LEDs and Lasers

Turn off all electronic devices

Observations about LEDs and Lasers

- LEDs and Lasers often have pure colors
- LEDs can operate for years without failing
- Lasers produce narrow beams of intense light
- Lasers are dangerous to eyes
- Reflected laser light has a funny speckled look

6 Questions about LEDs and Lasers

1. Why can't electrons move through insulators?
2. How does charge move in a semiconductor?
3. Why does a diode carry current only one way?
4. How does an LED produce its light?
5. How does laser light differ from regular light?
6. How does a laser produce coherent light?

Question 1

Q: Why can't electrons move through insulators?

A: Electrons can't easily change levels in insulators.

Electrons obey the rules of quantum physics

- In matter, electrons exist as quantum standing waves
  - three-dimensional patterns of nodes and antinodes
  - each wave "cycles" in place—it does not change with time
- In solids, those standing waves are called levels

To move, electrons must be able to switch levels

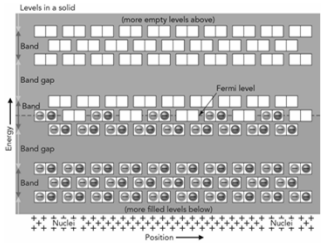
In an insulator, electrons can't easily change levels

Electrons in Solids

Electrons settle into a solid's lowest-energy levels

Levels clump into energy bands, leaving gaps

Fermi level: between last filled and first unfilled



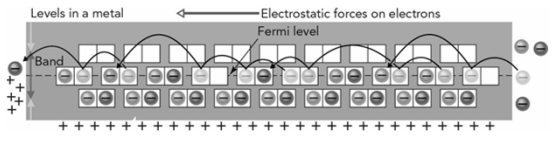
Metals

In a metal,

- the Fermi level has empty levels just above it in energy
- electrons near the Fermi level can change levels easily
- electrons can move in response to electric fields

The electrons are like patrons in a partly filled theatre

Current can flow through a metal



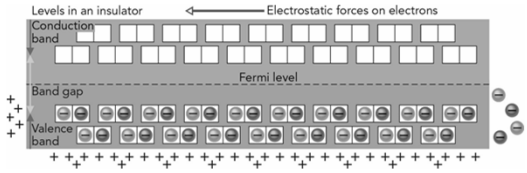
Insulators

In an insulator,

- the Fermi level has no empty levels nearby
- electrons can't move in response to electric fields

The electrons are like patrons in a completely filled theatre

Current can't flow through an insulator



Question 2

Q: How does charge move in a semiconductor?

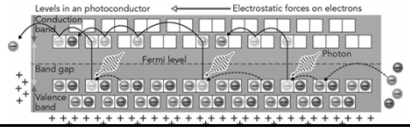
A: A semiconductor is an insulator with a small gap

Pure semiconductors are "poor insulators"

- empty conduction band is just above full valence band

The electrons are like patrons in a theater with a full ground floor but a low empty balcony

- Light or heat can allow current in pure semiconductor



Doped Semiconductors

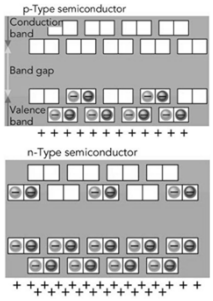
Dopant atoms can add or remove electrons

A p-type semiconductor

- has fewer electrons than normal
- has some empty valence levels

An n-type semiconductor

- has more electrons than normal
- has some filled conduction levels



Question 3

Q: Why does a diode carry current only one way?

A: Its p-n junction is asymmetric and special

When p-type and n-type semiconductors touch

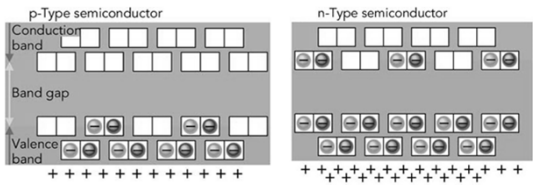
- they have different affinities for electrons
- electrons migrate from the n-type to p-type
- leaving a depletion region with no mobile charges

That junction can conduct current only one way

pn-Junction (before contact)

Before p-type semiconductor meets n-type,

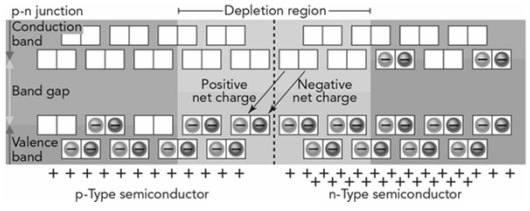
- each material can conduct electricity
- each material is electrically neutral throughout



pn-Junction (after contact)

After p-type semiconductor meets n-type,

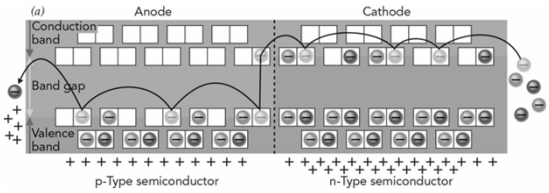
- electrons migrate from the n-type to the p-type
- an insulating depletion region appears at junction
- depletion region develops an electric field



Forward in the Diode

When electrons enter n-type and exit p-type,

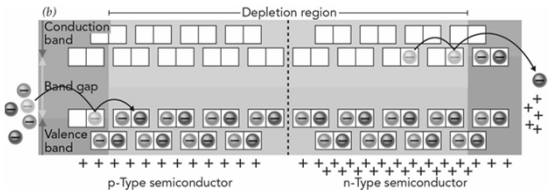
- depletion region's electric field is cancelled away
- depletion region shrinks
- diode can conduct current



Reverse in the Diode

When electrons enter p-type and exit n-type,

- depletion region's electric field is reinforced
- depletion region grows
- diode cannot conduct current



Question 4

Q: How does an LED produce its light?

A: Electrons emit light while changing bands

LEDs are Light-Emitting Diodes

- LED is a diode and has a pn-junction
- Electrons cross junction in the conduction band
- Electrons dropping into the valence band emit light
  - Electron briefly orbits the empty valence level
  - Electron drops into valence level via a radiative transition

The larger the band gap, the bluer the light

Question 5

Q: How does laser light differ from regular light?

A: Laser light is a single electromagnetic wave.

Most light sources produce photons randomly

- Each photon usually has its own wave

Laser light involves duplicate photons

- Laser amplification duplicates an initial photon
- Each photon becomes part of a single giant wave

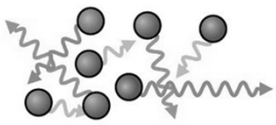
Spontaneous Emission

Excited atoms normally emit light spontaneously

These photons are uncorrelated and independent

Each photons has its own wave mode

These independent waves are incoherent light



Incoherent radiation
from excited atoms

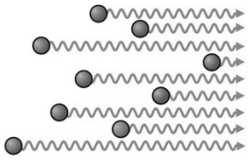
Stimulated Emission

Excited atoms can be stimulated into duplicating passing light

These photons are correlated and identical

The photons all have the same wave mode

This single, giant wave is coherent light



Coherent radiation
from excited atoms

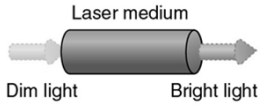
Question 6

Q: How does a laser produce coherent light?

A: A laser amplifier duplicates an initial photon.

Excited atom-like systems can act as laser medium

- Duplicate photons they're capable of emitting
- Duplication is perfect: the photons are true clones

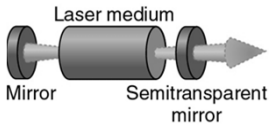


Laser Oscillation

A laser medium can amplify its own light

- A laser medium in a resonator acts as an oscillator
- It duplicates its one of its own spontaneous photons
- Duplicated photons leak from semitransparent mirror

The photons from this oscillator are identical



Summary about Lasers and LEDs

Lasers produce coherent light by amplification

Coherent light contains many identical photons

Laser amplifiers and oscillators are common

LEDs are incoherent, light-emitting diodes