Lecture 17: Photovoltaics

Course: MECH-422 – Power Plants

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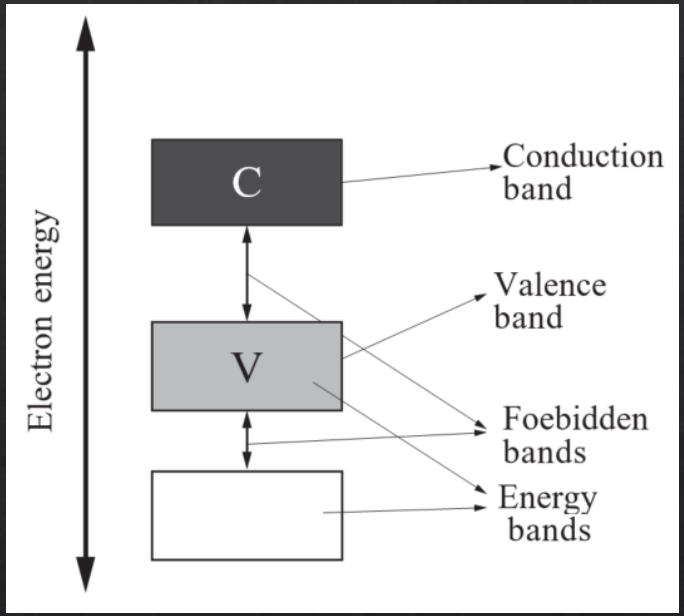
BUITEMS – DEPARTMENT OF MECHANICAL ENGINEERING

Energy Bands

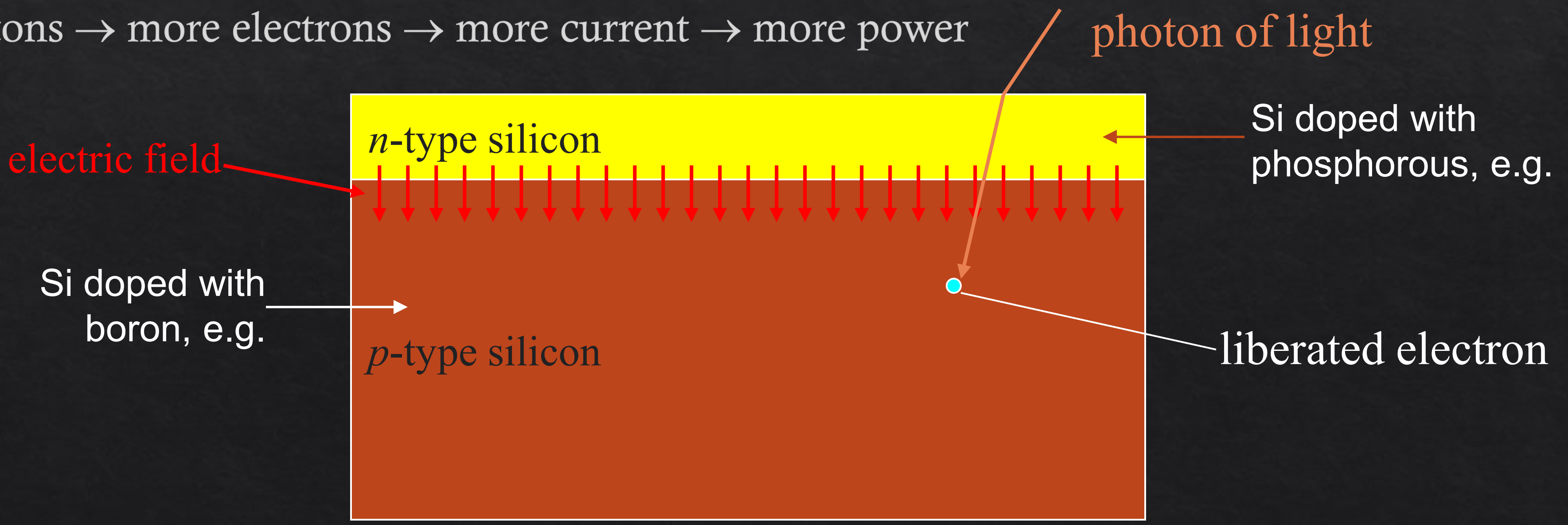
- It is proven that for a single atom, electrons can only occupy defined orbits with certain energy levels.
- These energy levels are expressed according to their energy in electron-volt (eV).
- Electrons can only “jump” from one energy level to a higher or lower energy level by absorbing or releasing a photon.
- The energy difference between the two energy levels must be equal to the energy of the absorbed or released photon.



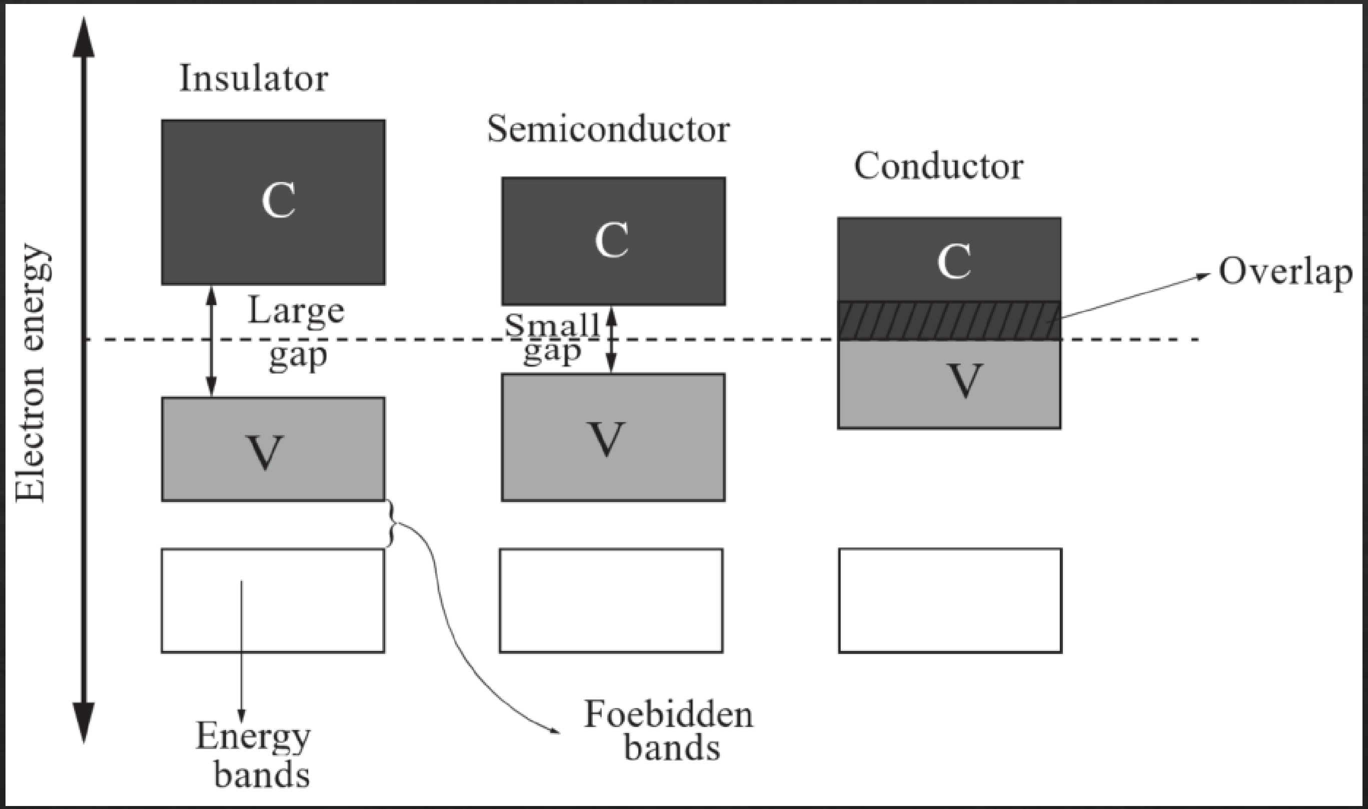
Electron energy levels in an atom

Photovoltaic (PV) Scheme

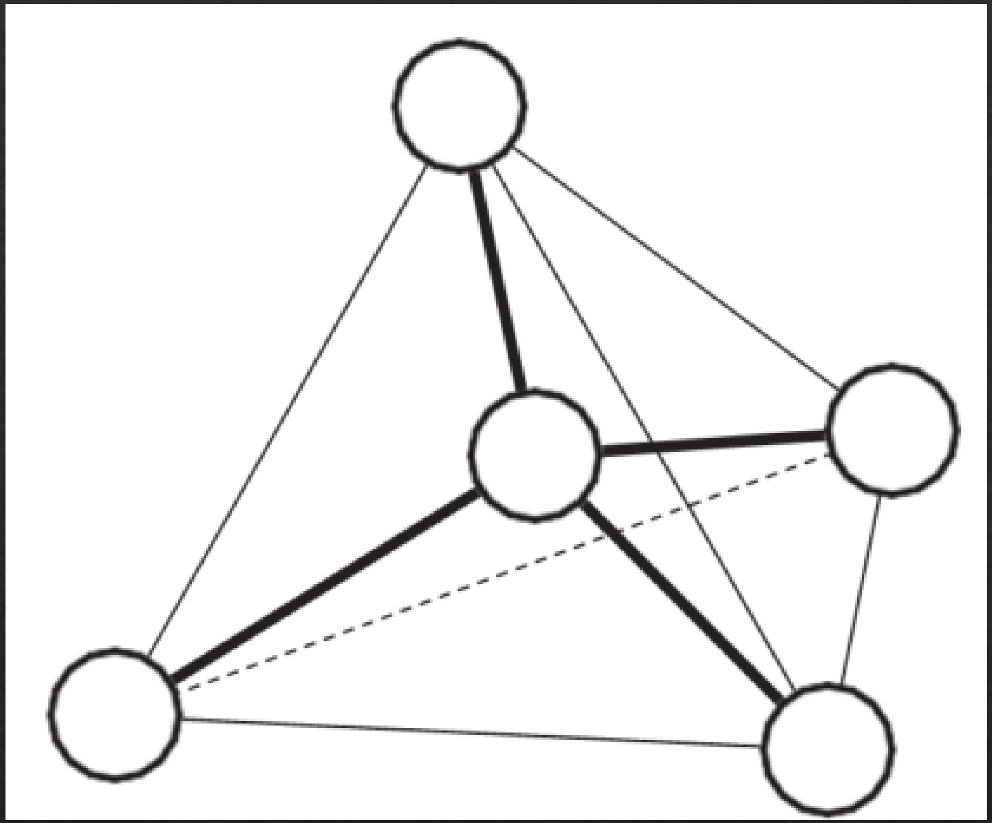
- Highly purified silicon (Si) from sand, quartz, etc. is "doped" with intentional impurities at controlled concentrations to produce a p-n junction
  - p-n junctions are common and useful: diodes, CCDs, photodiodes, transistors
- A photon incident on the p-n junction liberates an electron
  - photon disappears, any excess energy goes into kinetic energy of electron (heat)
  - electron wanders around drunkenly, and might stumble into "depletion region" where electric field exists (electrons, being negative, move *against* field arrows)
  - electric field sweeps electron across the junction, constituting a current
  - more photons → more electrons → more current → more power



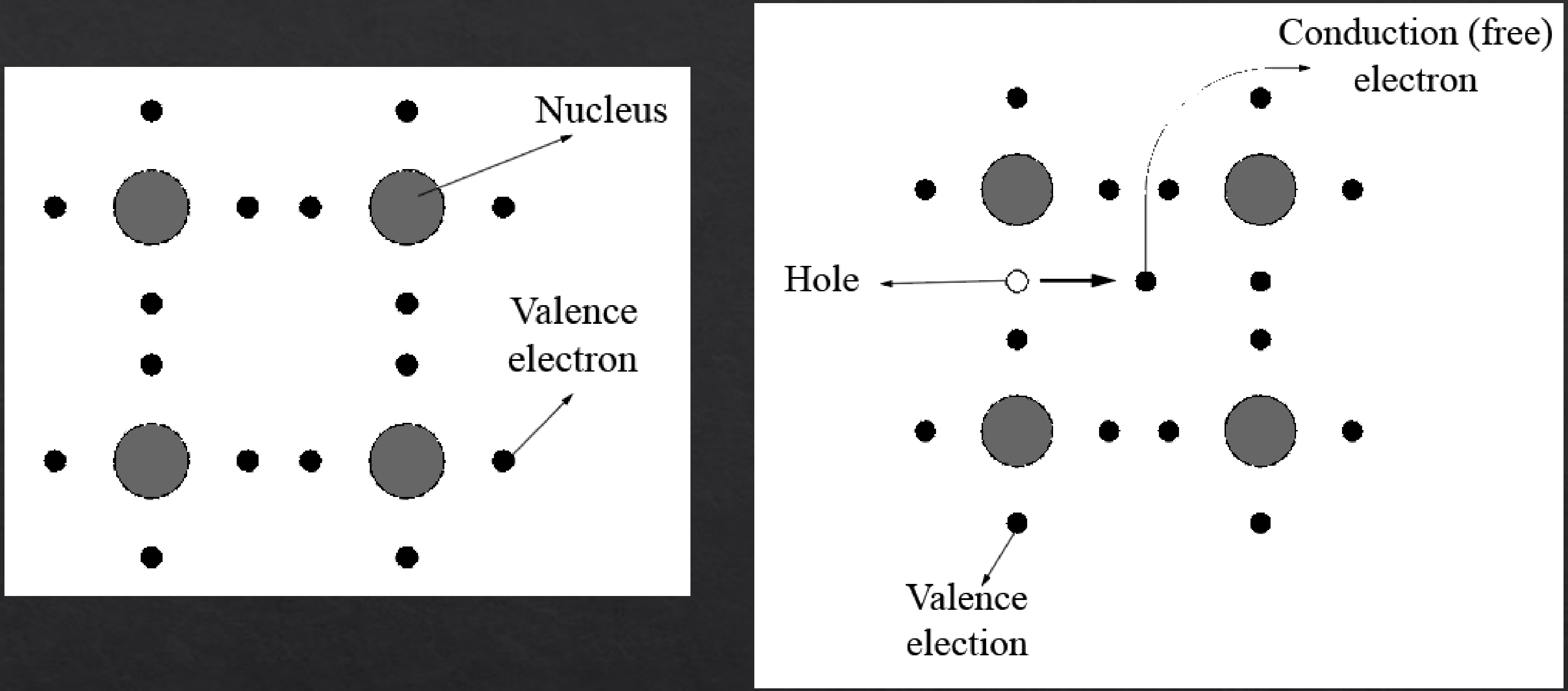
The band gap for some semiconductors that are used in the manufacturing of solar cells at the room temperature is as follows: silicon 1.1 eV, germanium 0.7 eV, gallium arsenide 1.4 eV, and cadmium telluride 1.4eV



Band gap for conductors, semiconductors, and insulators

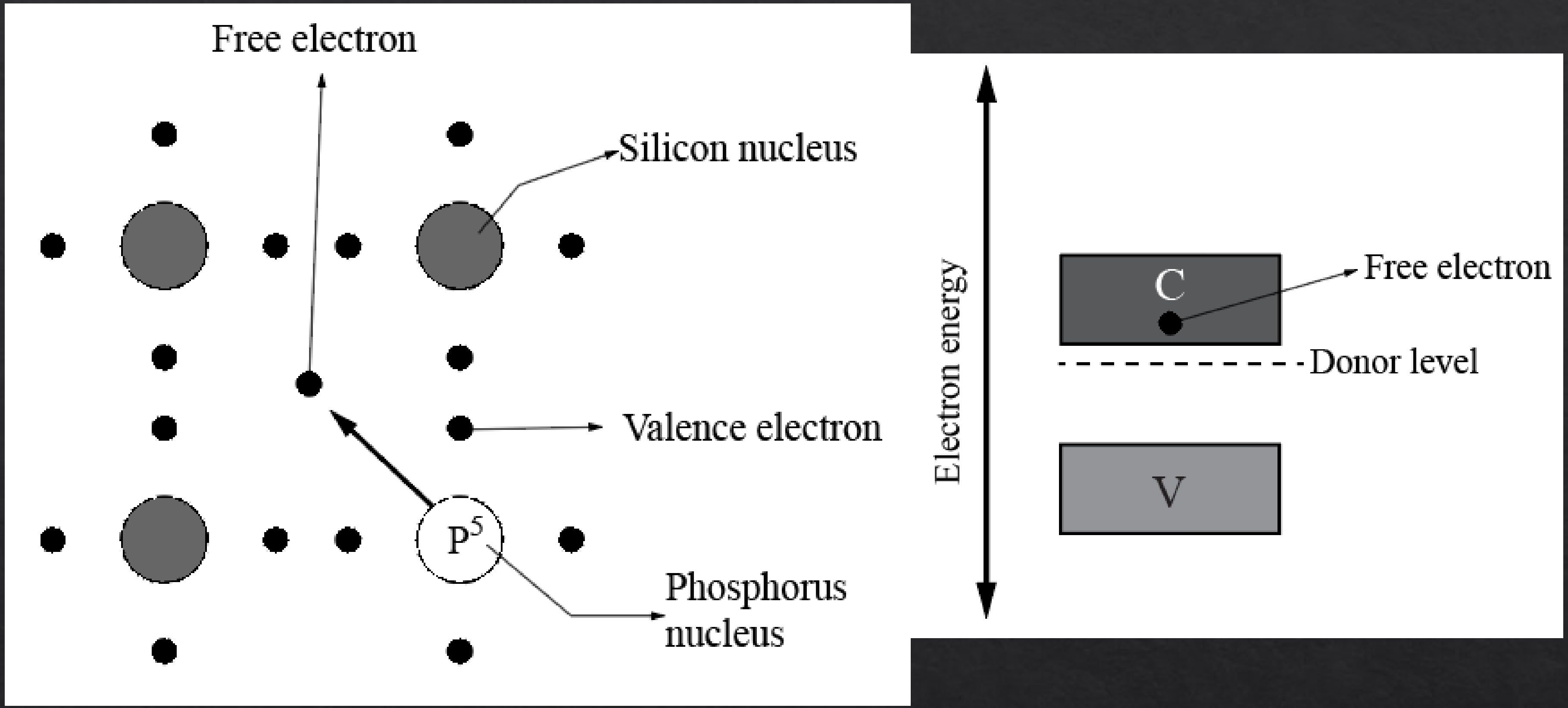


Atomic structure of silicon crystalline: three-dimensional structure with no electron promoted to conduction band

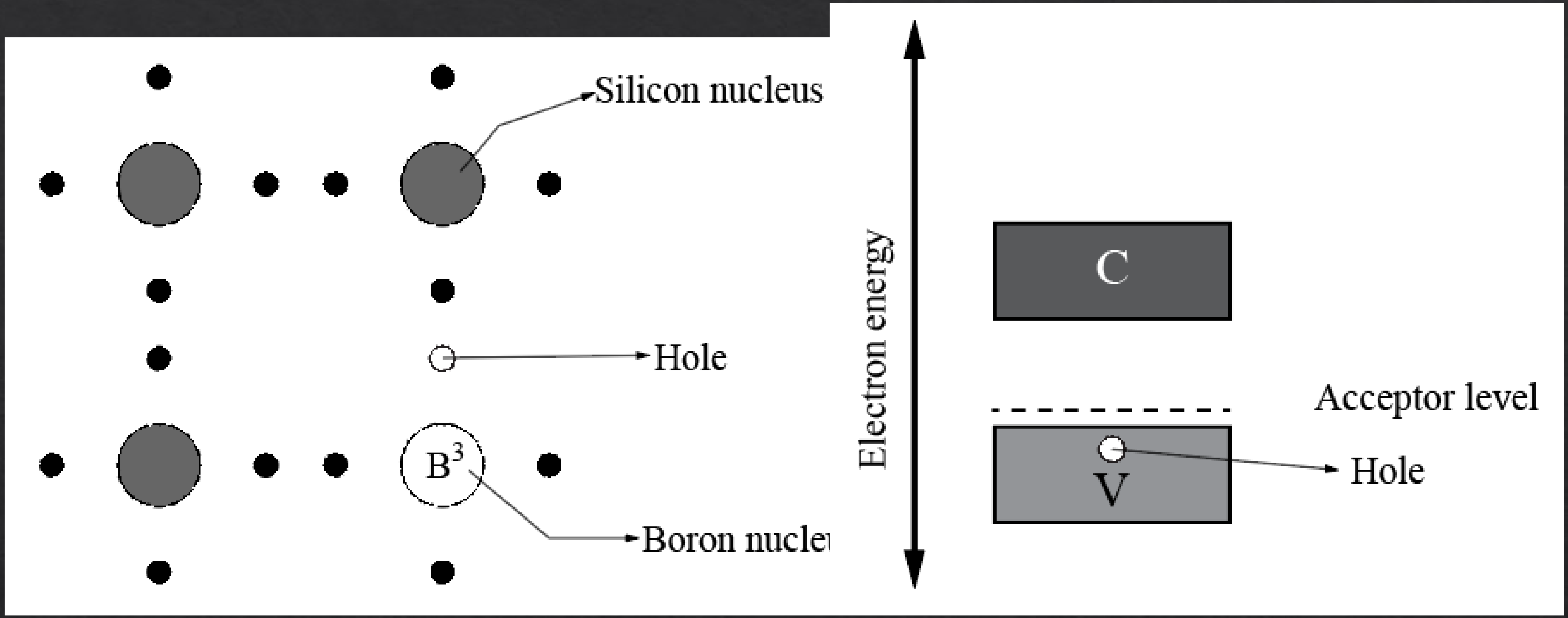


a b

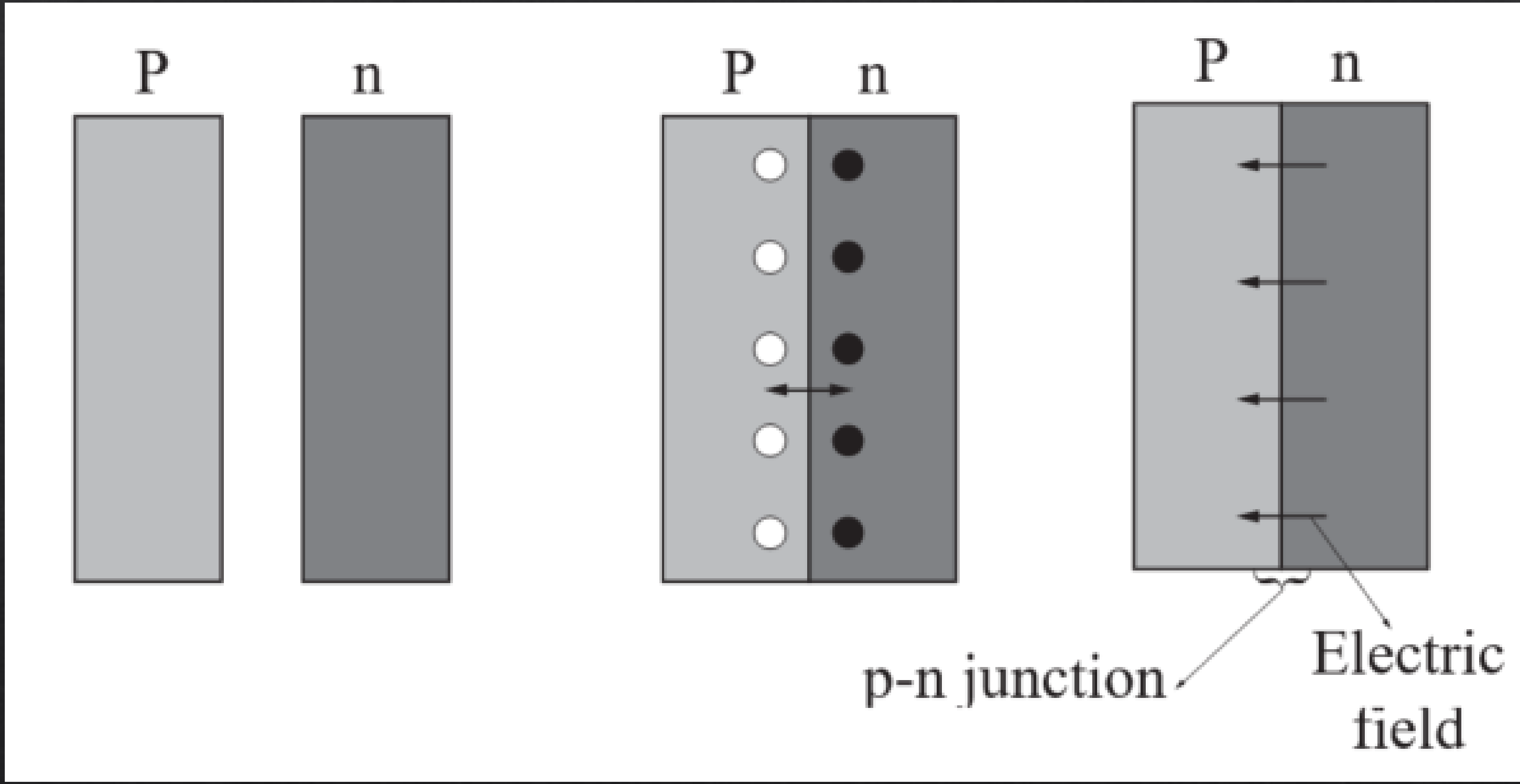
Atomic structure of silicon crystalline: a) simplified two-dimensional representation with no promoted electron b) simplified two-dimensional representation with one electron promoted to conduction band



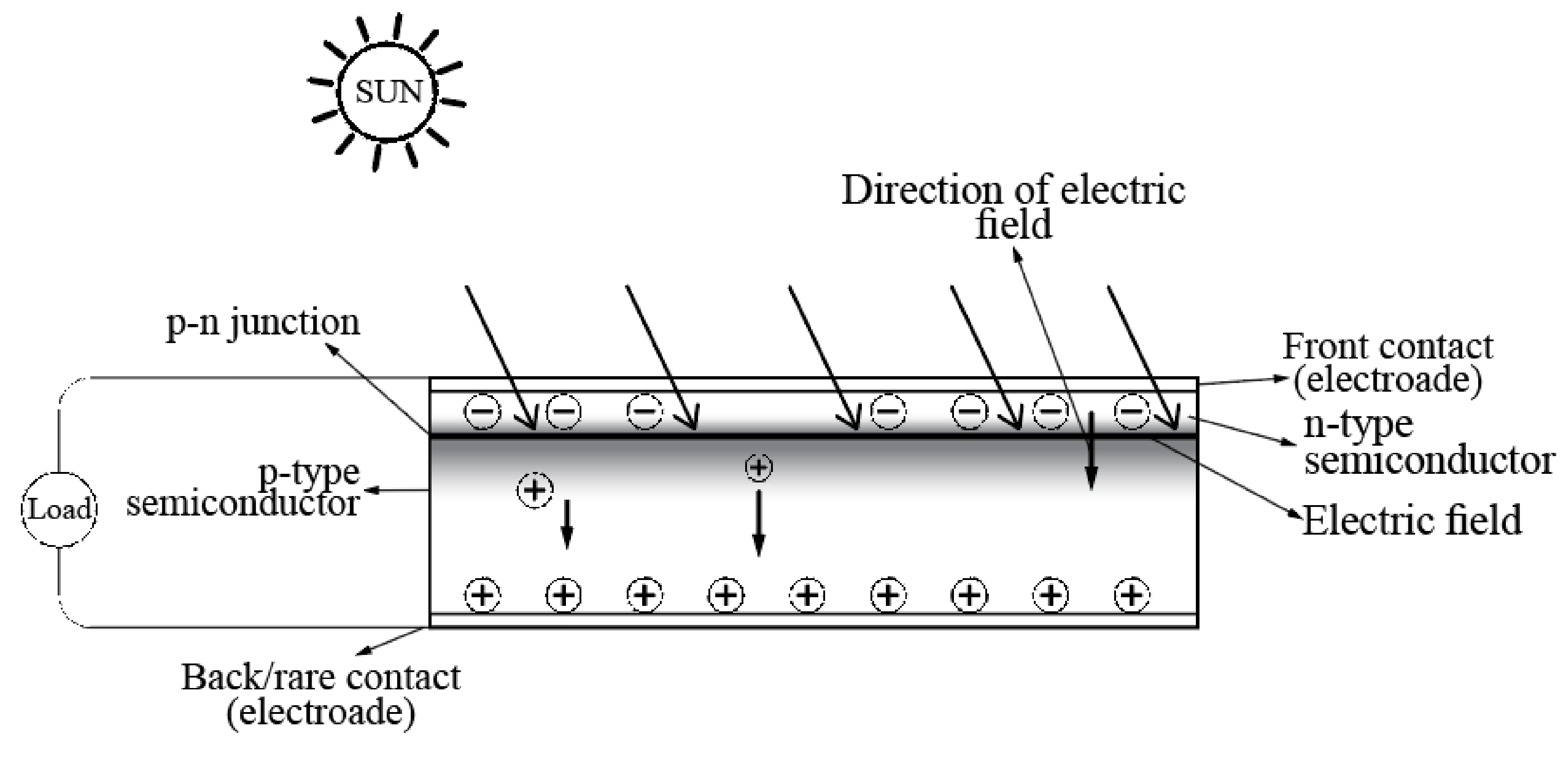
Doping silicon crystalline with phosphorus to create an n-type semiconductor



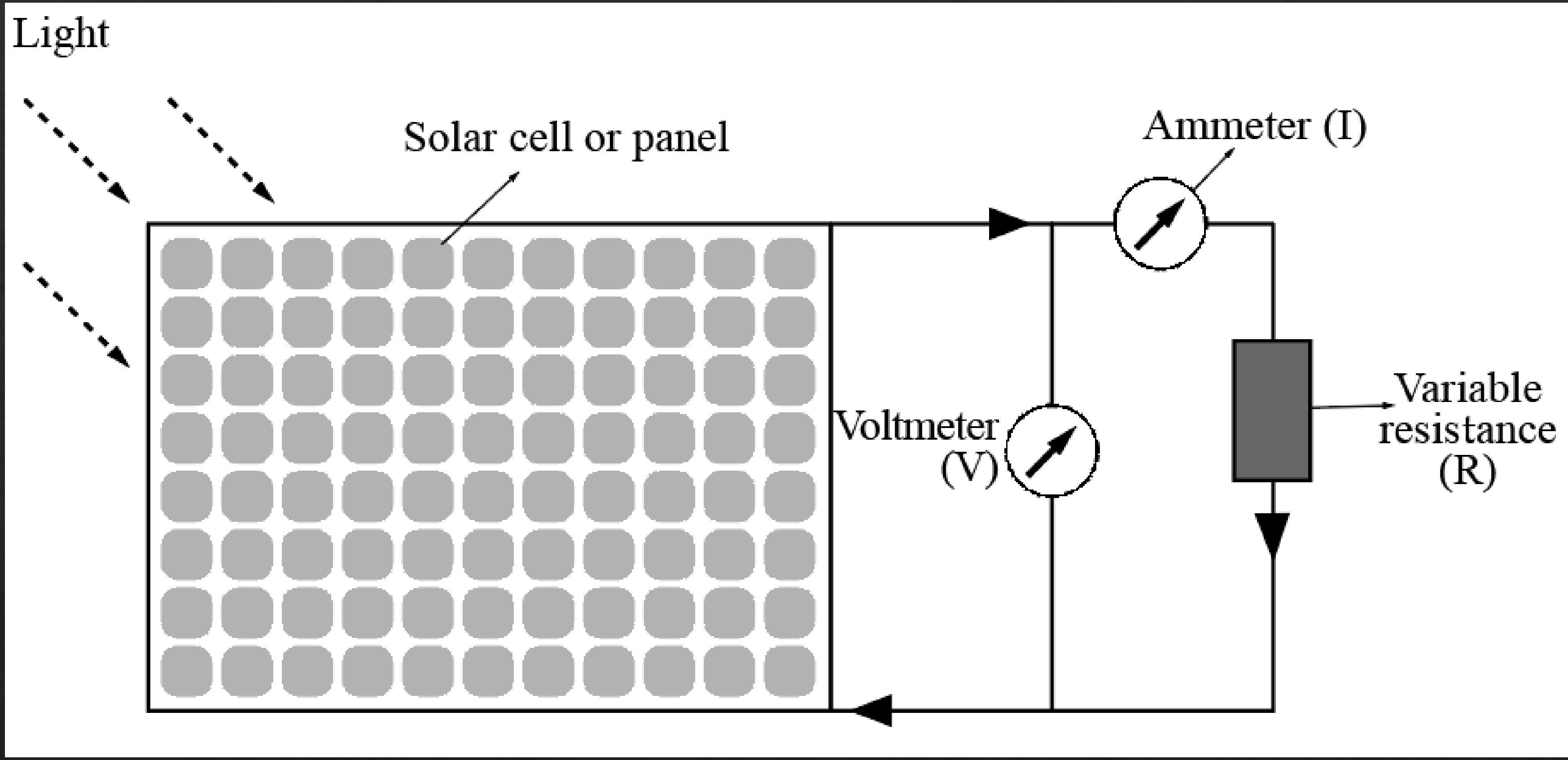
Doping silicon crystalline with boron to create a p-type semiconductor



Schematic of a p-n junction to separate electrons and holes in electron-hole pairs https://www.youtube.com/watch?v=xKxrkht7CpY



Schematic of what happens when sunlight strikes the surface of a solar cell



Schematic of a setup to create a characteristic curve (I-V curve) of a solar cell by varying the load’s resistance and measuring current and voltage

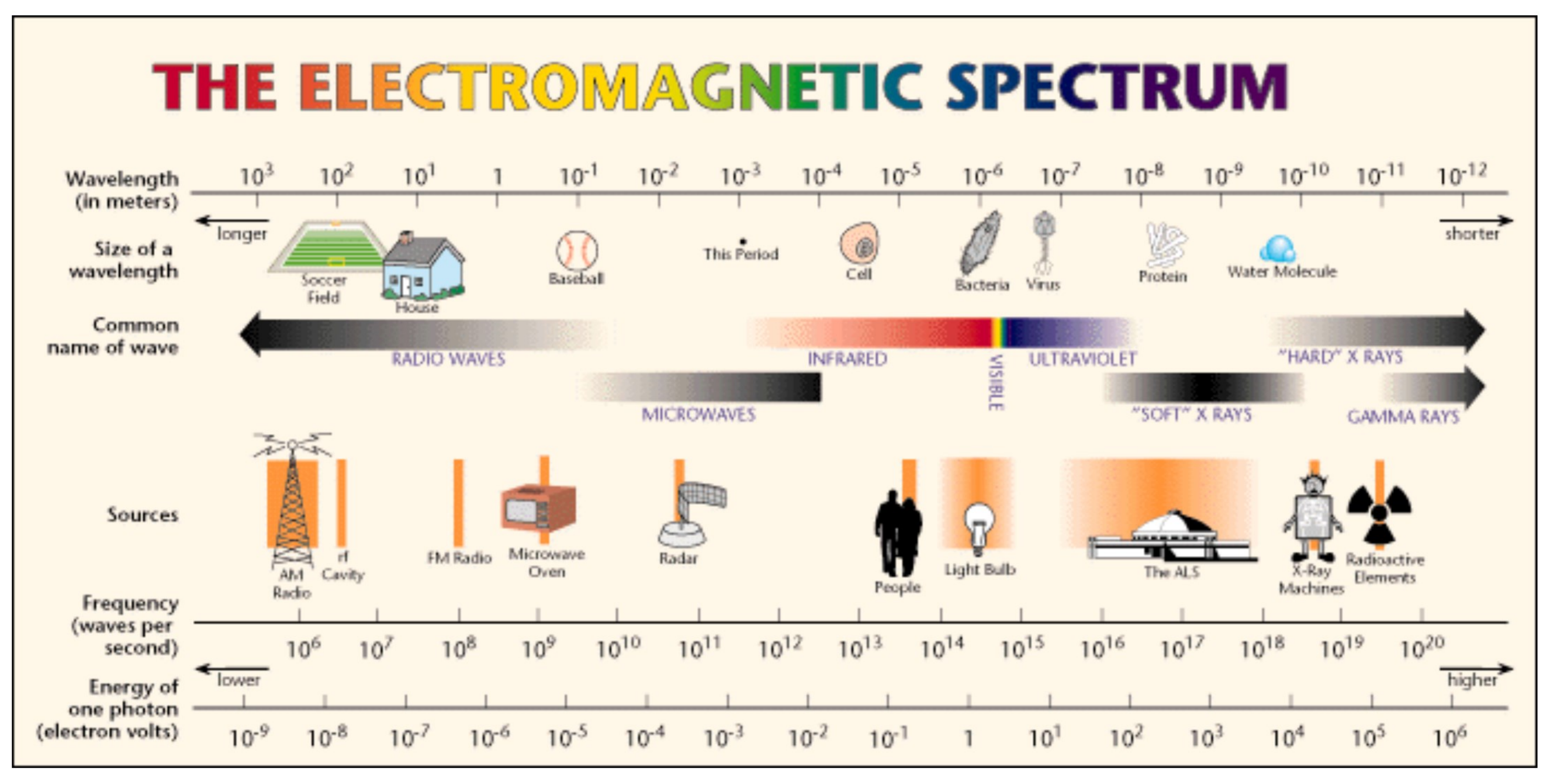
Photon Energy

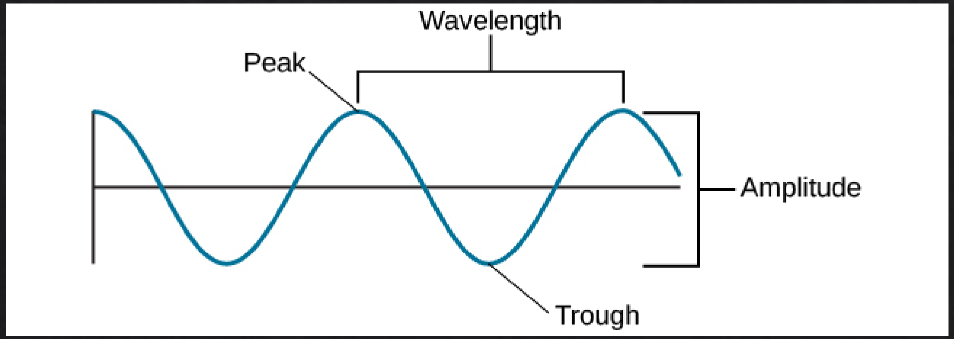
The photon energy, typically between 1 and 3.5 eV, is inversely proportional to its wavelength (or directly proportional to its frequency).

The energy of a photon as a function of its frequency and wavelength can be determined by the following equation:

$$E = hv = hc/\lambda \tag{11.5}$$

where E is energy of the photon (J), h is the Planck constant (h = 6.626 × 10^{-34} Js), v and λ are the frequency (Hz) and wavelength of the photon (m), respectively, and c is the light speed $c = 2.998 \times 10^8$ m/s.


THE ELECTROMAGNETIC SPECTRUM
Wavelength (in meters)
10^3 10^2 10^1 1 10^-1 10^-2 10^-3 10^-4 10^-5 10^-6 10^-7 10^-8 10^-9 10^-10 10^-11 10^-12
longer
shorter
Size of a wavelength
Soccer Field
House
Baseball
This Period
Cell
Bacteria
Virus
Protein
Water Molecule
Common name of wave
RADIO WAVES
INFRARED
VISIBLE
ULTRAVIOLET
"HARD" X RAYS
MICROWAVES
"SOFT" X RAYS
GAMMA RAYS
Sources
AM Radio
rf Cavity
FM Radio
Microwave Oven
Radar
People
Light Bulb
The ALS
X-Ray Machines
Radioactive Elements
Frequency (waves per second)
10^6 10^7 10^8 10^9 10^10 10^11 10^12 10^13 10^14 10^15 10^16 10^17 10^18 10^19 10^20
lower
higher
Energy of one photon (electron volts)
10^-9 10^-8 10^-7 10^-6 10^-5 10^-4 10^-3 10^-2 10^-1 1 10^1 10^2 10^3 10^4 10^5 10^6


Wavelength
Peak
Amplitude
Trough

Example 11.8

We know that the wavelength of solar radiation spectrum on Earth ranges from about 300 nm to about 2500 nm. For the light with the wavelength of 300, 1130, and 2500 nm,

a. determine the photon energy of the part of solar radiation with the above wavelength in J and eV.
b. determine the number of photons per second in each case if the light energy that is 0.1 W.

If the light with the wavelength of 300, 1130, and 2500 nm strikes a solar cell made of crystalline silicon (with the band gap of 1.1 eV).

1. Find the wavelengths that can generate electrical power?
2. What is the maximum efficiency for each wavelength?

End of Lecture!