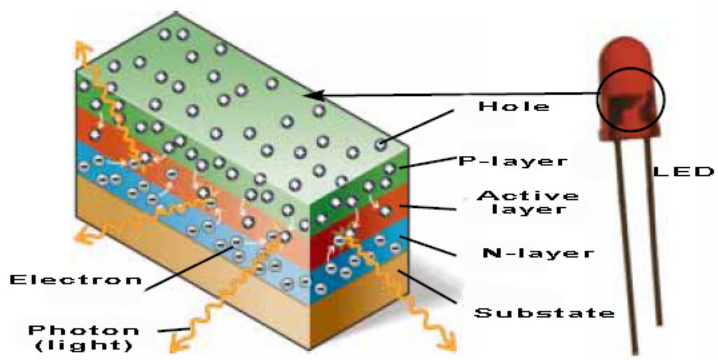
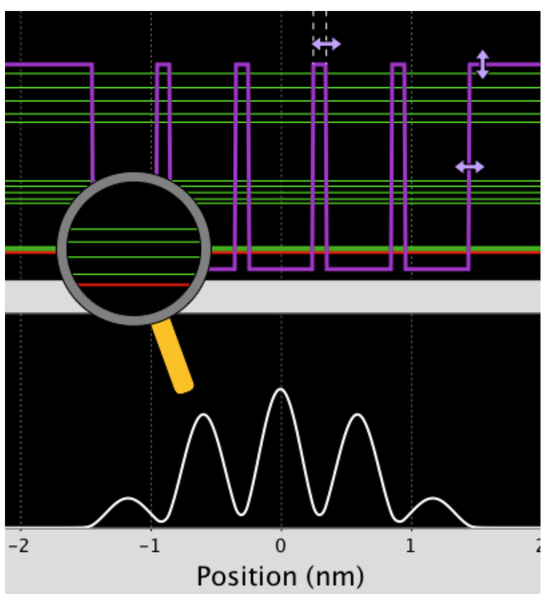
# Semiconductors & LEDs




Day 37, Phys 2130
Questions?
Semiconductors &LEDs

Next up:
EPR, Entanglement, Bell,

# Bound State Sim.. Many Wells

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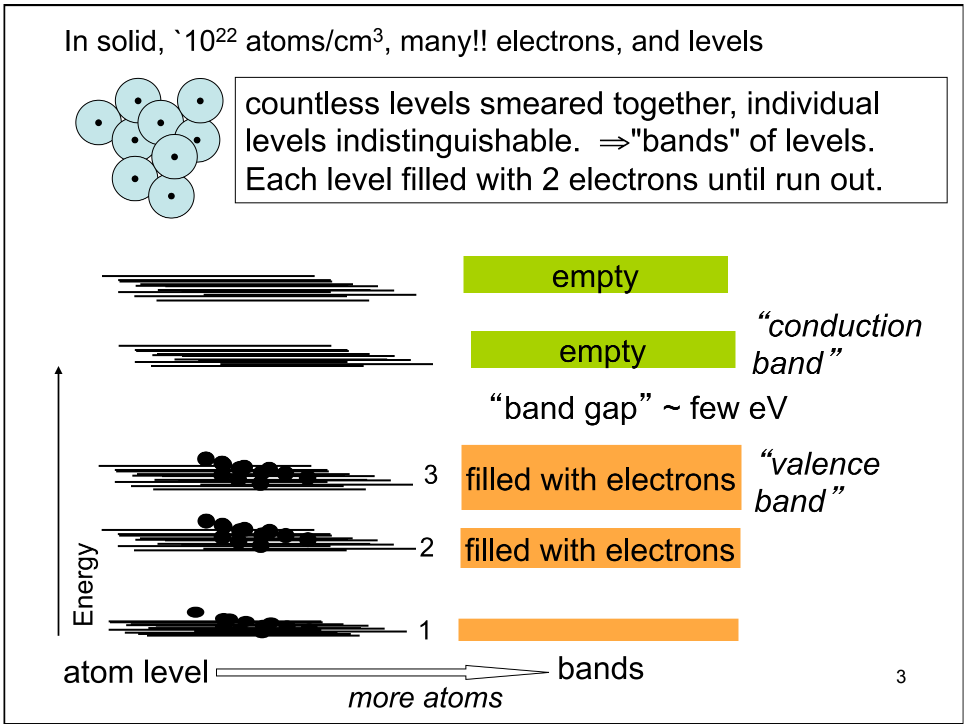
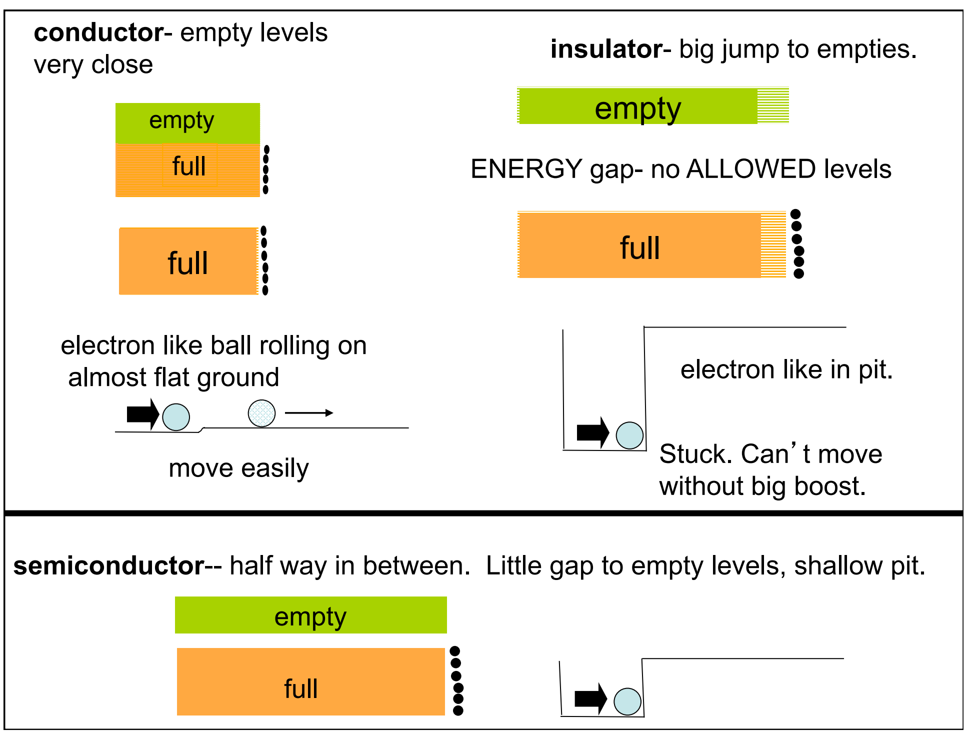
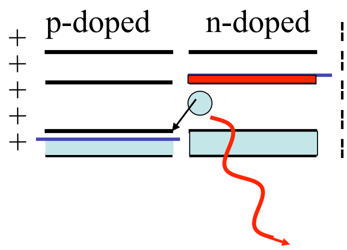
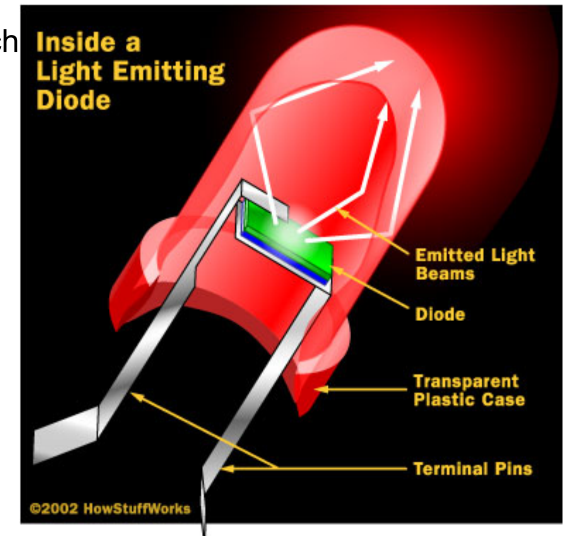

In solid, `$10^{22}$ atoms/$cm^3$, many!! electrons, and levels
countless levels smeared together, individual levels indistinguishable. ⇒"bands" of levels. Each level filled with 2 electrons until run out.
empty
empty
“conduction band”
“band gap” ~ few eV
3
filled with electrons
“valence band”
2
filled with electrons
1
Energy
atom level
more atoms
bands
3


conductor- empty levels very close
empty
full
full
electron like ball rolling on almost flat ground
move easily
insulator- big jump to empties.
empty
ENERGY gap- no ALLOWED levels
full
electron like in pit.
Stuck. Can’t move without big boost.
semiconductor-- half way in between. Little gap to empty levels, shallow pit.
empty
full

LEDs -- don't burn out, high efficiency. Stoplights, bike lights, fancy flashlights.

Really good LEDs reach laser conditions--
diode lasers

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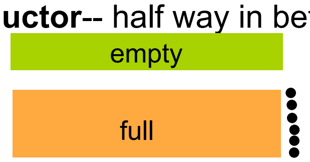
**Insulators and conductors**

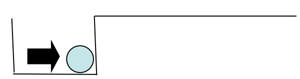
Good in wires, electricity for lights and heating, electric motors, telegraph (I=V/R stuff).

For more interesting electrical stuff need more control- small currents &voltages control higher powers ("nonlinear circuit elements").

**Semiconductor**-- half way in between. Little gap to empty levels.




how many have class on semicond?



sensitive enough so people can affect conductivity of material

What are possible ways could get electron to higher empty level (out of pit), so could move to conduct electricity?
Discuss as many as can think of that are practical.

**n.b.** Applying a voltage across (battery) will not work… why?
Think about voltage /electron…. (how much V how many e's…?)

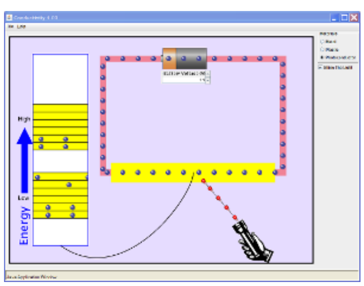
Change conductivity of semiconductors by:
1) light,
2) heat
**3) (most important) designer dirt "doping" basis of diodes and transistors (all electronics)**

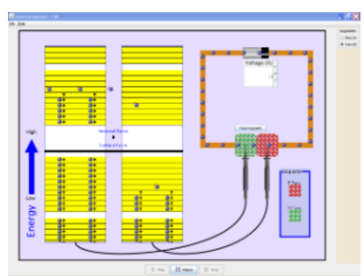
**diodes-** pass current in only one direction.
junction of P doped and N doped semiconductors.
(also light emitting diodes LEDs, diode lasers-pointer).

Analogy: turn-style for current.

**transistors-** use voltage (low power) to control large currents and voltages.

Analogy: valve for current





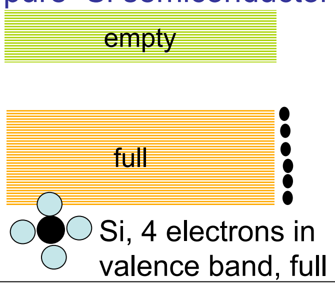

PhET conductivity sim on phet site
(also semiconductor and diode sim there)

https://phet.colorado.edu/en/simulation/conductivity

http://phet.colorado.edu/en/simulation/semiconductor

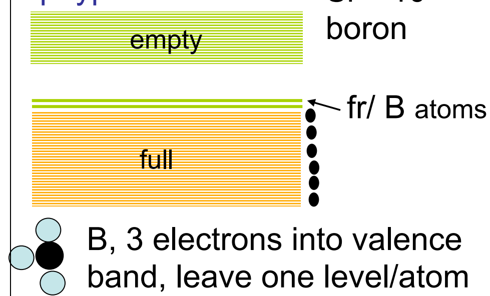
Diodes and transistors -Junctions of P doped and N doped semiconductors.

pure Si semiconductor



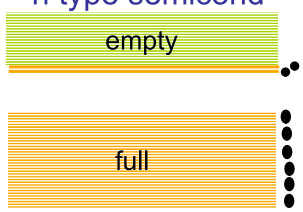

Si, 4 electrons in valence band, full

p type semicond. Si + $10^{-7}$ boron

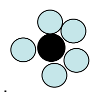



B, 3 electrons into valence band, leave one level/atom unfilled, $10^{-7}$ fraction

n type semicond



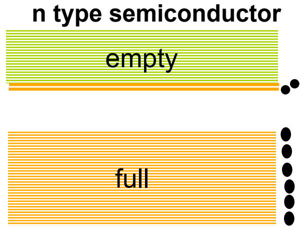

Si + $10^{-7}$ Phosphorus



P, 4 electrons go into valence band, 1 extra up into conduction

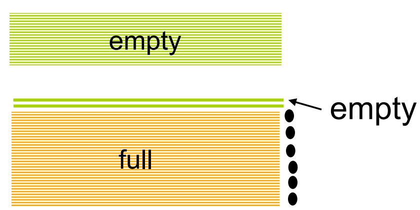
How conduct? a) all ~same
b) pure best, c) pure no, P and N ~same,
d) only N conducts, e) only P cond.

**n type semiconductor**




Si + tiny fraction Phosphorus

**p type semiconductor**



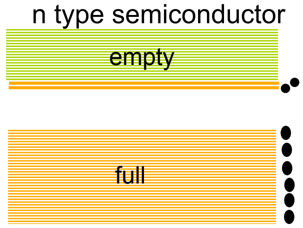

n- electrons in conduction (top) band can move.

p- electrons at top of valence band move into empty levels.

**ans. c.** n and p type both conduct ok (not great), pure Si does not conduct. **See phet sim.**

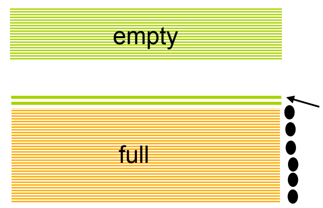
**DOPING--EXTRA OR MISSING FREE/MOVEABLE ELECTONS, IS NOT(!) EXTRA TOTAL CHARGE.**
**ATOMS ARE ALSO EXTRA OR MISSING PROTONS!**
**TYPICALLY BOOKS (AND THESE NOTES) JUST SHOW MOVEABLE ELECTRONS!**
Have to pay careful attention to keep straight moveable electrons vs. net charge,but distinction is important. Take some notes to refer to later in class.

n type semiconductor




Si + tiny fraction Phosphorus

p type semiconductor



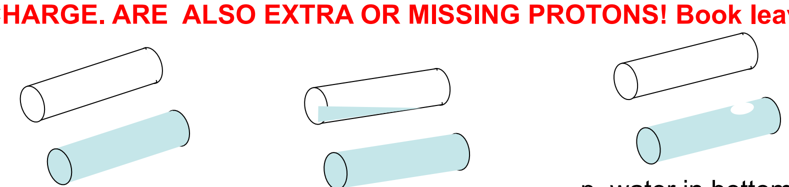

Si + tiny fraction Boron

n and p type both conduct ok (not great)

n- electrons in conduction (top) band can move.

p- electrons at top of valence (lower) band can move into empty levels.

**DOPING--EXTRA OR MISSING FREE ELECTONS, NOT(!) EXTRA CHARGE. ARE ALSO EXTRA OR MISSING PROTONS! Book leaves out!**

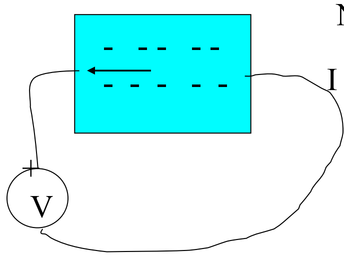


pure, no flow when tilt

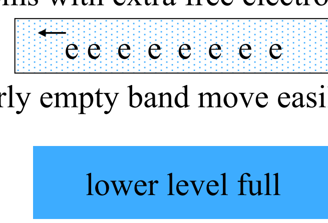
n, water in top flow

p, water in bottom flows, but if small bubble, see it.

Doped semiconductors, add or subtract some charges to allow charges to move.

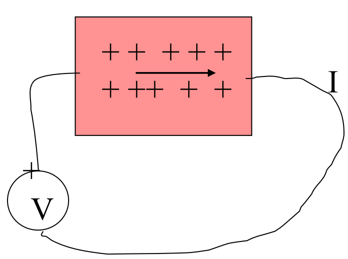


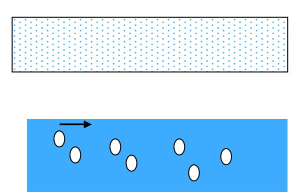

N type- atoms with extra free electrons




in nearly empty band move easily

**DOPING--EXTRA OR MISSING FREE ELECTONS, NOT(!) EXTRA CHARGE. IS ALSO EXTRA OR MISSING PROTONS! Book leaves out!!!**



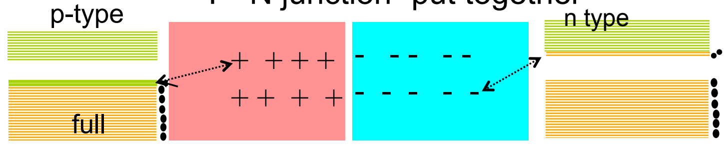



electrons missing,"holes", leave room to move easily

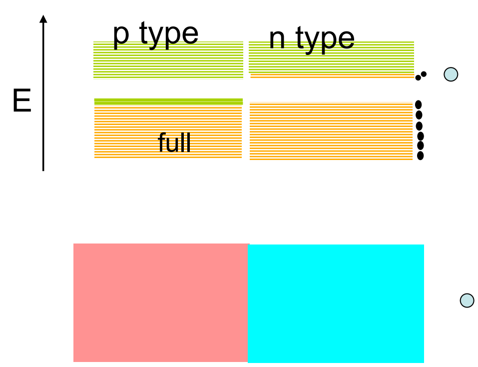
**When semiconductors get really useful--**

P and N types stuck together.
Diodes (& LEDs) - PN junctions.
Transistors- PNP or NPN junctions

P- N junction- put together




diode conducting



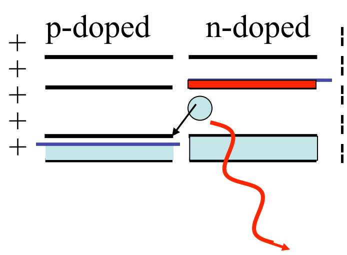

As electron moves across junction going from N type on right to P type on left

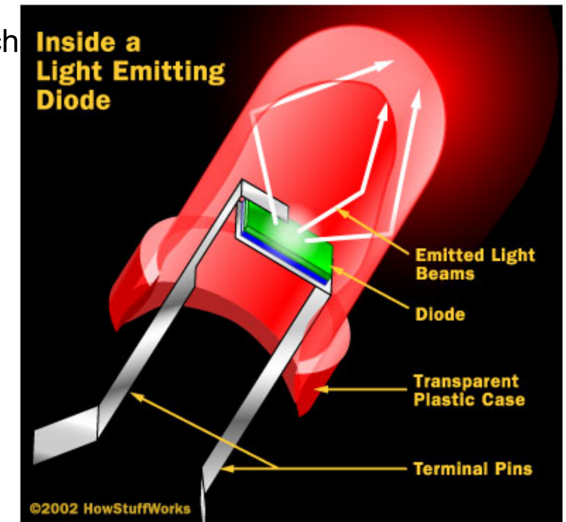
a. it stays at the same energy
b. it gains potential energy (if so from where?)
c. it loses potential energy (if so to where?)

**c. loses potential energy-** goes into 1) heat (vibrating atoms) or 2) if proper materials, light ( light emitting diode)

LEDs -- don’t burn out, high efficiency. Stoplights, bike lights, fancy flashlights.

Really good LEDs reach laser conditions-- diode lasers

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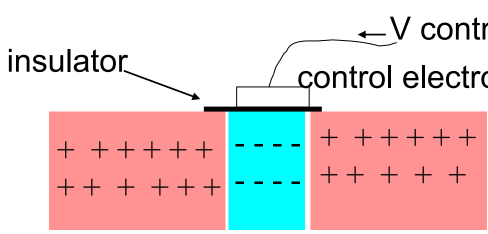


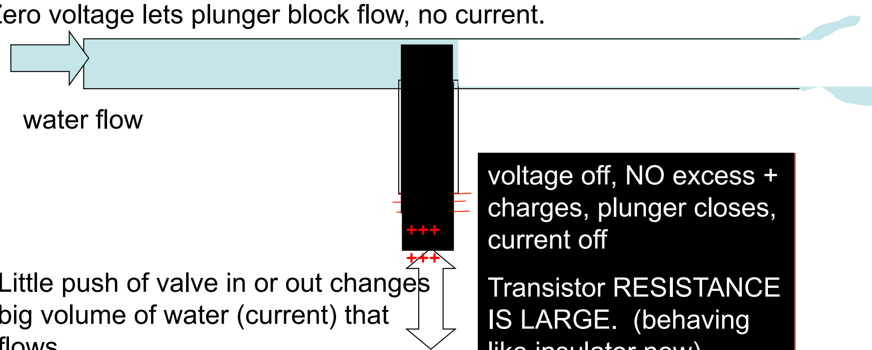

P-N-P doped semicond.
“P type” transistor(?!)

**<u>transistors-</u>** have two NP junctions
NPN or PNP sandwiches-- double depletion region.
Plus have “gate” electrode to control depletion region.

**Control voltage sucks in or pushes out moveable electrons from depletion region.**
**Controls whether current can flow or not.**

**Just FYI: not responsible for HW /exams**

Transistor like plunger valve on spring that blocks flow of water as the block moves in and out.
Positive voltage applied is like pulling plunger back, big current,
Zero voltage lets plunger block flow, no current.

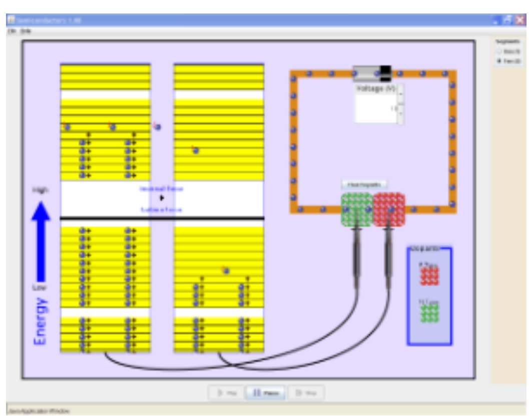



Little push of valve in or out changes big volume of water (current) that flows.

voltage off, NO excess + charges, plunger closes, current off

Transistor RESISTANCE IS LARGE. (behaving like insulator now)

# Prelude to Long Answer



What does it take to:

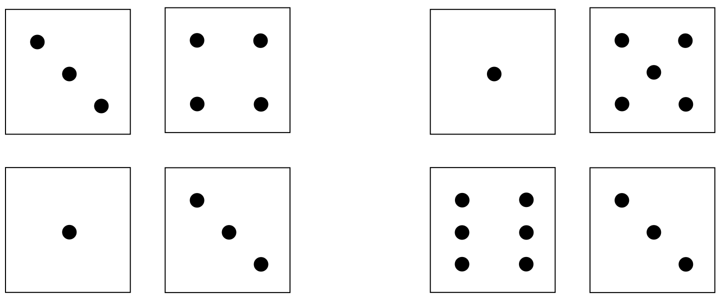
- Change the current?
- Change the brightness? (how?)
- Change the color? (How?)

# The Farmer and the Seeds

(a parable of scientific reasoning)

- A seed is a square with some dots on it.
- The farmer always plants 4 seeds in a group.

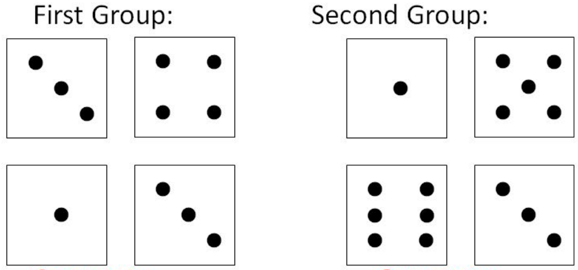
First Group: Second Group:



- Farmer observes # of sprouts each group produces.

# The Farmer and the Seeds

First Group: Second Group:



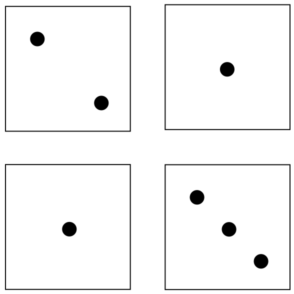
4 sprouts 6 sprouts

**Possible Schemes**

1. Totally Random (Numbers aren't related to # of sprouts)
2. (Largest Number) = (# of Sprouts)
3. (Number that is even) = (# of Sprouts)
4. (Second Largest Number) + (Smallest Number) = (# of Sprouts)
5. [(Sum of all Numbers) – 3] / 2 = (# of Sprouts)

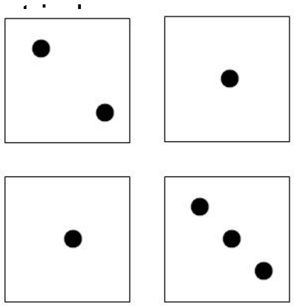
# The Farmer and the Seeds

Another seed grouping the farmer tried:



What is the prediction of each of the different schemes the class has come up with for this seed grouping?

Another seed grouping the farmer



**2 sprouts!**

**<u>Possible Schemes</u>**

1. Totally Random (???)
2. ~~(Largest Number) = 3 Sprouts~~
3. (Number that is even) = 2 Sprouts
4. ~~(Second Largest Number) + (Smallest Number) = 3 Sprouts~~
5. [(Sum of all Numbers) – 3] / 2 = 2 Sprouts

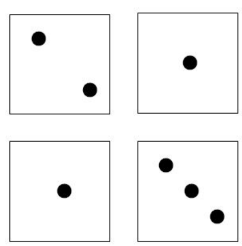
## Questions from this story:

**Possible Schemes**
1. Totally Random (???)
2. (Number that is even) = 2 Sprouts
3. [(Sum of all Numbers) – 3] / 2 = 2 Sprouts

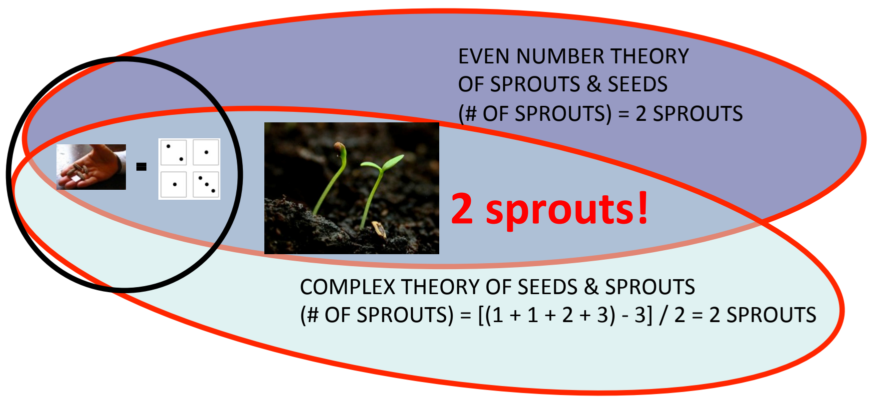
1. How could we decide if any of these three schemes is the correct one?
2. If the farmer had to wait to plant more seeds, are there reasons we might in the meantime favor one scheme over another?
3. How do we know if we've figured out all the possible schemes?
4. Where did these schemes we've been discussing come from? (Note: This question is not about the elements of the schemes, but the decisions as to what elements to use and how to use them.)

## A MODEL

=

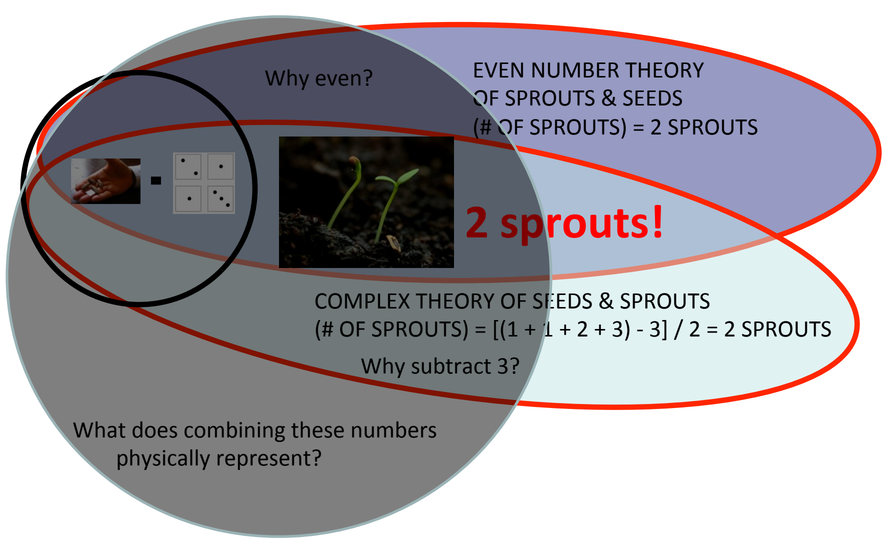


# COMPETING THEORIES




…constrained by observation

# INTERPRETATION



# Summary

- Scientists "make up" theories to explain the evidence they see.
- These theories are constrained by experiment.
- We can't always open up the seed and look inside. Have to make inferences from indirect evidence.
- A theory with a plausible mechanism is more convincing than a rote algorithm.
- The more different cases our theory works on, the more we believe it.
- But it could always be wrong…