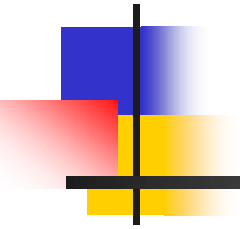


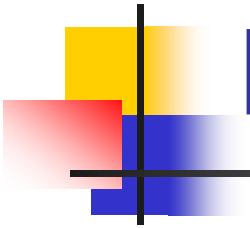
Organic Light Emitting Diodes (OLEDs)

Physics 496/487

Matt Strassler

Why OLEDs

- Lighting efficiency
  - Incandescent bulbs are inefficient
  - Fluorescent bulbs give off ugly light
  - LEDs (ordinary light emitting diodes) are bright points; not versatile
  - OLEDs may be better on all counts
- Displays: Significant advantages over liquid crystals
  - Faster
  - Brighter
  - Lower power
- Cost and design
  - LEDs are crystals; LCDs are highly structured; OLEDs are not –
    - Malleable; can be bent, rolled up, etc.
    - Easier to fabricate
- In general, OLED research proceeds on many fronts

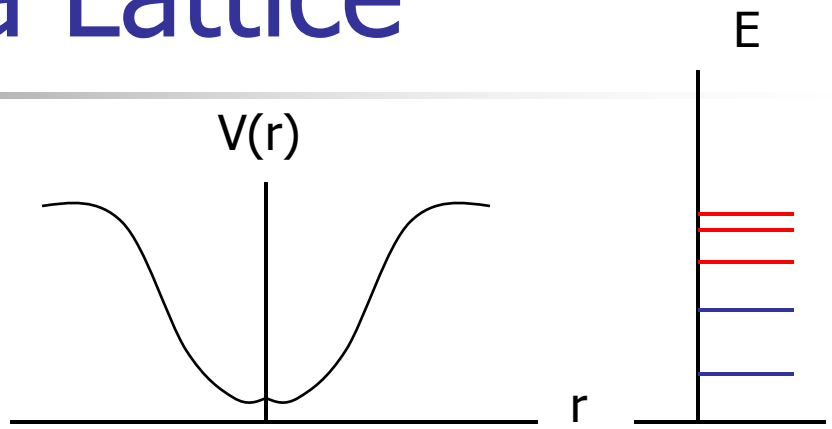


Plan of talk

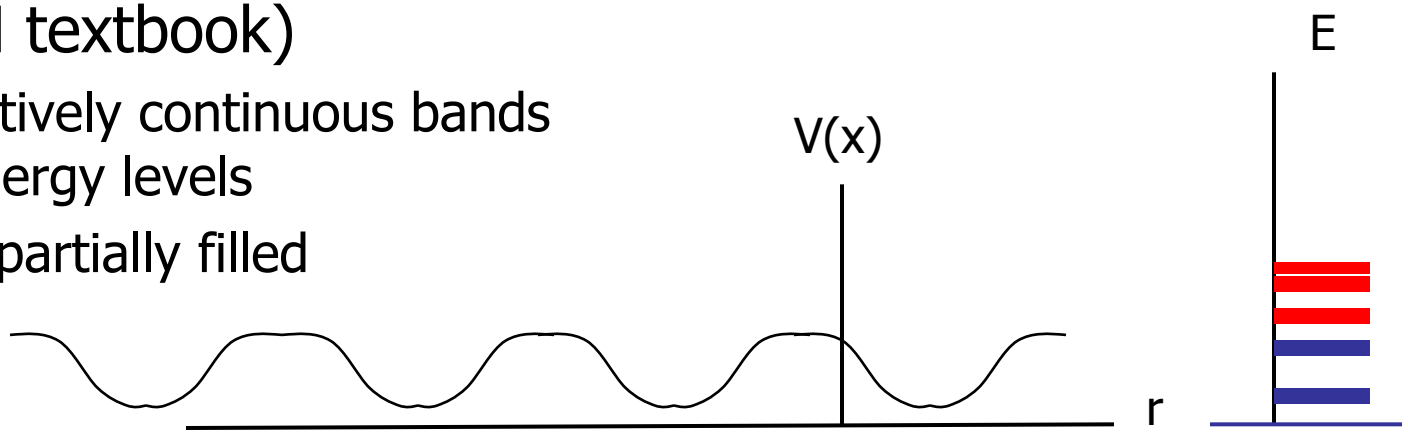
- Light-Emitting Diode
  - Bands and Conduction
  - Semiconductor
  - Standard Diode
  - Light Emission
- Organic Light-Emitting Diode
  - Organic Semiconductors
  - Organic Diode
  - Light Emission

Electrons in a Lattice

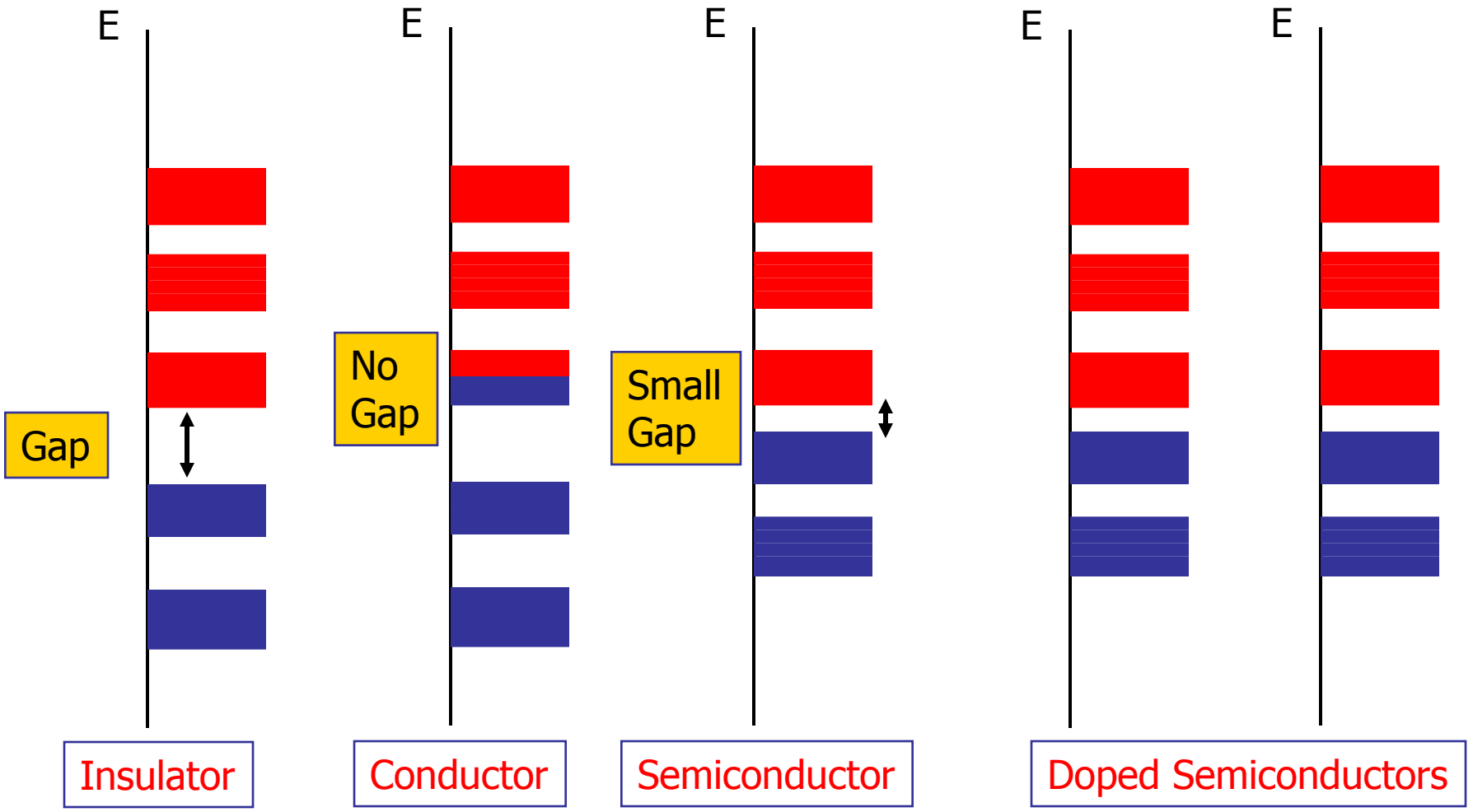
- Atom has bound states
  - Discrete energy levels
  - Partially filled by electrons



- Periodic array of atoms (cf. QM textbook)
  - Effectively continuous bands of energy levels
  - Also partially filled

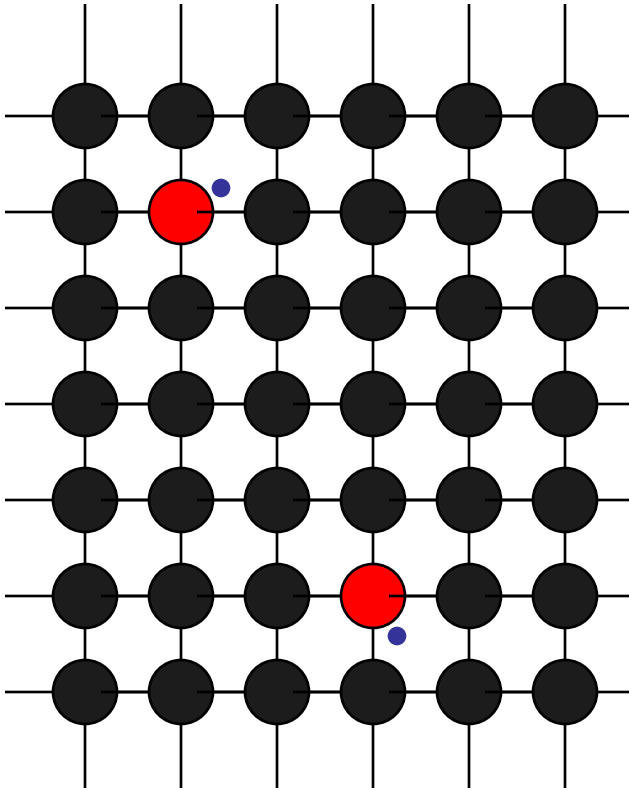


The Bands on Stage

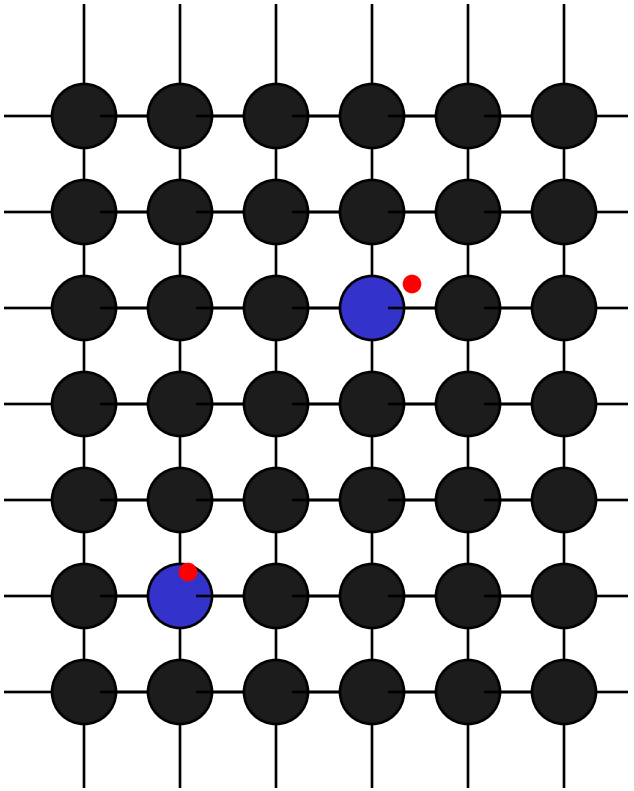


Doping – Add Impurities

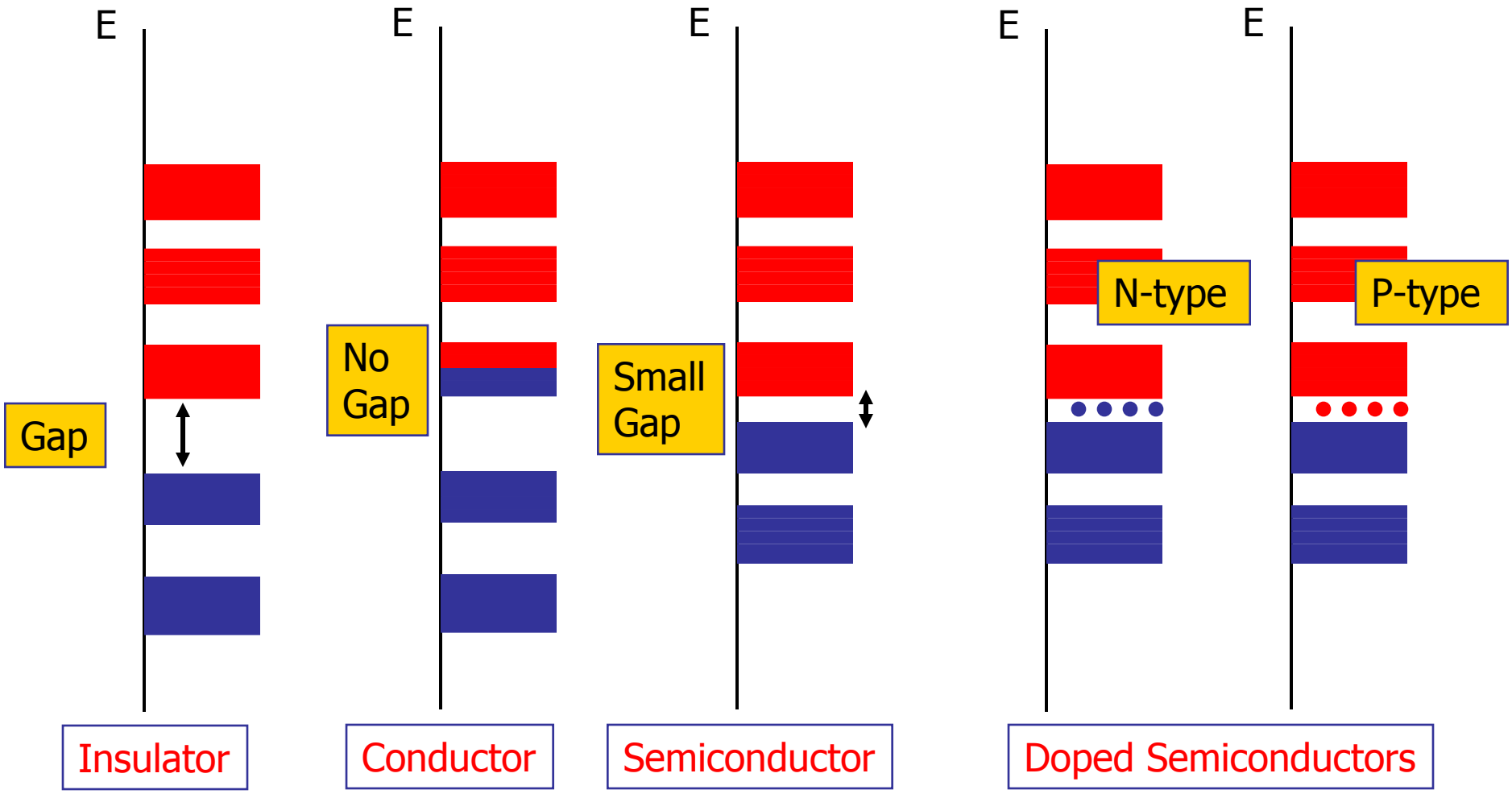
N-type



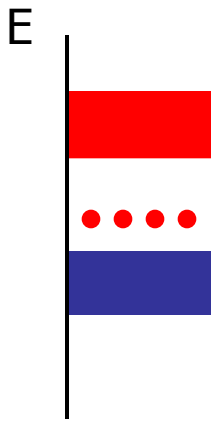
P-type

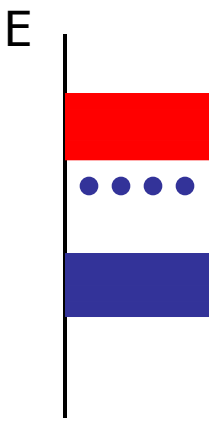


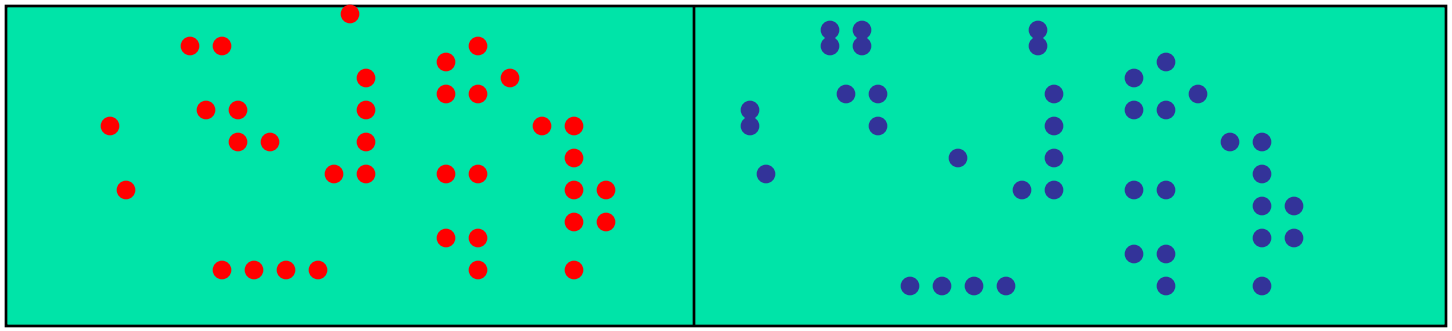
The Bands on Stage



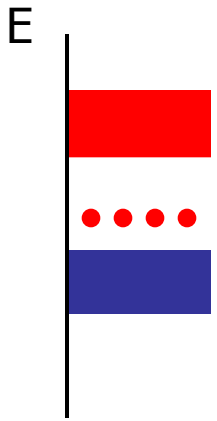
Diode: p-type meets n-type

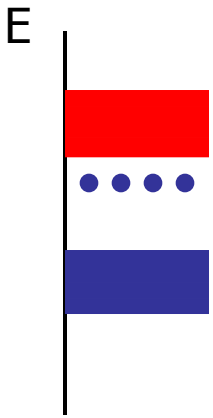


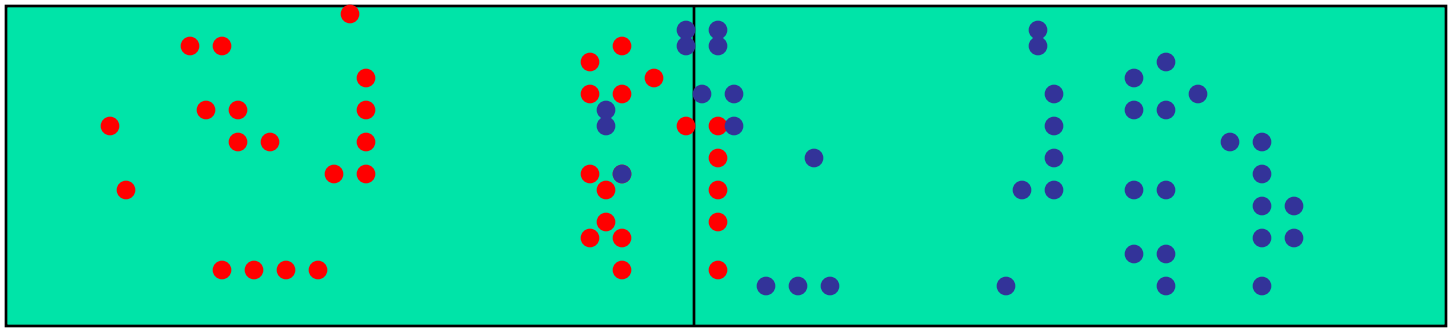




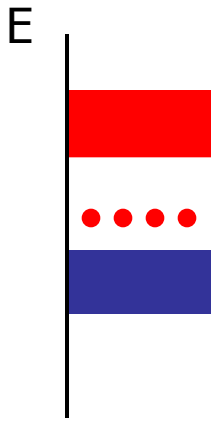
Diode: p-type meets n-type

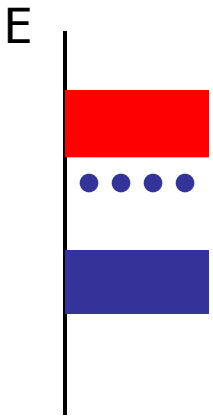


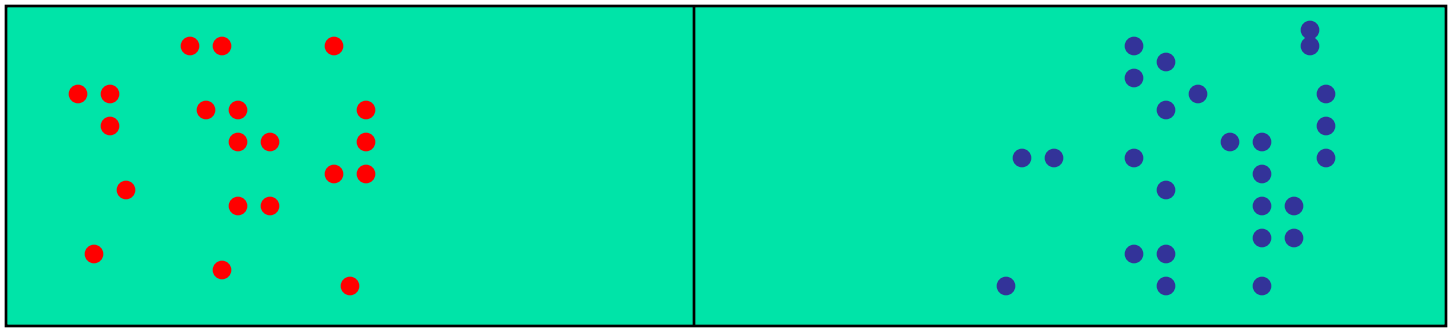




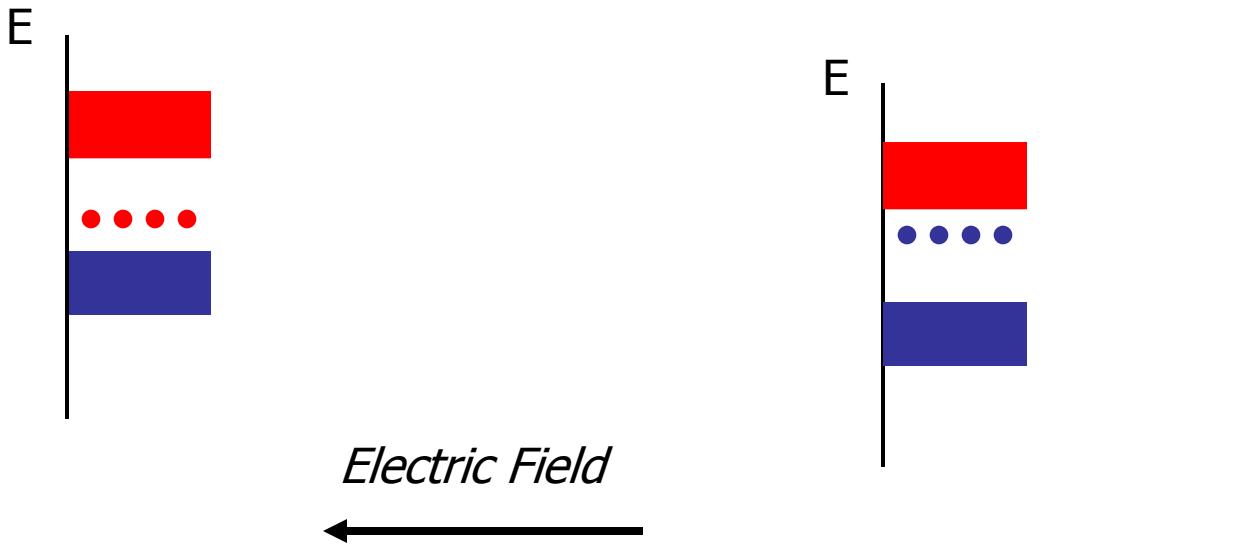
Diode: p-type meets n-type







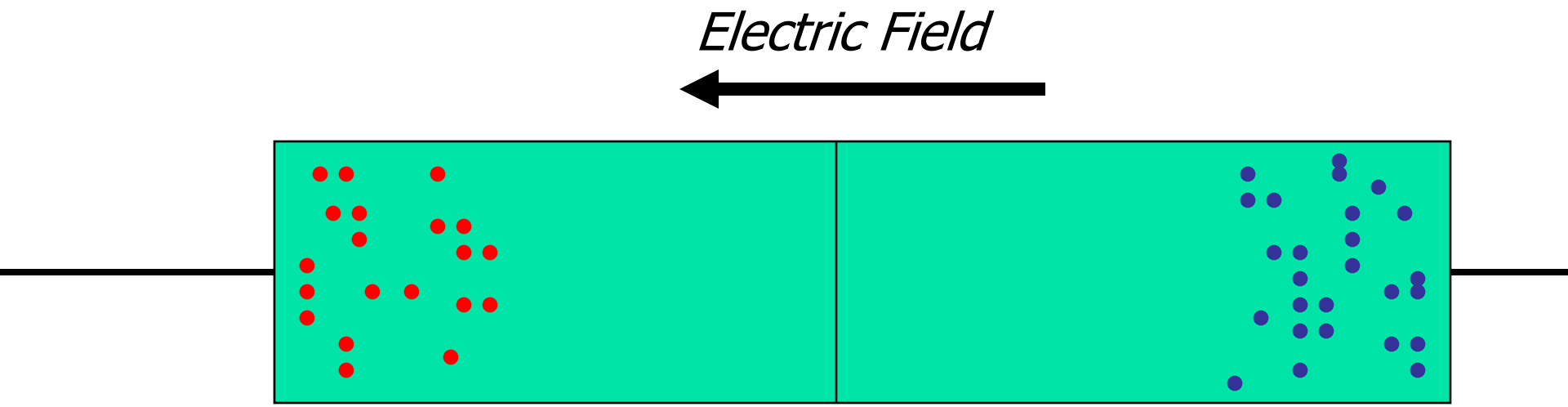
Diode: p-type meets n-type



Diode: p-type meets n-type

Try to make current flow to **left**?

Depletion Zone Grows

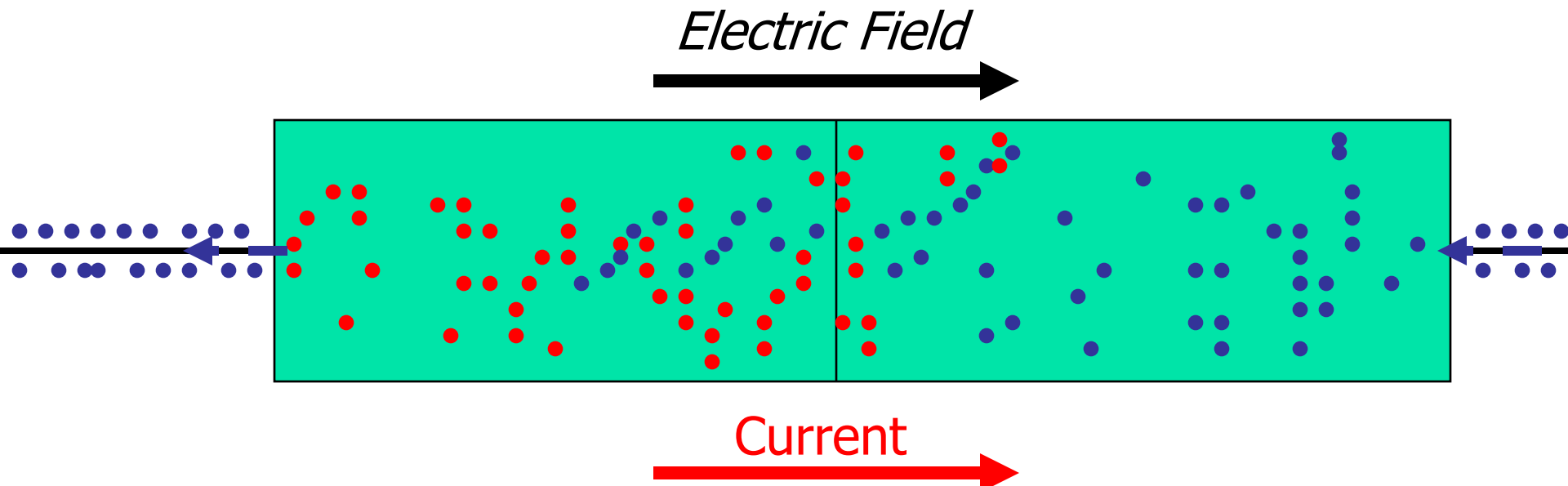


Diode: p-type meets n-type

Try to make current flow to **right**?

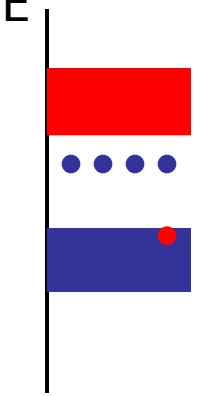
Current Flows!

Electrons in higher band meet Holes in lower band



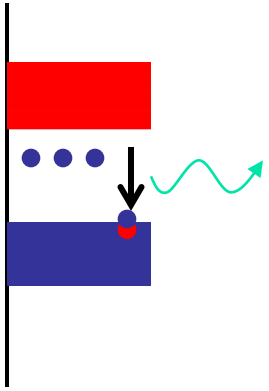
Excitons

- Electron in higher band meets a hole in lower band



- The two form a hydrogen-like bound state! ***Exciton!***
  - Like "positronium"
    - Can have any orbital angular momentum
    - Can have spin 0 or spin 1
  - Annihilation
    - Rate is slow
    - Electron falls into hole
    - Energy emitted

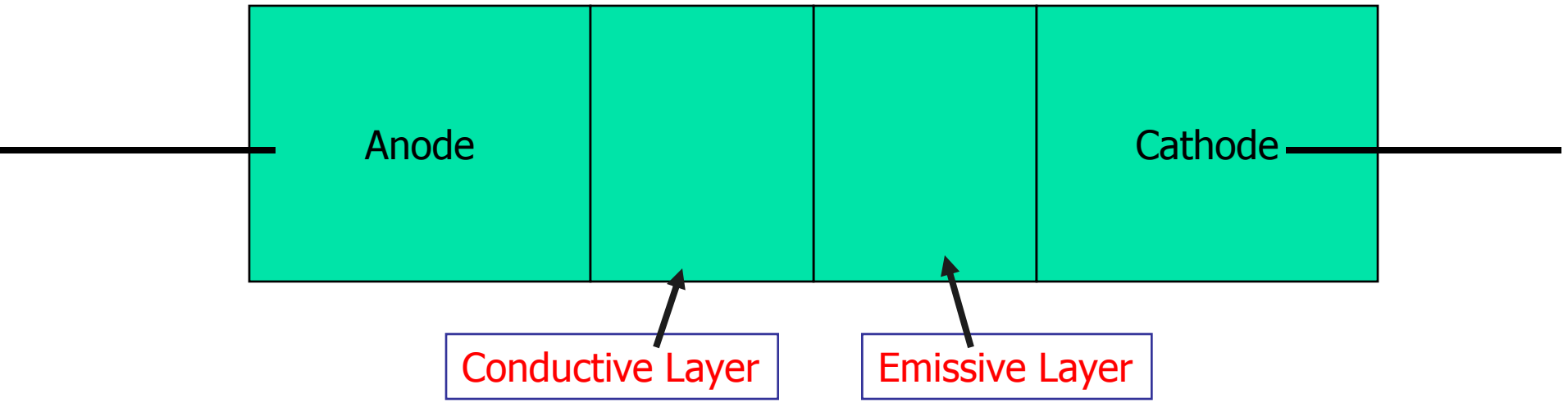
- Energy released as electron falls into hole
  - May turn into vibrations of lattice ("*phonons*") – heat
  - May turn into ***photons*** (only in some materials)
    - Infrared light (if gap ~ 1 eV) – remote control
    - Visible light (if gap ~ 2-3 eV) – ***LED***
  - May excite other molecules in the material (if any; see below)



Organic Semiconductors

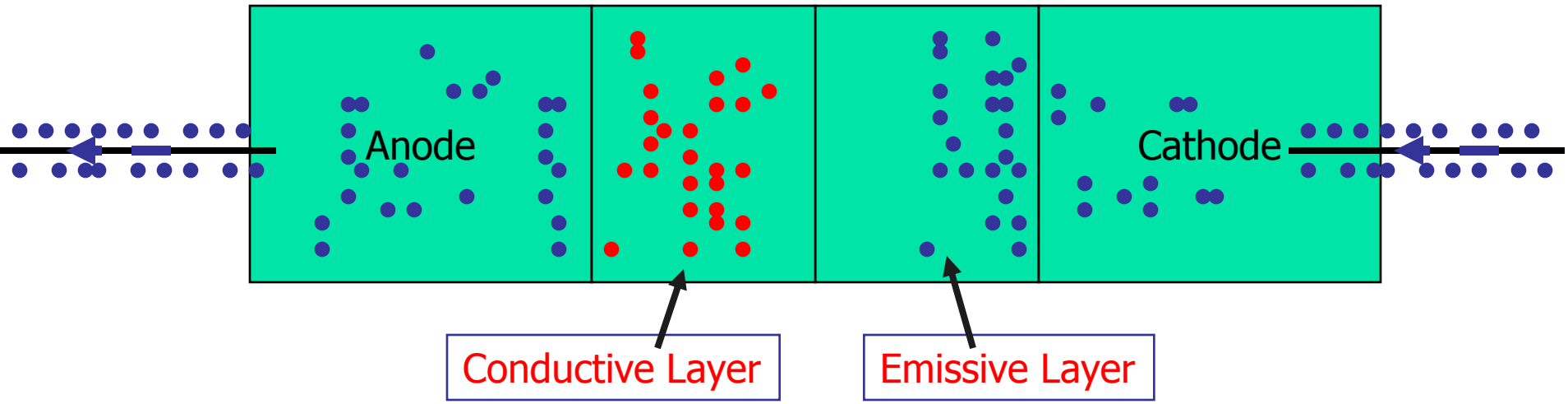
- These are not crystals! Not periodic structures
- Band structure is somewhat different
  - "Orbitals" determined by shape of organic molecule
    - Quantum chemistry of pi bonds, not simple junior QM
  - Polymers are common
- Conduction is different
  - Electrons or holes may wander along a polymer chain
  - As with inorganic conductors
    - Some materials allow electrons to move
    - Some materials allow holes to move – *typical for organics!!*
- Doping is more difficult
  - Doping typically not used
  - Instead electrons/holes are provided by attached metals

The basic OLED



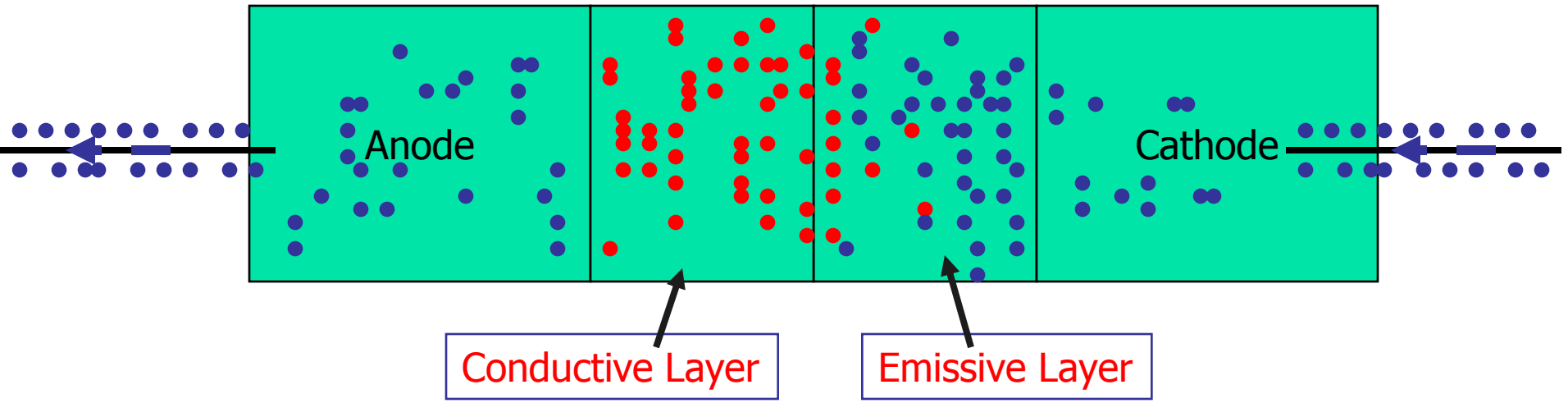
The basic OLED

- The holes move more efficiently in organics



The basic OLED

- The holes move more efficiently in organics
- Excitons begin to form in emissive layer



The Exciton Exits in a Flash

- As before, excitons eventually annihilate into
  - Molecular vibrations → heat (typical)
  - Photons (special materials, rare)
- But with organics, can add
  - Fluorescent molecules
  - Phosphorescent molecules

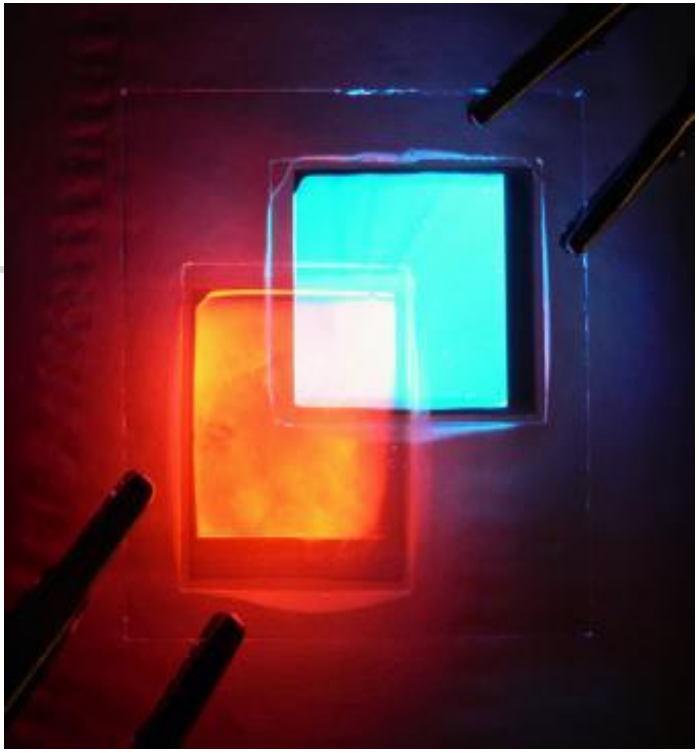
  e.g. attach to end of polymer
- Light can be generated indirectly:
  - Exciton can transfer its energy to this molecule
  - Molecule is thus excited
  - Returns to ground state via fluorescence or phosphorescence
- Greatly increases likelihood (per exciton) of light emission
- Also allows for different colors
  - determined by the light-emitting molecule(s), not the exciton

OLEDs

- Similar physics to LEDs but
  - Non-crystalline
  - No doping; use cathode/anode to provide needed charges
  - Fluorescence/phosphorescence enhance exciton→light probability
- Manufacturing advantages
  - Soft materials – very malleable
  - Easily grown
  - Very thin layers sufficient
- Many materials to choose from
- Relatively easy to play tricks
  - To increase efficiency
  - To generate desired colors
  - To lower cost

- ***Versatile materials for future technology***

Some references



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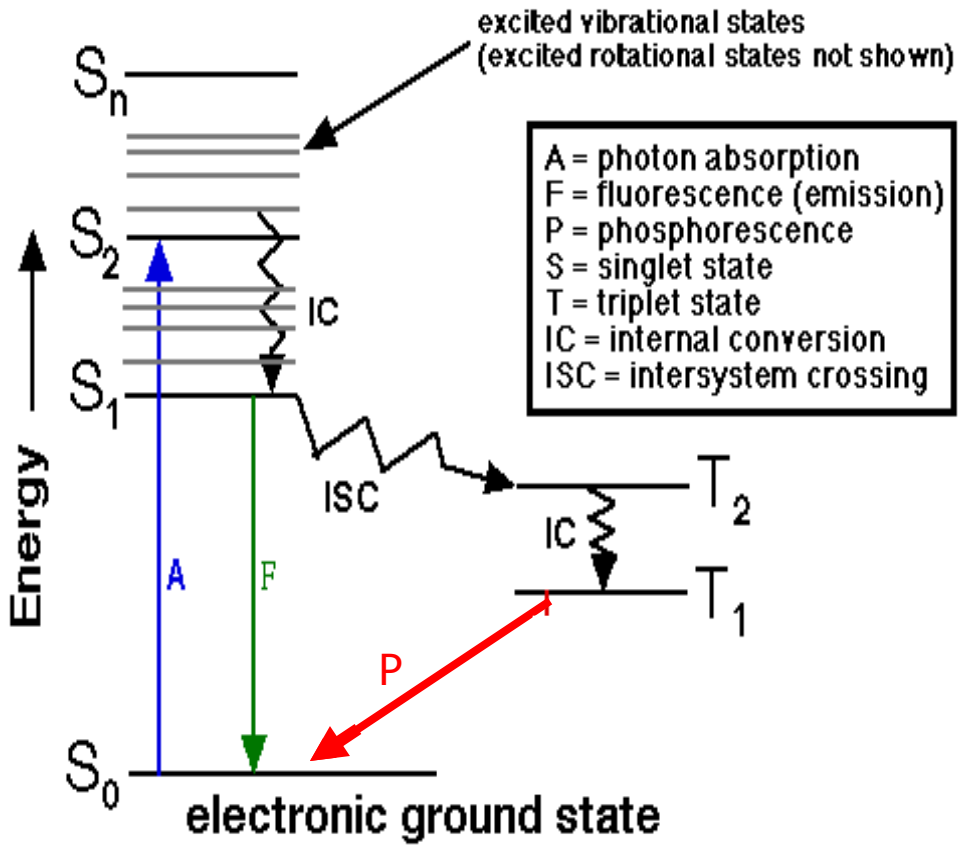
  - Nature 395, 151-154 (10 September 1998)
- *Various Wikipedia articles, classes, etc.*

A neat trick



- Exciton
  - Spin 0 (singlet)
  - Spin 1 (triplet)
  - Can transfer its energy but not its spin to molecule
  - Thus spin-1 can't excite fluorescents
  - Lose ¾ of excitons
- But
  - Use phosphors
  - Bind to polymer so that exciton can transfer spin
- Then 4 times as many excitons cause light emission