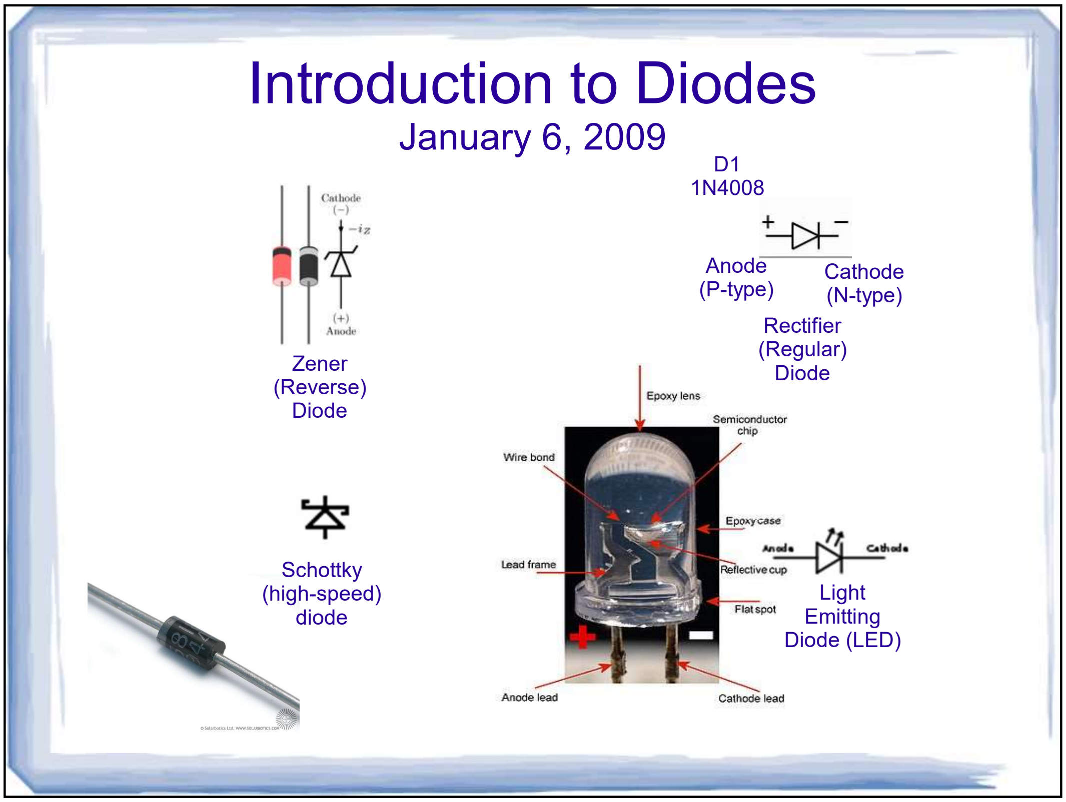


Can be used as LEDs to generate light

Can be used as solar panels to generate voltage

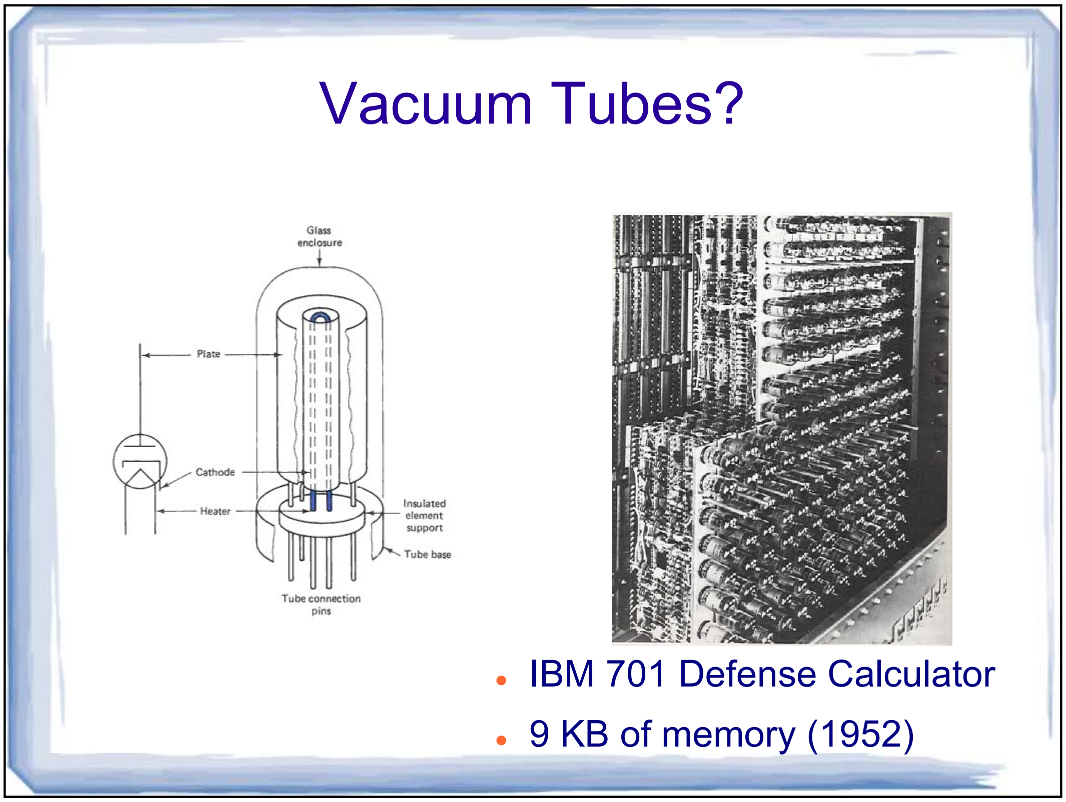
Can be used to turn AC power, where the voltage and current periodically switch directions, into DC c

Why AC?

- Generation
- Transformers

Why DC?

Most electronics need a steady 5V, or 12 V



How can we make something conduct in one direction but not in the other?

Could heat one wire, put it in a vacuum, and let electrons be “thermionically” emitted toward another wire

- big
- slow
- Inefficient
- delicate

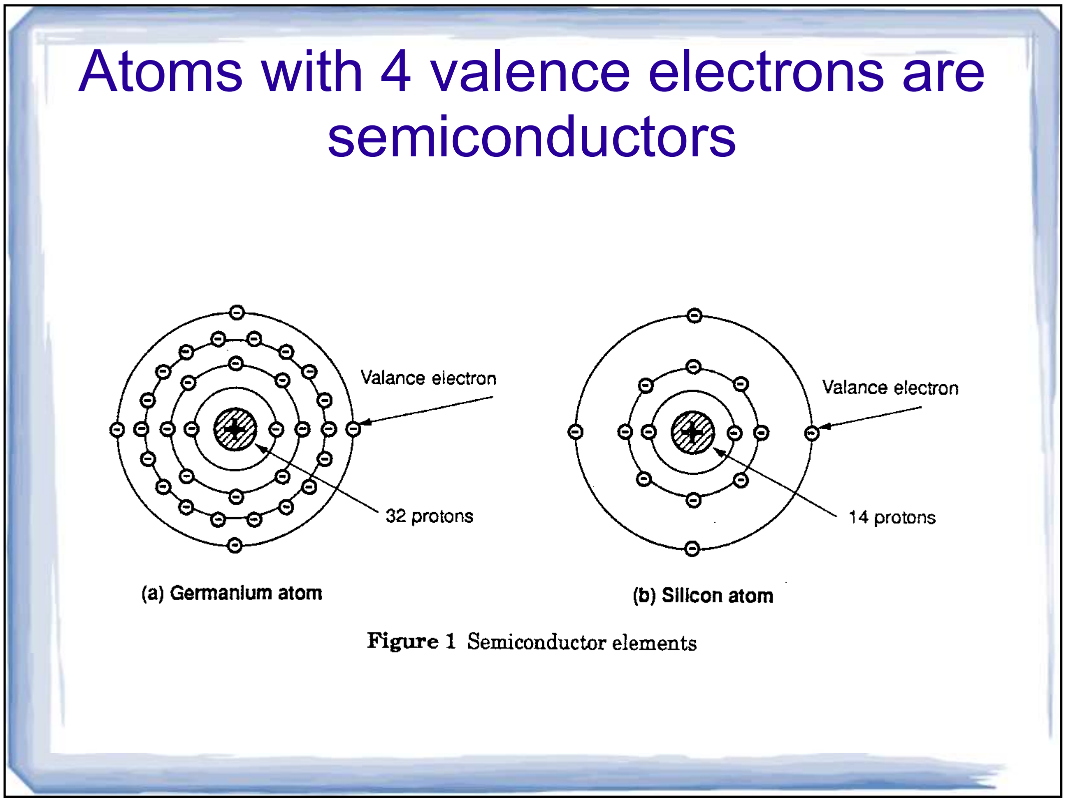


Figure 1 Semiconductor elements

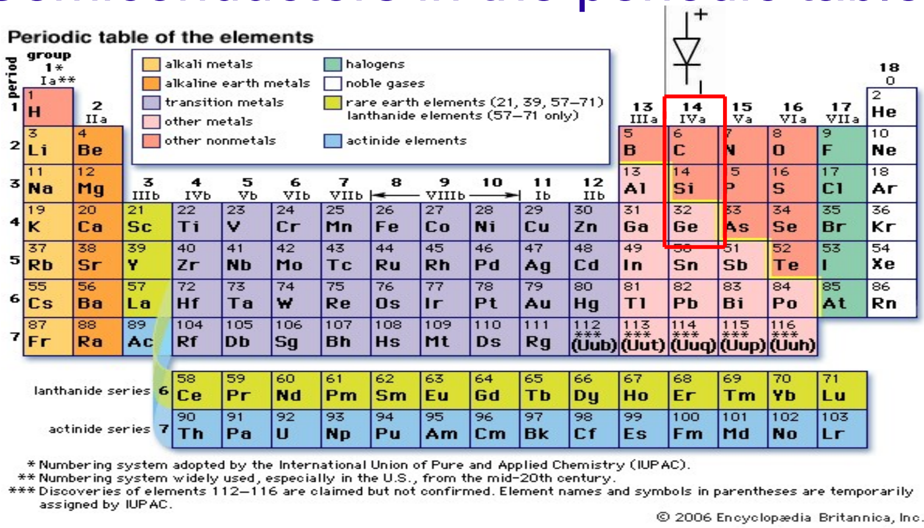
Or, we can harness the conflicting impulses of electrons. (slide)

- Electrons tend to move around to be **electrically balanced** with nearby protons (same number of electrons orbiting, as there are protons in the nucleus)
- But, they also tend to bunch up in groups of 8 (full valence shells), for reasons we don't totally understand. (a shell is a bunch of electrons with similar amounts of energy)
- (check out the concept of "band gap" if you want to learn what we know so far)
- A type of crystals made from semiconductors

makes use of both phenomena

Note typo in slide: these are VALENCE electrons, not VALANCE electrons. No curtains here!

Semiconductors in the periodic table

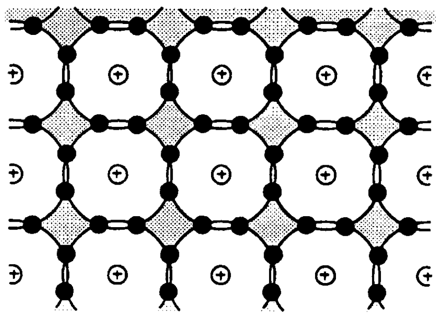


- Halfway between an insulator and a conductor

Conductor: often 1 valence electron
Insulator: often 8 valence electrons
Semiconductor: 4 valence electrons

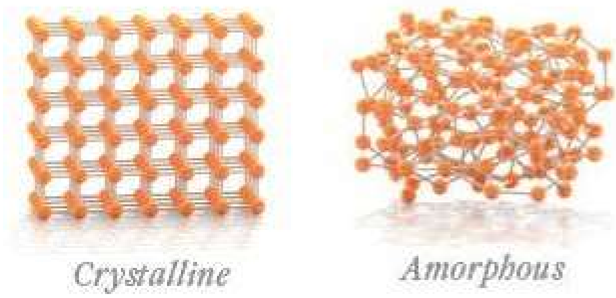
Examples:
•Carbon
•Silicon
•Germanium

Semiconductor bonded in a crystal

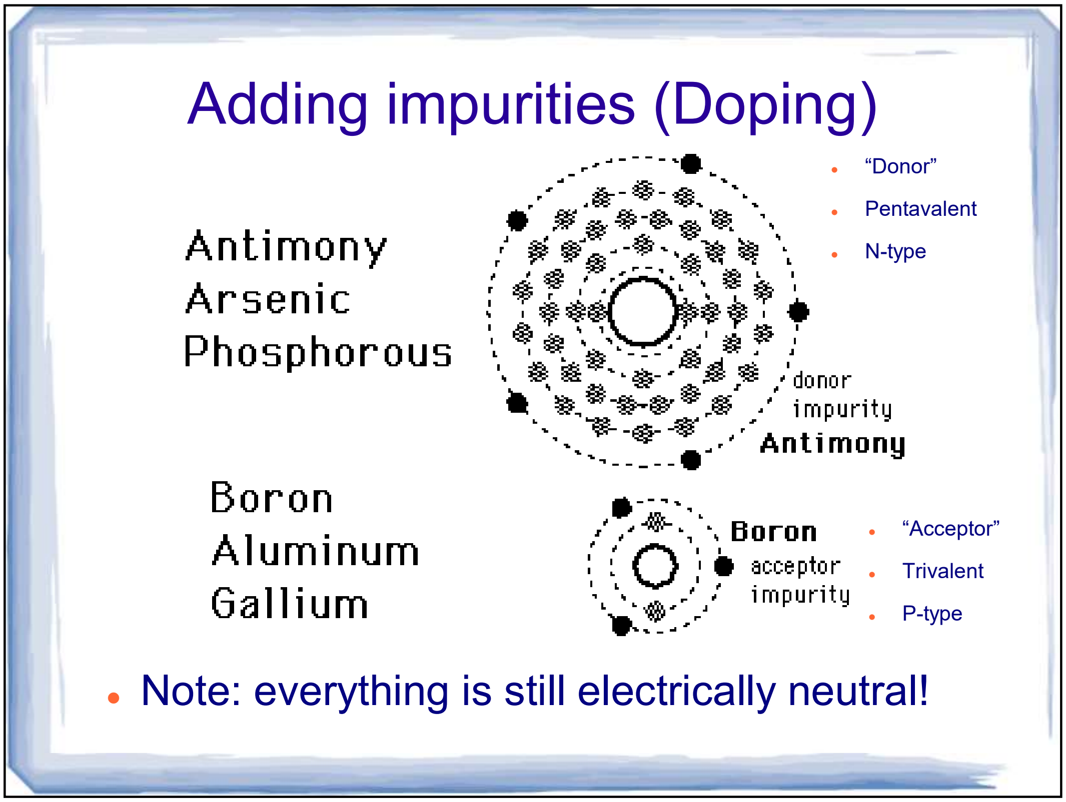


- Once bonded, they share electrons to fill their valence shells.
- Now the electrons are both electrically balanced, and in full valence shells.
- Electrons have no tendency to move. We've just made an insulator.

Crystals Vs. Non-Crystals



- Everybody get up and be atoms in a gas! A liquid, amorphous solid, crystalline sold



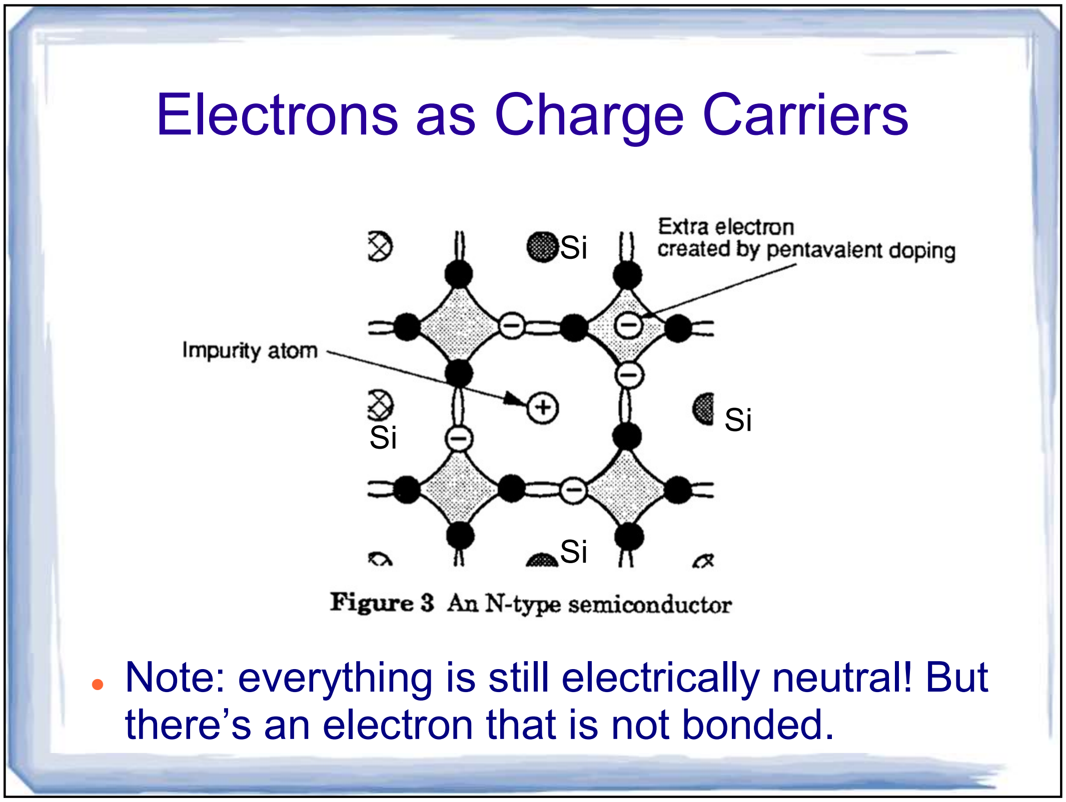
We add impurities to semiconductors to change their performance. This is called doping. Anyone need to get their giggles out?

Semiconductor doesn't mean we are trying to make it "partly conductive." That's called a resistor.
Semiconductor means we want to make it able to transition back and forth. It should act like an insulator when we tell it to, a conductor when we tell it to, and an "in-between" when we tell it to. (Remember, when converting AC to DC, we need it to conduct sometimes and block other times!)

Pentavalent: 5 electrons in the valence shell.
Still electrically balanced!

Trivalent: 3 electrons in the valence shell.
Still electrically balanced!

Advanced Note: doping atoms have conduction band energy levels that fall in the gaps between intrinsic material bands



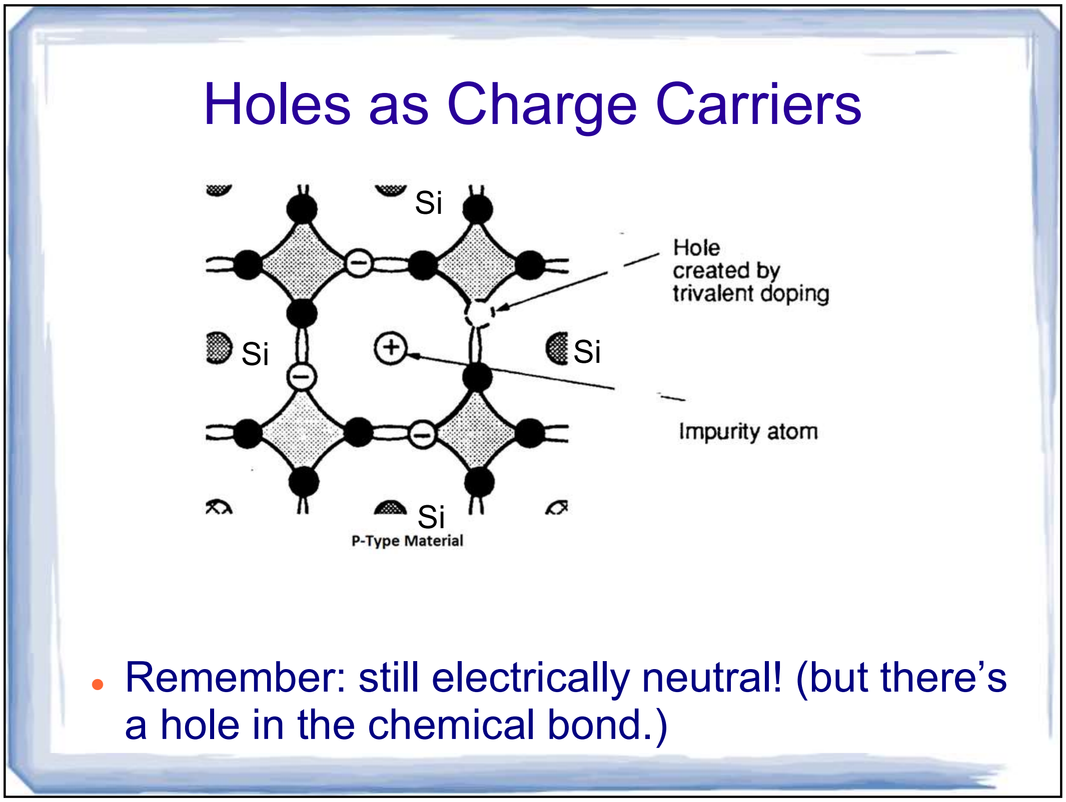
Add pentavalent doping material to semiconductor:

- Electrically balanced
- Valence shell is overfull.
- Extra electron is easier to move around than the bonded electrons
- This extra electron is available for current: it is considered a **"charge carrier"**

This is a terrible name. All electrons have "charge". But only this one gets the name. I apologize on behalf of electronics everywhere.

- THE ATOM IS NOT NEGATIVE! but it has an electron that doesn’t fit in the valence bonds.

- **N-type**



Add trivalent atom to the semiconductor lattice:

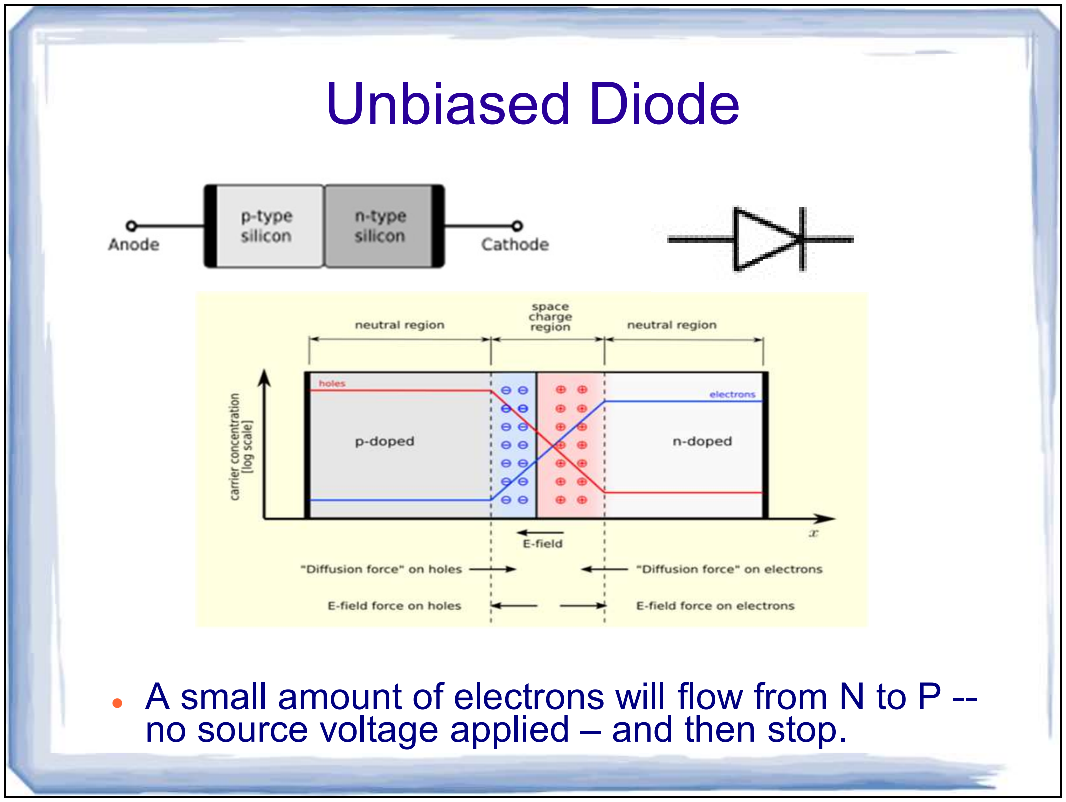
- Still electrically balanced
- Valence shell is not full – an electron can easily settle into the open spot, will be difficult to get back out
- The "holes" where electrons can go are considered to be **charge carriers**

This is also terrible. I'm so sorry. Holes don't have charge. I apologize on behalf of electronics again.

- ATOM IS NOT POSITIVELY CHARGED! It **CANNOT** attract an electron.
- But. If an electron, in its normal, inevitable,

random-ish movement around its nucleus, happens to overlap with that hole, it won’t be able to get itself back out.

- **P-type**



With no voltage across the component:

- Electrons flow a little, even though there is no voltage source! This is **diffusion current.** The place where they recombine: **Depletion region** (depleted of free charge carriers)
- They stop recombining when the negative ions in the P-type material repel the electrons strongly enough that the electrons' normal random motion no longer gets close enough to empty holes for the electrons to "fall in"
- Note: what is the electrical charge on the P, N material inside the depletion region? (P has negative ions in the depletion region and neutral ion elsewhere… N has positive ions in the depletion region and neutral ions elsewhere…)
- This is "charge separation" – i.e. voltage. This small voltage is called "**barrier potential**"

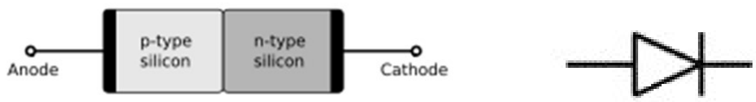
Now what happens if we put a voltage across it?

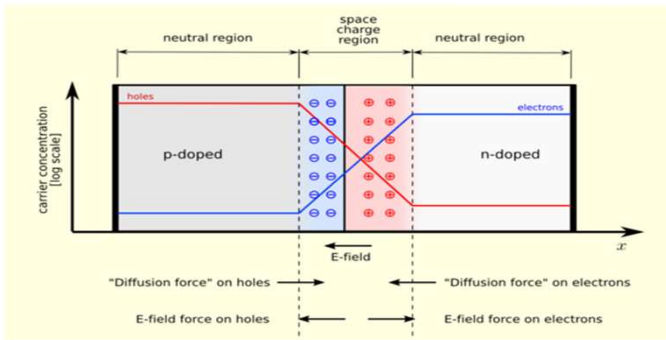
- If you push electrons into the N-type region, suck them out of the P-region: there are lots of holes for them to move through, and it conducts well. This is **forward bias**.

- If you push electrons into the P-type region: they recombine with holes, and settle down!   Now nothing is moving. This is “**reverse bias**” – when we consider the diode to be not conducting at all. This is a normal way to use a diode, and as long as the voltage isn’t too high, the diode is not permanently affected.

(Advanced note: A very small reverse (or “leakage”) current does flow – typ 50 nA; small enough that we usually ignore it.)

Forward Bias

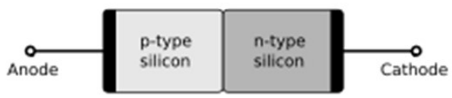


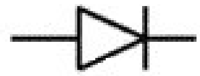


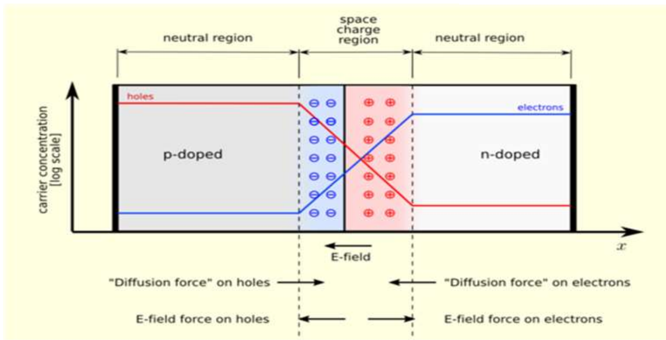
- When external voltage is applied, Electrons entering the cathode narrow the depletion region until it (nearly) disappears (forward bias)

(have students draw a battery and attach to the diode to show forward bias. Draw the electrons and effect on the ions)

Reverse Bias

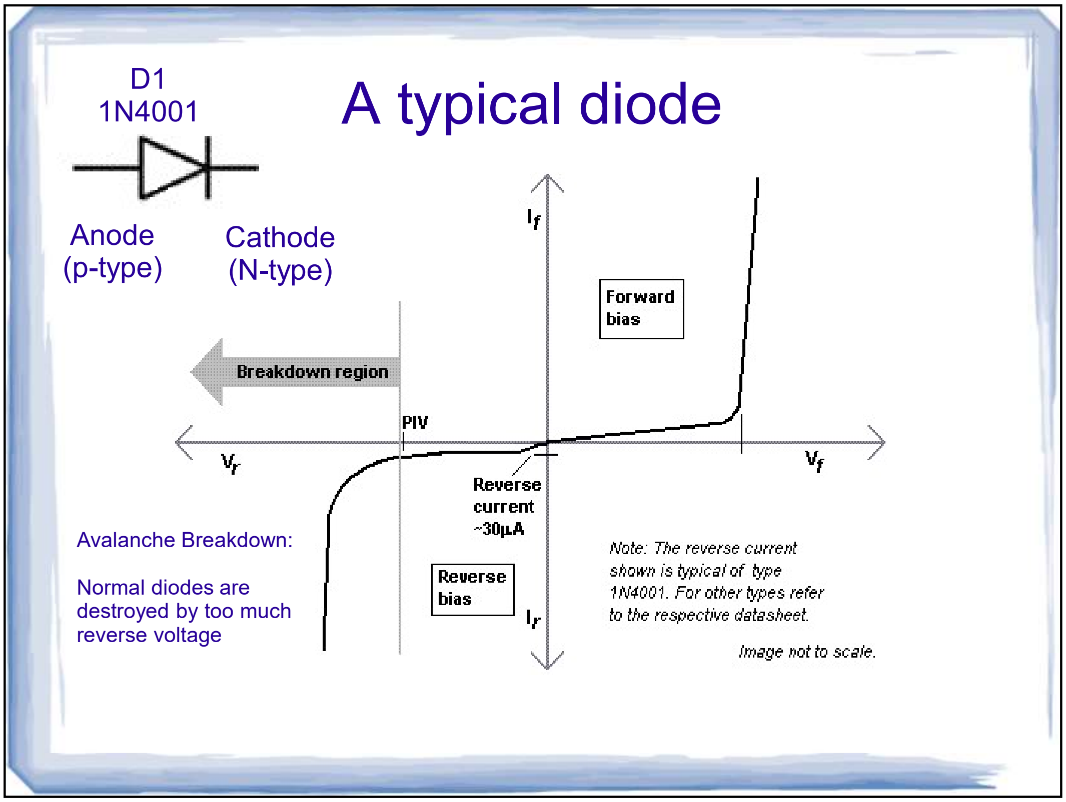






- Once external voltage is applied, electrons entering the anode widen the depletion region (reverse bias)

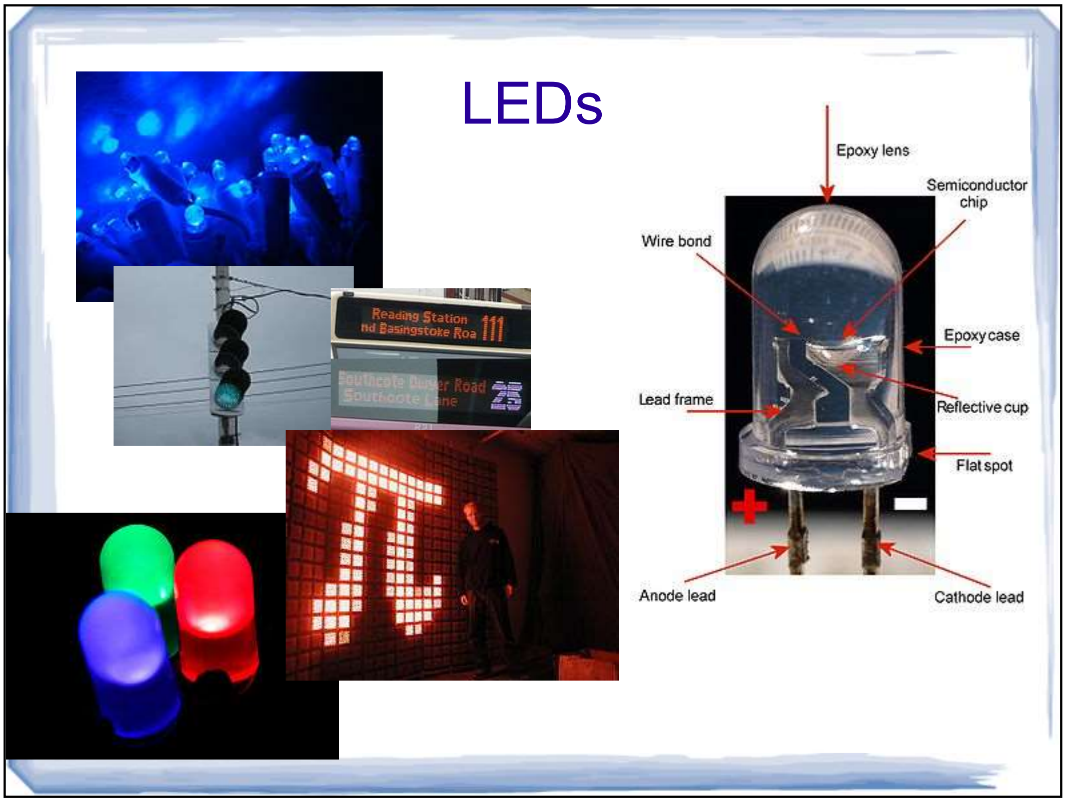
(have students draw a battery and attach to the diode to show reverse bias. Draw the electrons and effect on the ions)



- **Peak Inverse Voltage (Avalanche breakdown):** that's when you broke it
- You put enough voltage across it **backwards** that electrons are forced out of their bonds, knock other electrons out of their bonds, and tear the material apart
- How much backwards voltage is too much? This level is different for each model – depends on level of doping

- Some diodes are designed to work well and very stably when reverse biased: they experience **Zener breakdown**, which is not “broken” at all. It is the normal way a Zener diode works, and can be done without damaging the component.

- Semiconductors conduct MORE when **warm** – both forwards and backwards. (With resistors and most other materials, the reverse is true).
- Silicon is less affected by heat than germanium
- Internal heating can contribute to failure! That's why semiconductors need heat sinks, care when soldering

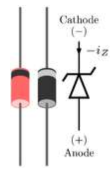


The P-N junction, when it is forward biased, not only conducts, but also emits photons (sometimes in the visible spectrum)

The photons are the energy released when loose electrons drop into holes

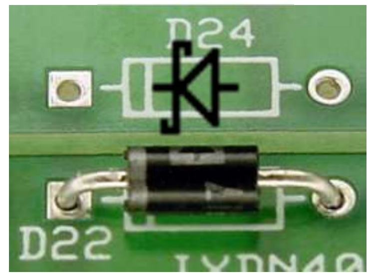
Like many physical effects, the reverse is also true. If you hit a PN junction with enough photons, some electrons will become energized enough to jump to the next energy level. No longer trapped in a group of 8, they are available to conduct, and the barrier potential causes them to flow. This is a solar panel, and it is the reason why the voltage of a single cell (0.5V or so) is the same as the voltage needed to make a diode begin to conduct (lots of textbooks will say that it’s exactly 0.7V, and below that it’s open and above that it’s closed, but that’s a lie, as you can see if you look at literally any diode data sheet on earth, I don’t know why textbooks say that, it’s awful.)

Other Special Diodes



- Zener diode: extremely stable voltage in reverse bias
- Zener Breakdown:

Normal reverse operation, not destructive



- Schottky diode: Very fast switching

Questions

1. Describe valence band's role in conductivity
2. Describe differences between conductor, insulator, resistor, semiconductor
3. Describe Structure of silicon crystal
4. Describe doping and carriers
5. Describe unbiased PN junction's depletion region
6. What happens to the atoms/electrons in forward bias?
7. What happens to the atoms/electrons in reverse bias?
8. Describe 2 types of breakdown current