Physics 228

Today:
Light-Emitting and Laser Diodes
Solar Cells
Transistors
Atomic Nuclei
Charge transfers across the junction until the Fermi levels on both sides are the same. This results in

- Two opposite space charge regions
- An electric field between these space charges
- A shift in the energy bands as shown below.

Review: p-n Junction Diode
Apply reverse bias (positive V on right):

- Electrons and holes are pulled away from junction, leaving the charged dopant ions behind.
- This adds to the internal field, until it counterbalances the applied voltage.
- No current flows (except for thermal generation of carriers)

Apply forward bias (positive V on left):

- Electrons and holes are pushed toward junction, into the depletion region.
- This reduces the internal field.
- In the junction region, there are now electrons and holes, which recombine.
- Current flows.
Light Emitting Diodes (LEDs)
Green, blue, or UV laser beams are obtained by nonlinear frequency doubling ("second harmonic generation") in a nonlinear crystal.
You are designing a light-emitting diode with a shorter wavelength than an existing one. Compared with the existing LED, what material should you choose?

a) A material with a smaller bandgap
b) A material with a larger bandgap.

c) A material with a smaller Fermi energy.

d) A material with a larger Fermi energy.

e) The wavelength does not depend on material but on the temperature of the LED.
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Why is it easier for current to flow from p-type to n-type in a diode, than the other direction?

a) The p-type naturally has a more positive voltage, that is why we call it p-type.

b) The Fermi energy is lower in n-type, so the electrons fall into it.

c) It is easier for the current to flow when we apply a voltage that pulls electron-hole pairs out of the junction.

d) It is easier for the current to flow when we apply a voltage that pulls electrons and holes towards the junction, where they recombine.

e) The question has it wrong: it is easier for the current to flow from the n-type to the p-type.
Solar electricity generation is now economically competitive with non-renewable sources (fossil fuels, nuclear power).

Advantages:
- Renewable energy
- No pollution
- No greenhouse gases
- Lowers dependence on foreign countries
Transistor

Transistors are the key active components in practically all modern electronics. A transistor is essentially an electrical switch, which can be turned on (conducting) or off (not conducting).

The switching signal is given electrically instead of a person pushing a lever. Thus a transistor has three “leads”, or wires.

Historically, the first transistors to be developed were “bipolar junction transistors”, consisting of two p-n junctions, in a pnp or npn configuration.

Although bipolar junction transistors are still used in some analog applications such as amplifiers, “field effect” transistors (FETs) have replaced them in digital and power applications.
In a field effect transistor (FET), a voltage applied to a “gate” electrode creates an electric field in (let’s say) a p-type semiconductor. If the field pulls the conduction band below the Fermi level, we get n-type carriers (electrons) near the interface of the p-type semiconductor. This is called electric-field doping, creating an n-type “inversion layer”.

The inversion layer acts as an n-type conduction path between the n-type source electrode and the n-type drain. It can be turned “on” and “off”, as well as changed in width, by changing the gate voltage.
Atomic Nuclei

The nucleus the center of the atom is positively charged and contains almost all the atom’s mass.

The size of the nucleus is about four to five orders of magnitude smaller than the atom. A typical nuclear radius is several femtometers (fm = 10^{-15} m).

Nuclei are made up of nucleons (protons and neutrons, each with similar mass). Protons have a charge +e (electron charge: -e), neutrons have zero charge.

Consider an atom of charge 3 (Li). Its nucleus has 3 protons, which we write as Z = 3.

How many neutrons are there? It turns out that there are two stable ‘isotopes’ of Li, one with 3 neutrons, and one with 4 neutrons. These are called Li-6 and Li-7, respectively.

Most atoms have several stable isotopes (and several more that are not stable or radioactive).
Since the protons repel each other, they must be held together by a force that is much stronger than the Coulomb repulsion. For this reason, the attractive force holding nuclei together is called the “strong” nuclear force.

The neutrons are subject to the same “strong” force potential as the protons, but only the protons experience the Coulomb force. As a result, the protons’ energy levels are higher in energy and tend to decay to lower-energy neutrons. This leads to stable nuclei that have more neutrons than protons.
In order to have the highest efficiency for converting sunlight to electric power, the bandgap of a solar cell material should

a) be as large as possible, such that a large photovoltage can be generated.
b) be as small as possible, such that most photons can be absorbed.
c) match the photon energy at the peak of the solar spectrum.
d) be zero, such that there is the least resistance to current flow.
e) be much larger than the typical solar photon energy such that the material is transparent to sunlight.