PHYSICS 102N
Spring 2022

Week 1

Structure of Matter

Overview for this semester

- So far (PHYS101):
  - Point particles or rigid objects
  - motion and rotation
  - interactions and force laws (gravity, electromagnetism); collisions (momentum conservation)
  - Electric currents and their effects.
- Now (PHYS102):
  - Extended media (solids, liquids, gases, fields)
  - Internal degrees of freedom
  - vibrations and waves
  - statistical description
  - fundamental structure of matter

Unifying Principle: Energy

Energy…

- comes in multiple forms
  - kinetic, gravitational, elastic, electric, chemical, thermal, radiation, nuclear, rest mass…
- can be transferred from one form to another
- can be transferred from one object to another
- can neither be created nor destroyed

Unifying Principle: Energy

Energy is something an object **has** and…

- …can be internal to the object
  - kinetic, elastic (deformation), heat, chemical …
- …can be due to external, **conservative** forces acting on the object (= potential energy)
  - gravitational energy, electrostatic energy…
- …can be transferred from one object to another
  - heat flow, collisions
  - interactions with external, **non**-conservative forces doing work (Force x displacement) on the object *)

(even electric or gravitational fields can carry energy)

*) Even in this case, total energy is conserved - something else must be exerting the force and its energy will change by equal but opposite amount

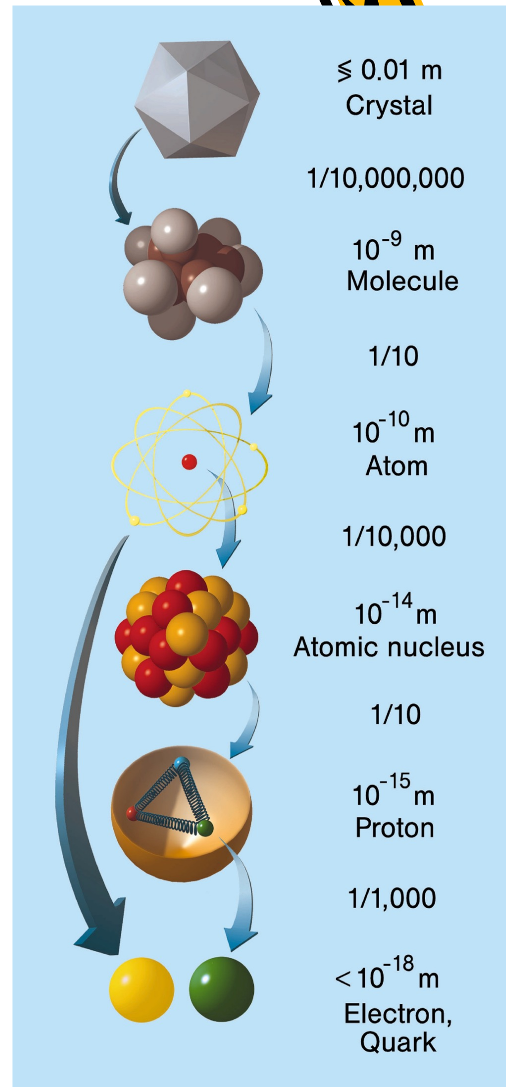
Some more points to remember…

- Something (like total energy) "is conserved" **MEANS** its total quantity remains the **same** as time passes
  - Do not confuse energy (momentum,…) of a **single** object with the **total sum** of a whole system - only the latter is conserved!
  - Distinguish directional (vector) quantities (momentum, …) from non-directional ones (energy,…)
- Do not confuse different concepts - Energy is **not** the same thing as force, friction, momentum, velocity,... - all of these things have different **units**
- Kinetic energy can never be less than zero; it has an absolute scale and it is only greater than zero if the object is moving (relative to IS): K.E. = $^1/_2 mv^2$
- Potential energy can be positive or negative; it is always counted relative to a reference point. An object has potential energy if a conservative force is acting on it and it is at a **position** (whether it's moving or at rest) where that force can do work on it by moving it towards the reference point.
- Only in the **absence** of any non-conservative forces (like friction) is total mechanical energy of an object conserved.
- Friction converts mechanical energy into heat. Heat is another form of energy (see later), but usually NOT counted as "mechanical" energy.

  If you include all types of energy, of all types of objects and fields in the world, then total energy is conserved. The same is true for any system on which no external forces act and into which no energy flows.

What happens if you keep cutting something into smaller and smaller pieces?

- Two possible outcomes:
  - You keep getting smaller and smaller chunks of the same stuff (continuous matter → Aristotle)
  - You reach a smallest possible entity that you cannot cut any further (Greek “a-tomos” = un-cut-able → Democritus)
- Today: We know that there is a whole chain of “elementary” objects:
  - Compounds → molecules → “atoms” → electrons and nuclei → nucleons → quarks → ???
  - Each step requires more energy for “cutting” until it exceeds that needed for new particle creation ($E=mc^2$)



- All observable phenomena are ultimately due to fundamental particles and their interactions
- But often it is more practical to “pretend” matter is uniform and continuous

Molecules and atoms are small!

- Drip a drop of oil (1 mm^3) on a perfectly still surface of perfectly clean (distilled water)
- Result: the oil spreads out to a thin film that covers as much as several m^2 *)
- That film must therefore be millions of times thinner than 1 mm (volume conservation)
- An oil molecule must therefore be millions of times smaller than 1 mm (a few Ångstrøm = 10^{-10} m)

*) You can tell because the film appears darker than the water - see later in the semester why (interference of light)

Nano-technology

- Controlled shaping of materials on the size scale of one to a few atoms (1 nanometer = 10^{-9} m)
- Examples:

  sun screen (Ti-Oxide nanoparticles)

  integrated circuits

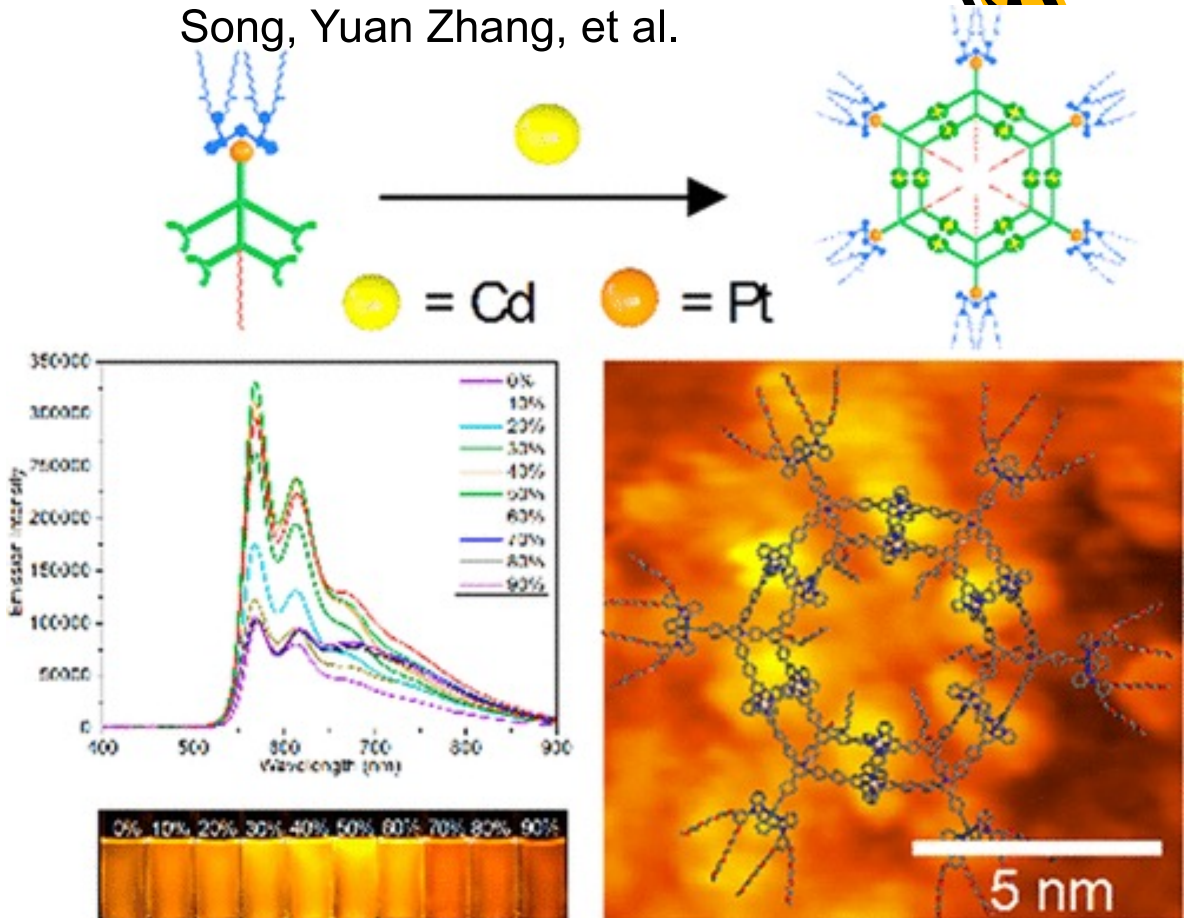
  bucky-balls and carbon tubes (fullerenes)

  biological macromolecules (DNA etc.)

Use *e.g.* electron, scanning tunneling, or atomic force microscopes to image

Giant Concentric Metallosupramolecule with Aggregation-Induced Phosphorescent Emission

Yiming Li, Gui-Fei Huo, Bingqing Liu, Bo Song, Yuan Zhang, et al.



Fluorescent metallosupramolecules have received considerable attention due to their precisely controlled dimensions as well as the tunable photophysical and photochemical properties. However, phosphorescent analogues are still rare and limited to small structures with low-temperature phosphorescence. Herein, we report the self-assembly and photophysical studies of a giant, discrete metallosupramolecular concentric hexagon functionalized with six alkynylplatinum(II) bzimpy moieties. With a size larger than 10 nm and molecular weight higher than 26 000 Da, the assembled terpyridine-based supramolecule displayed phosphorescent emission at room temperature. Moreover, the supramolecule exhibited enhanced aggregation-induced phosphorescent emission compared to the ligand by tuning the aggregation states through intermolecular interactions and significant enhancement of emission to CO_2 gas

There are lots and lots of molecules and atoms

- That 1mm^3 drop of oil contains as many as 10^{20} atoms; 12 gram (< 1/2 oz) of graphite contain $6.022 \cdot 10^{23}$ Carbon atoms (this number is called N_A after Avogadro who didn't know its value ;-)
- New way of expressing "amount of stuff": if you have N_A molecules (or atoms) of a homogeneous material, you call this "1 mol" of the material
- 1 breath (1/2 liter) $\approx 10^{22}$ atoms
- Whole atmosphere $\approx 5 \cdot 10^{21}$ liters

$\rightarrow$ if you exhale and wait until your breath has completely mixed with the rest of the atmosphere, anyone else on the world who draws a breath will be inhaling one of the air molecules that you exhaled (on average)

Atoms and molecules have incredibly small mass

- 1 Carbon atom has mass of $2 \cdot 10^{-26}$ kg
- Nearly all of that mass is in the nucleus - electrons weigh even 2000 times less
- Alternative mass unit: atomic (or molecular) mass
- Since “standard” carbon nucleus (^{12}C) has 6 protons and 6 neutrons (“nucleons”), we give the neutral carbon atom an atomic mass of 12.0000
- Any atom or molecule has A.M. = 12 x mass(molecule)/mass(^{12}C)
- ordinary hydrogen has **approximate** A.M. = 1

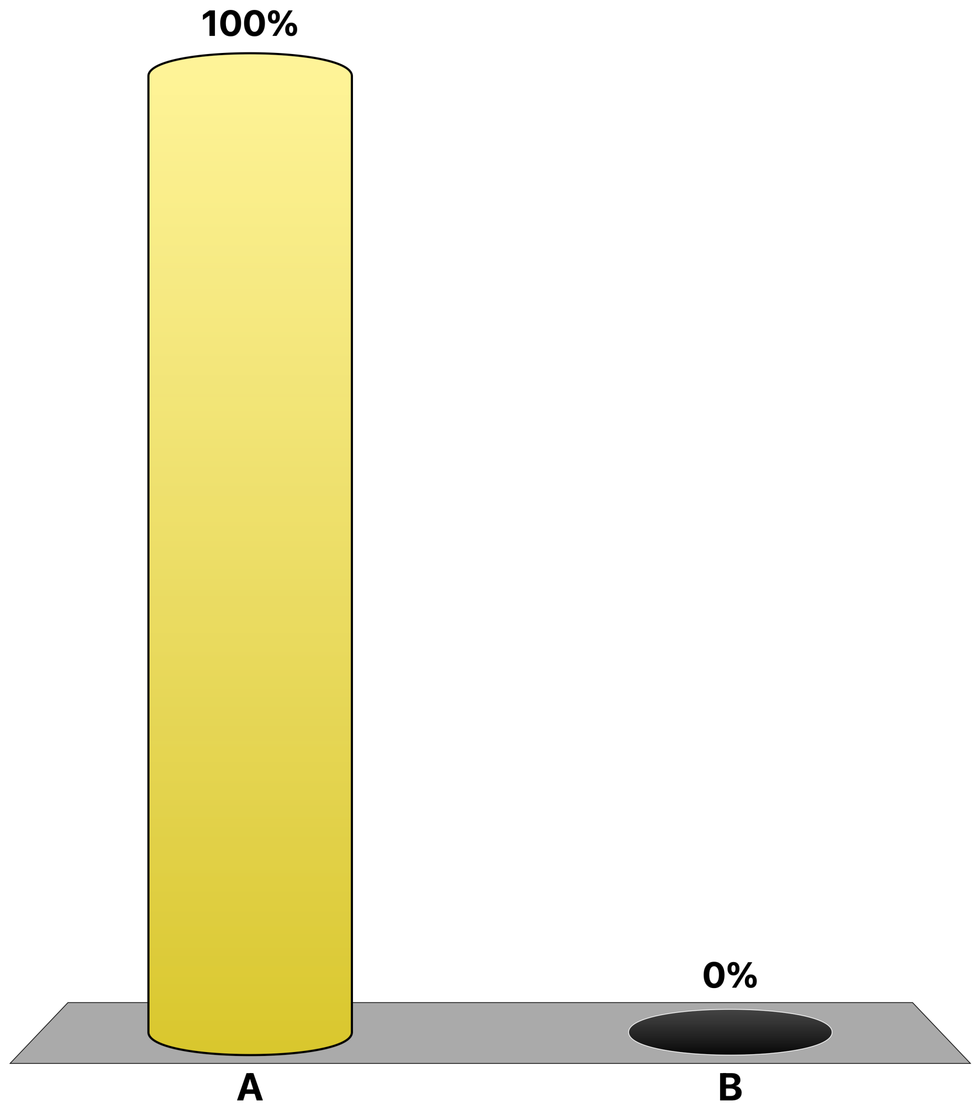
A.M. grams of any chemical element or compound = 1 mol = N_A atoms or molecules

Warm-up Clicker Quiz:

Have you taken PHYS101 last Fall?

A. True

B. False

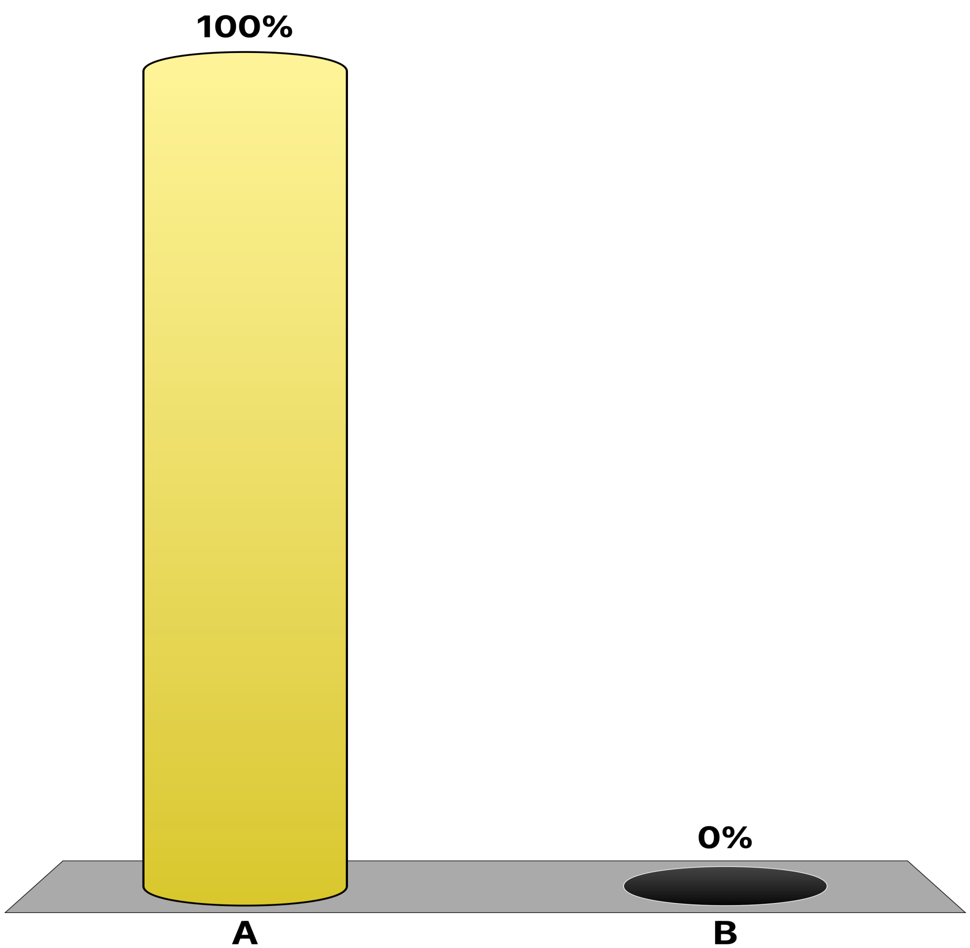


Warm-up Clicker Quiz II

Have you read the syllabus from the first to the last page?

A. True

B. False

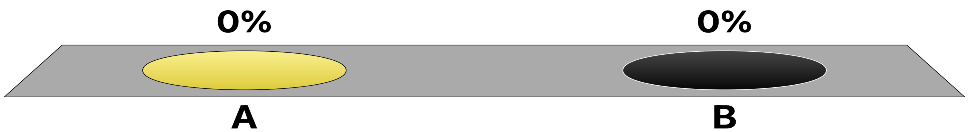


Warm-up Clicker Quiz III

Have you read or will you read *everything* on the course Blackboard site, as well as the web site at http://ww2.odu.edu/~skuhn/PHYS102/Home102.html ?

A. True

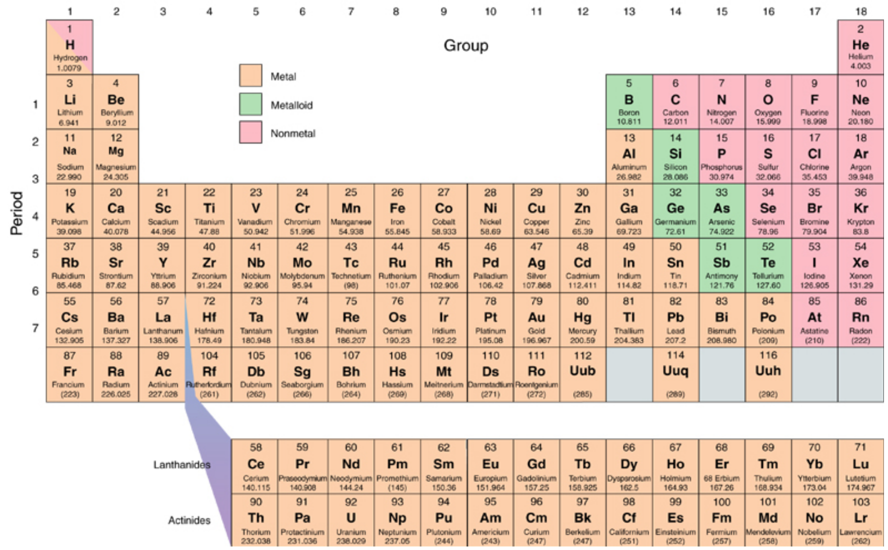
B. False



Atomic structure

- Nucleus at the center - contains nearly all of the mass and nearly none of the volume (10^{-5} times smaller than atom) (1 cm^3 of nuclear matter = 1 billion tons)
- Made of Z protons (charge = +Ze) and N neutrons (nearly same mass, no charge)
- Neutral atoms have Z electrons (total charge -Ze); ions have one or more extra or missing electrons
- Electrons form “cloud” or “orbits” surrounding nucleus (attracted by Coulomb force)
- Orbits can be organized into “shells” (2, 8,… electrons)

Properties of atoms can only be understood with the true theory of small objects, Quantum Mechanics. See later…



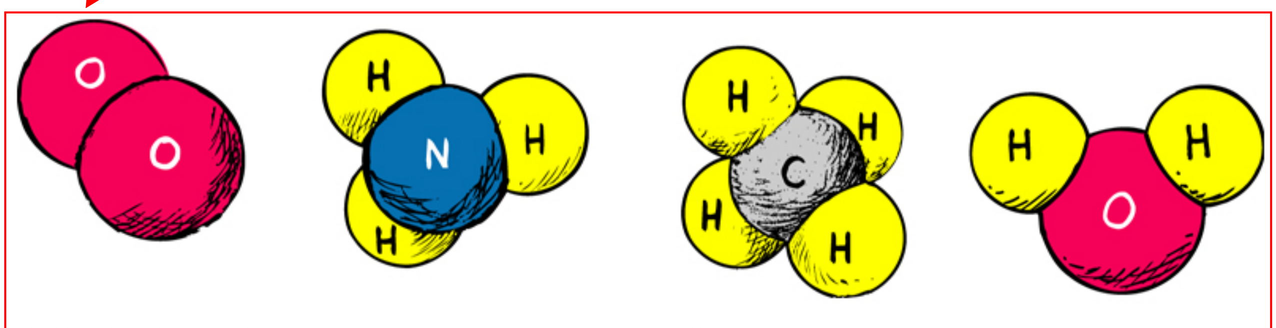
Elements

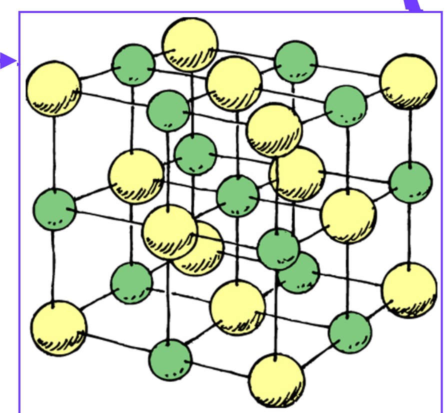
- Element = Any substance made up of only one kind of atom
- Examples: gases like hydrogen (H_2), helium (He), Nitrogen (N_2), Oxygen (O_2), Chlorine (Cl_2), Neon (Ne), Argon (Ar)…; liquids like mercury (Hg); metals like sodium (Na), calcium (Ca), iron (Fe), silver (Ag), gold (Au)…; semi-conductors like silicon (Si) and germanium (Ge); non-metallic solids like carbon (C) and sulfur (S).
- Some occur as single atoms (He), others in binary molecules (indicated by subscript "$_2$"), others in solid lattices (all metals)

- Element type determined by Z of nucleus (1…118, 92 = U)
- Can be arranged in periodic table (determined by closed electron shells

Molecules and Compounds

- Molecules: Made of more than one atom (more than one nucleus)
- Shared electrons (attracted to both nuclei) or exchanged electrons (ionic bound)





Compound: Any substance made of molecules with more than one type of atom

Nuclei

- Densely packed collection of protons and neutrons
- Stick together by strong nuclear force
- Protons repel (Coulomb force) - limit of stability
  - alpha, beta decay; fission
  - large nuclei (Z > 10) tend to have more n's than p's
- Nuclei are charged - they repel each other
  - usually need large energies to force them to interact; also can get large amounts of energy out

All nuclei made from "primordial" H, He (big bang) in stars and supernova explosions; more later in semester

Isotopes and atomic masses

- Add or subtract neutron from nucleus => same element (Z unchanged) but different masses
- Most elements come in such different “isotopes”: ^{1}H, ^{2}H = Deuterium, ^{3}H = Tritium; ^{12}C, ^{13}C, ^{14}C (radioactive);…Uranium 235/238
- Atomic mass = Sum of masses of all protons and neutrons minus (binding energy)/c^2 (Einstein!) - not exactly integer!
  - Natural elements: often mixtures
  - e.g. Magnesium: Z = 12, <A.M.> = 24.3
  - Since # of mols = mass [g] / A.M. => need to know isotopic composition of sample

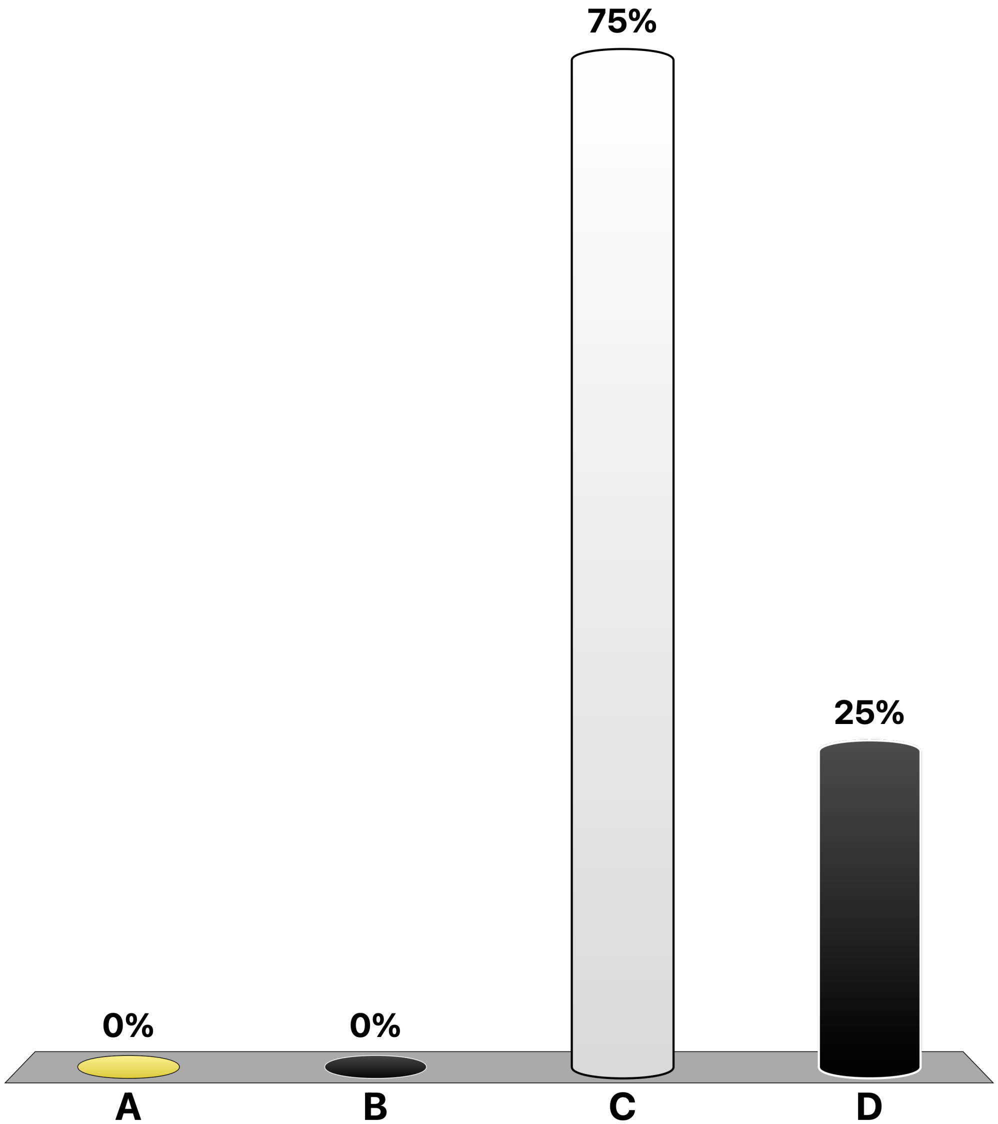
Is it true that some atoms in your body also were, at some time, inside the body of Julius Caesar?

A. No, because "his" atoms were all buried with him.

B. No, because the chances of one of "his" atoms ending up in my body are miniscule.

C. Yes, that's true. Also o.k.

D. It's not entirely clear whether we can say this, as atoms are indistinguishable from each other.



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