Physics 228

Today:
Photovoltaics
Transistor
Nuclear Physics
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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.
Field Effect Transistor

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.
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.
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 (\(10^{-15}\) 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).
Coulomb and Nuclear Forces

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.
Stability of Nuclei

Here we plot the lifetime of the nuclei (color, black is stable) in a chart of neutron number $N$ (y-axis) vs. proton number $Z$ (x-axis).

There is a narrow “valley of stability” around an optimal neutron-to-proton ratio.
Why do nuclei tend to have more neutrons than protons?

a) The neutrons have a magnetic attraction that the protons do not.
b) The neutrons form pairs but the protons do not.
c) The nuclear force is short range.

**d) Protons repel each other due to the Coulomb force.**

e) Protons are Fermions and go in different orbits, but neutrons are bosons and all can go into the lowest $n = 1$ ground state.
Nuclear Sizes

The volume of atomic nuclei is approximately proportional to the number of nucleons (think of a liquid droplet of nucleons).

Thus, the mass density of all nuclei is quite similar, $\rho \approx 2.3 \times 10^{17} \text{ kg/m}^3$ (compare with $10^3 \text{ kg/m}^3$ for water!)

As a consequence, the nuclear radii are a simple function of the number of nucleons $A$: $r \approx R_0 A^{1/3}$ with $R_0 = 1.2 \text{ fm}$. 
Nuclear Masses

Nuclear masses are measured in a convenient unit: The atomic mass unit 1 u = 1.66053892 \times 10^{-27} \text{ kg}.

The a.m.u is defined as 1/12 of the mass of the $^{12}\text{C}$ atom.

The mass of the proton is 1.0073 u.

The mass of the neutron is 1.0087 u.

The mass of the electron is 0.00055 u.

The $^{12}\text{C}$ atom consists of 6 electrons, 6 protons, and 6 neutrons, thus one would expect it to have a total mass of 12.099 u. Yet it is only 12.000 u. What is going on?

The nucleus consists of bound nucleons, not free nucleons. Binding in an attractive potential lowers the energy by an amount called the "binding energy". But remember that mass is energy, and energy is mass, measured in different units (via $E = mc^2$). Thus the mass of the nucleus will be lower than the mass of the free nucleons by this "binding energy", converted to mass units.
Binding Energy per Nucleon

The plot shows the total binding energy divided by the number of nucleons. The binding energy per nucleon exhibits maximum at $A = 62$.

Thus, if two light nuclei fuse into a heavier nucleus, energy is released (nuclear fusion in the sun).

If a heavy nucleus splits into two light ones, energy is released (fission, nuclear power plant).
By what factor is the radius of the nucleus $^{160}\text{Dy}$ larger than that of $^{20}\text{Ne}$?

a) $<1$ - because of the strength of the nuclear force, nuclei get smaller as you add more nucleons

b) 1 - all nuclei are about the same size

c) 2

d) 4

e) 8