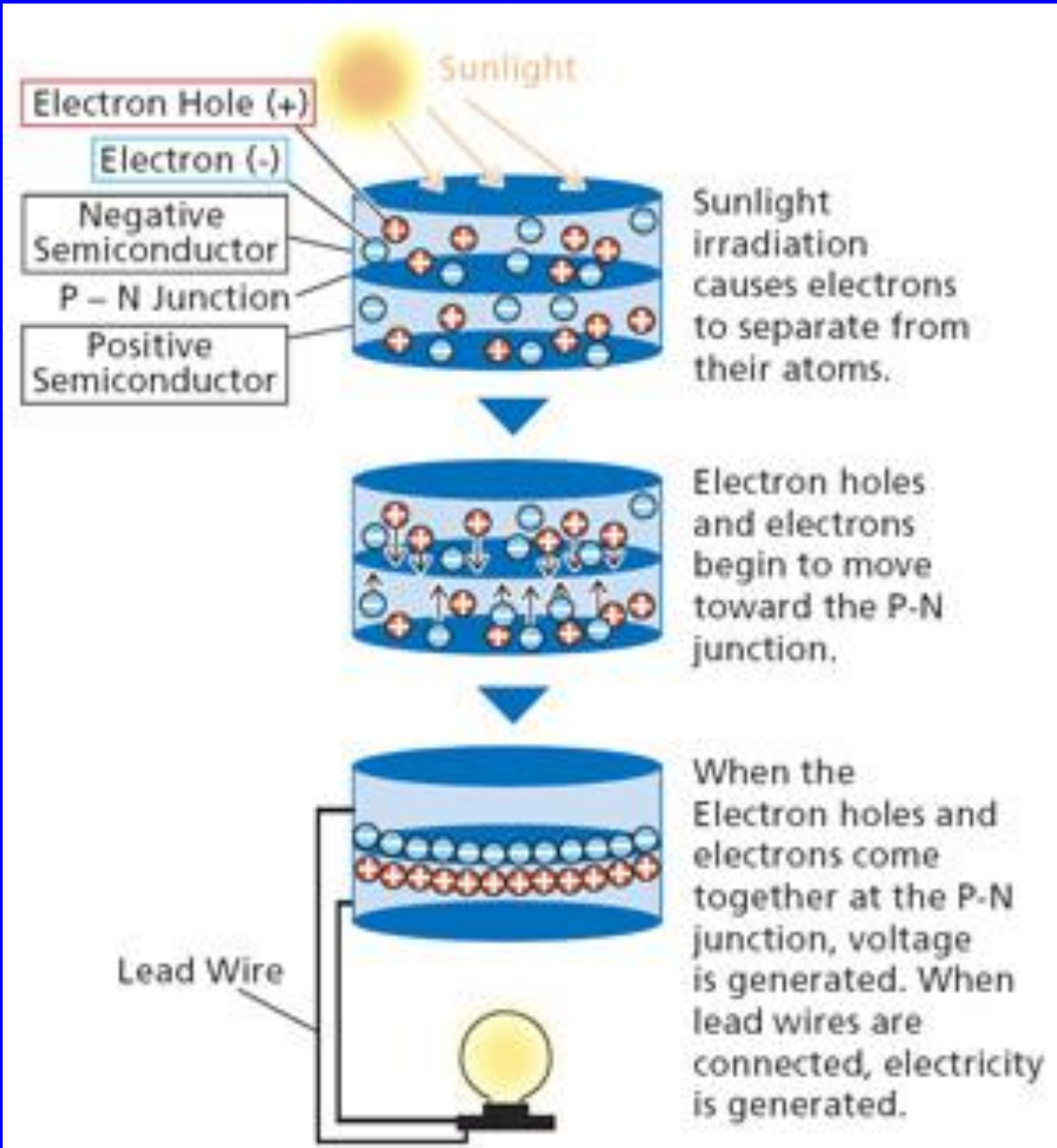

N-TYPE SEMICONDUCTOR
P-TYPE SEMICONDUCTOR
e
h
NEAR THE PN-JUNCTION IS CALLED
THE DEPLETION ZONE WHERE THERE ARE NO CHARGE CARRIERS ANY MORE

Clicker Question 3

The purpose of the PN junction in a solar cell is:

(a) to generate free electrons
(b) to generate holes
(c) to isolate P and N materials
(d) to accelerate the electrons flow
(e) to direct the direction of electron flow

Summary

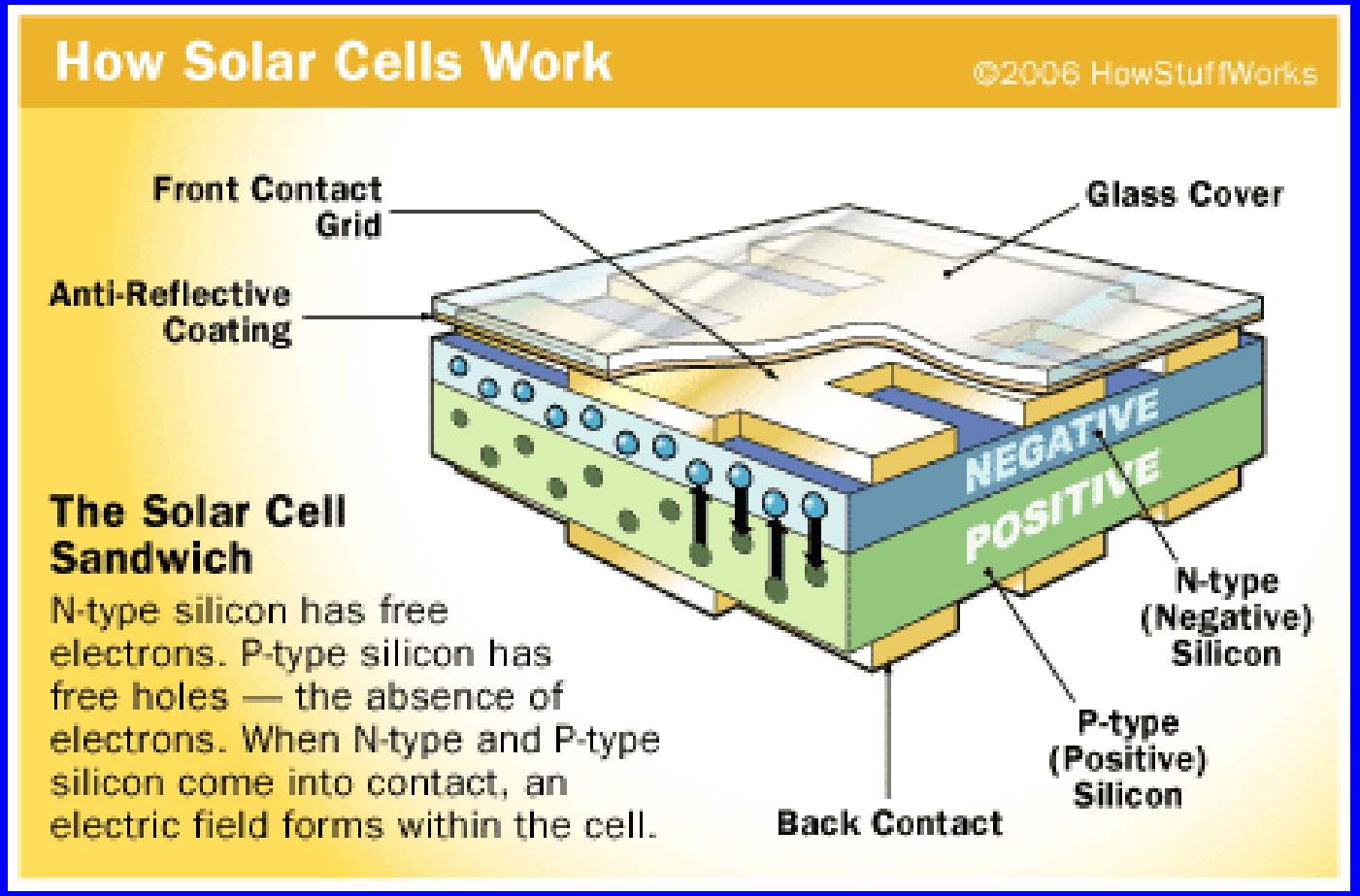

Sunlight
Electron Hole (+)
Electron (-)
Negative Semiconductor
P – N Junction
Positive Semiconductor
Sunlight irradiation causes electrons to separate from their atoms.
Electron holes and electrons begin to move toward the P-N junction.
When the Electron holes and electrons come together at the P-N junction, voltage is generated. When lead wires are connected, electricity is generated.
Lead Wire

Clicker Question

Q4. P-type material conducts current by

(a) Metallic element
(b) Free electron
(c) Electric ‘holes’
(d) Conductor
(e) Insulator

Photovoltaic Cell



Solar panels capture sunlight and convert it to electricity using photovoltaic (PV) cells like the one illustrated above.

The name implies photo meaning "light" and voltaic meaning “electricity"