PHYSICS 102N
Spring 2022

Week 3

Gases, Temperature and Heat

Gases vs. Liquids

- Both are fluids - laws about pressure from previous lecture apply!
- Main difference: Gas is much less dense, *) and its density can vary substantially:
  - mass density of water at sea level: 1000 kg/m^3
  - mass density of air at sea level: 1.3 kg/m^3
  - mass density of air at 6 km height: 0.6 kg/m^3
  - density is related to pressure in two directions:
    - increased pressure => increased density (see later)
    - pressure decrease with height proportional to density

$$\Delta p = \rho g(-\Delta h)$$

    - Consequence: Atmosphere does not have definite “thickness” - it just peters out…

*) Individual atoms roam freely, mostly far from each other

Atmospheric Pressure

- Air has mass and therefore weight!
  - Roughly 1 kg/m^3 average at low altitude
  - Roughly equivalent height of 10,000 m => column of 1 m^2 has mass of 10,000 kg (Weight 100,000 N) = 10 $tons/m^2$ (equals weight of 1 kg mass per cm^2)
  - Pressure = 103,000 Pascal (dependent on weather)
- Consequences:
  - Empty containers get crushed *)
  - Unbalanced air pressure can exert large force
  - Air pressure can push liquids up tubes (straw!) *)
  - buoyancy (Helium balloons!)

*) Working principle for some kinds of barometer

Boyle's Law (for ideal gases)

- 2nd relationship between pressure and density: Increased pressure produces increased density and vice versa (for constant temperature): $\rho \propto P$
  - Put double as much gas into same volume => pressure doubles
  - Compress same gas in half volume *) => pressure doubles
  - Constant amount of gas: $PV = const. \quad \Leftrightarrow \quad \rho \propto \frac{1}{V} = \frac{P}{const.}$
- Reason: Pressure due to bouncing of gas molecules (atoms) off walls => more density means more molecules (atoms) hit walls per unit time

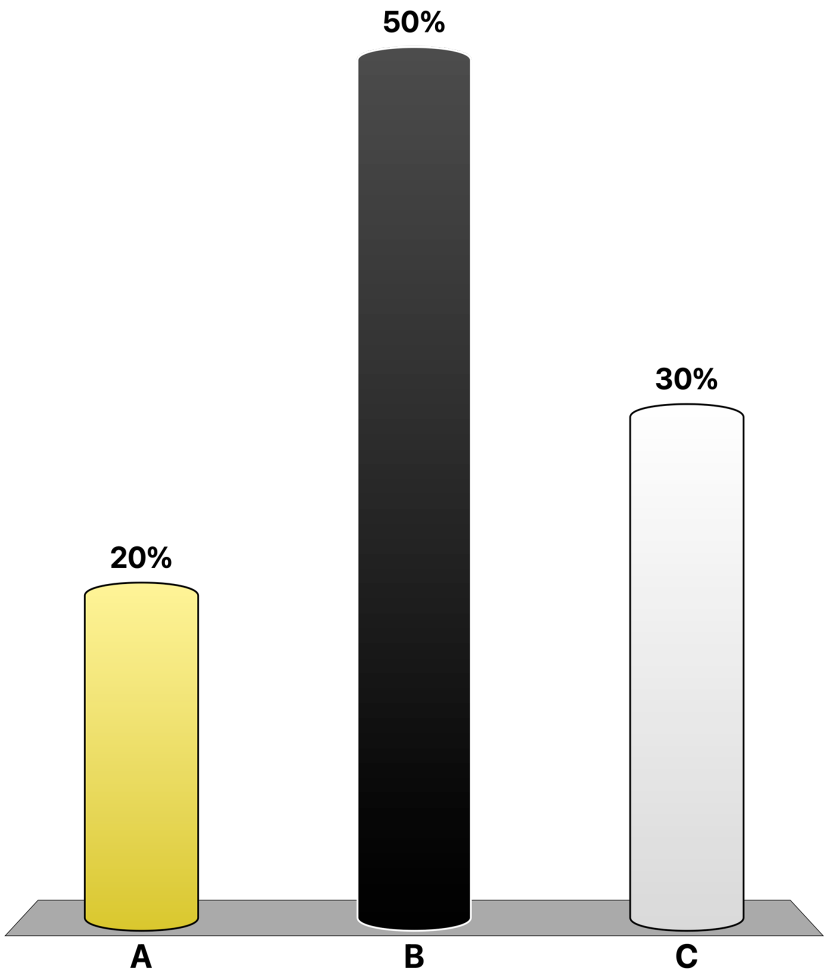
*) Disclaimer: only if you do it slowly and in contact with environment – counterexample: bicycle pump

Bernoulli's Principle

- Relationship between **speed** and pressure:
  In a flowing fluid (gas or liquid), pressure is decreased; the decrease is more pronounced the faster the flow
- Handwaving argument: to speed up, molecules have to reduce "random bouncing around" and direct speed along flow (can also argue via energy conservation)
- Can be used to explain 100's of phenomena (but watch out: Not always is the truth quite as simple…)
  - airfoils, sails, roofs lifting off, umbrellas invert, trucks attract
  - liquid flow pump, perfume dispenser, shower curtain pushes in
  - ball caught in air stream, curve balls in baseball/soccer…

Q1 Compared with the mass of a dozen eggs (about 0.7 kg), the mass of air in an "empty refrigerator" (about 0.6 m^3) is

A. negligibly small
B. about the same
C. way more



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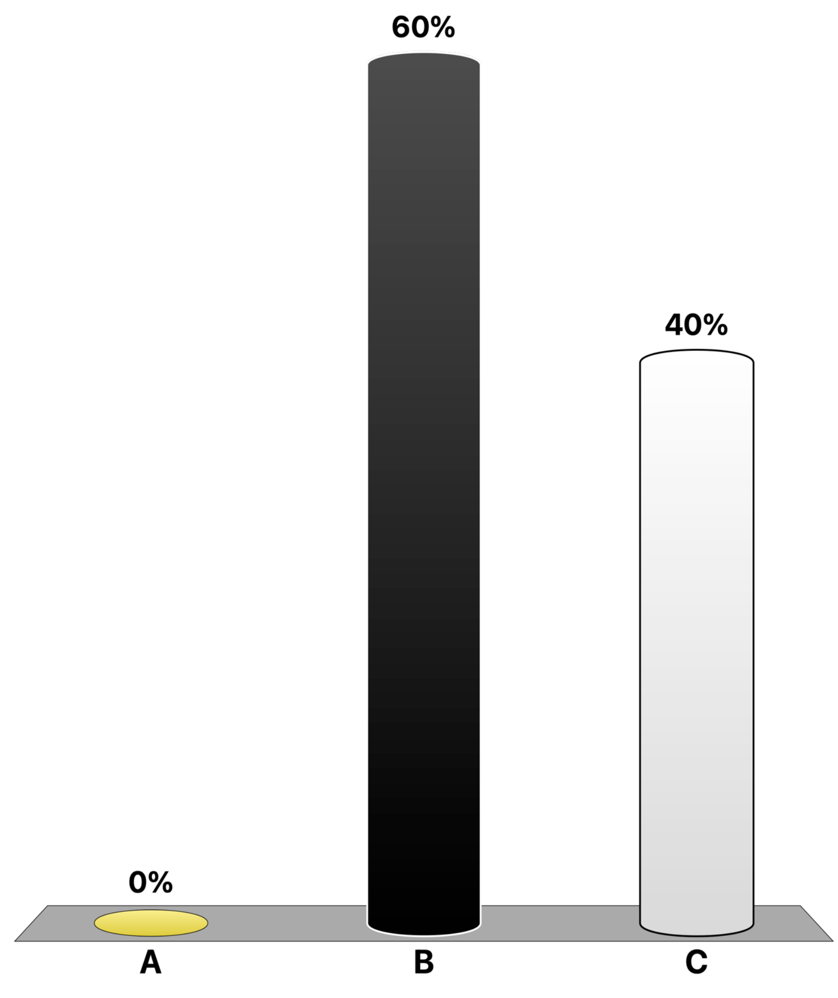
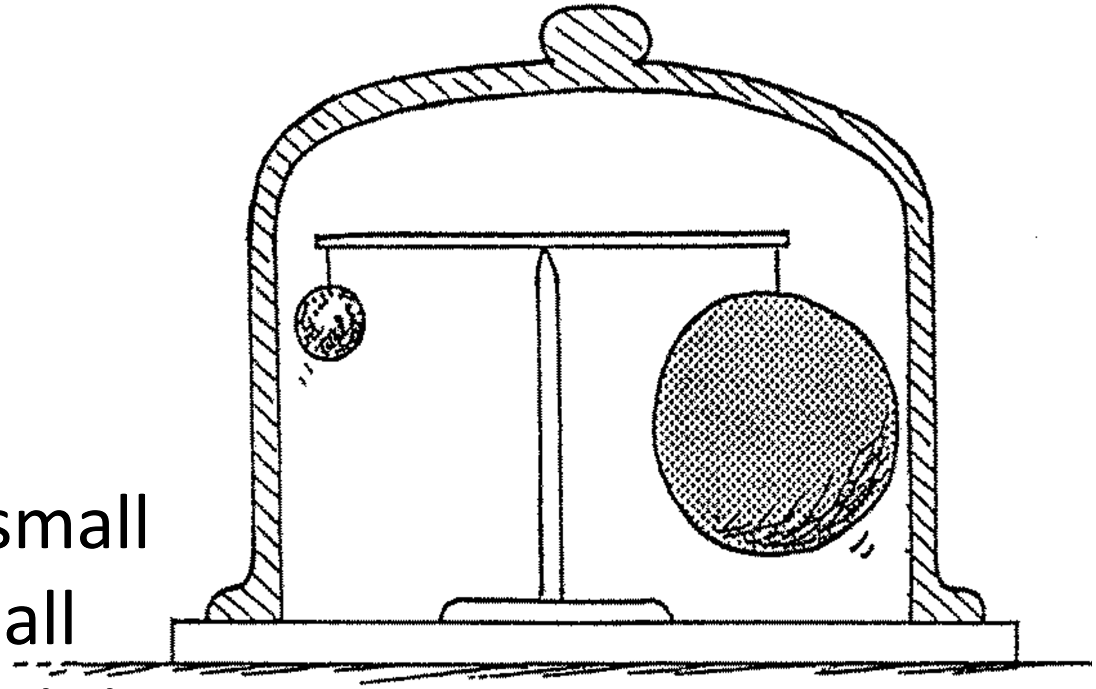


Q2

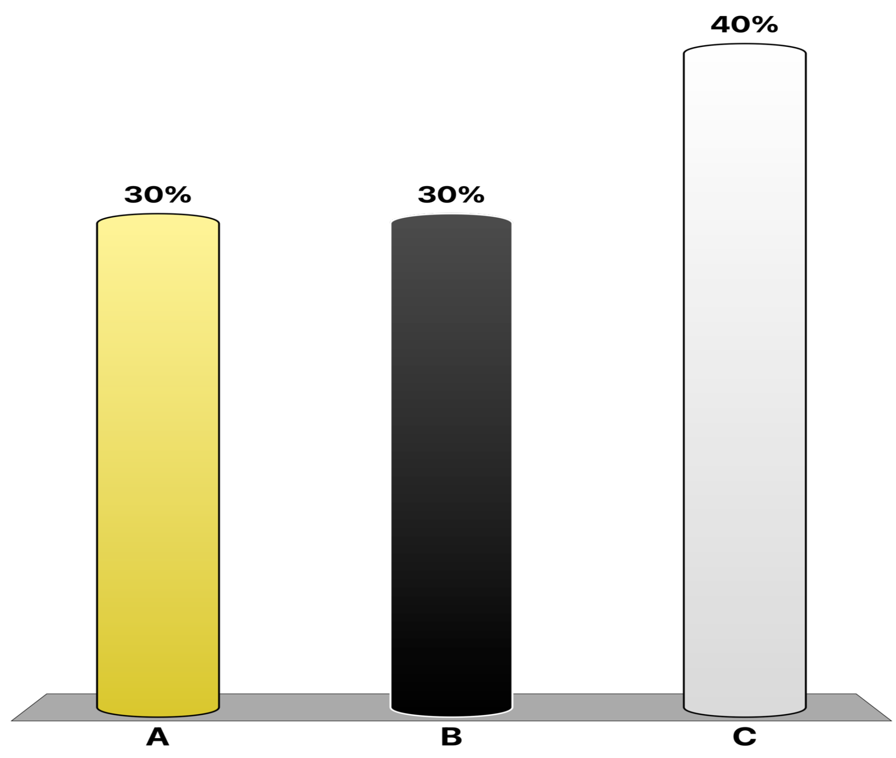


In the presence of air, the small iron ball and large plastic ball balance each other. When air is evacuated from the container, the larger ball

A. rises

B. remains in place

C. sinks lower



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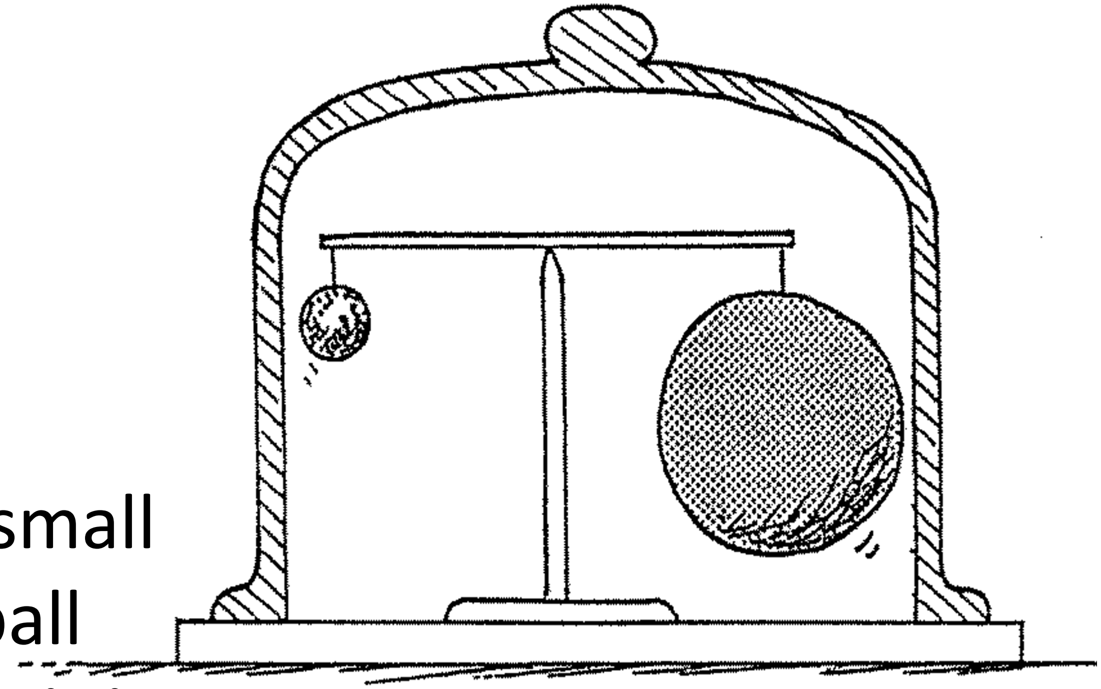

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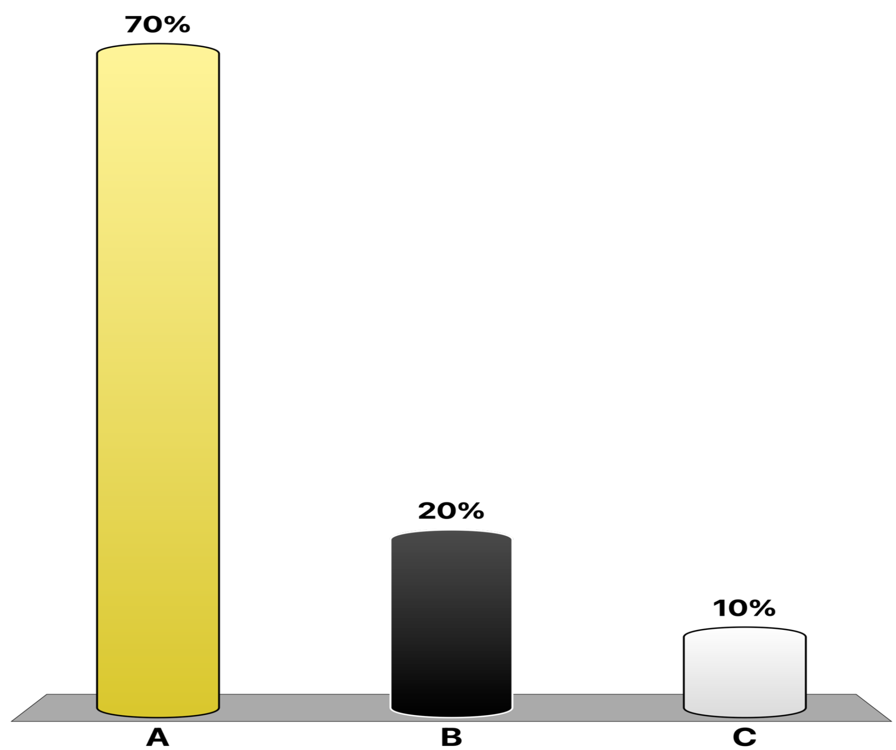


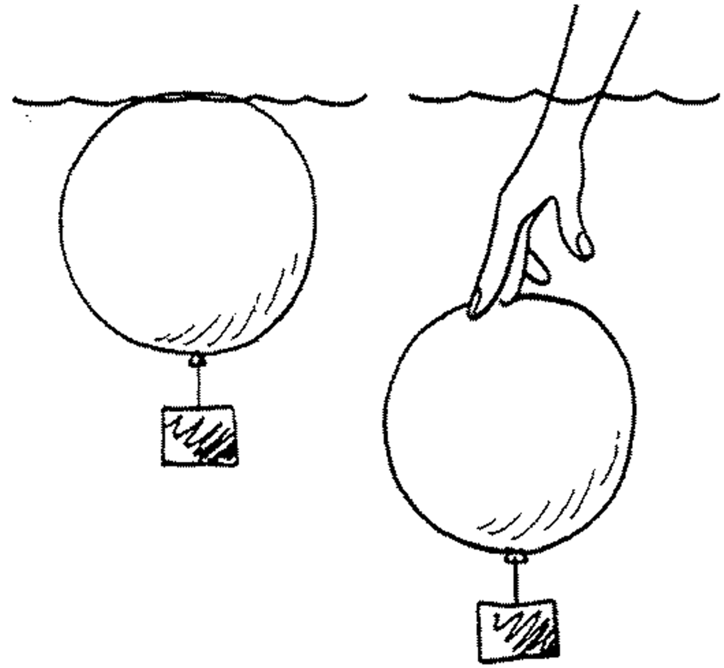
Q3

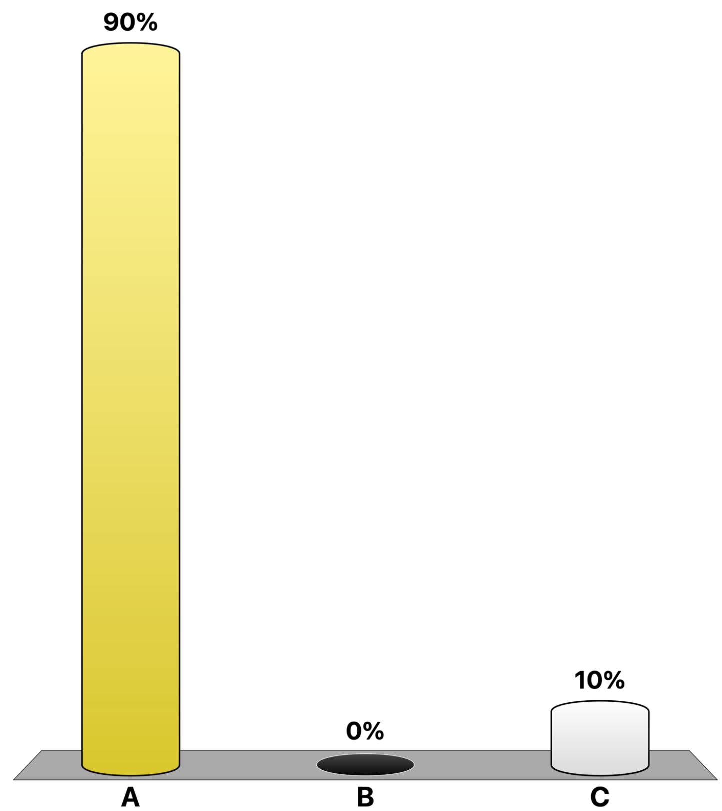
Consider an air-filled balloon weighted so that it is on the verge of sinking—that is, the buoyant force is equal to the combined weight of balloon and weight. Now if you push it beneath the surface, it will

A. sink

B. Return to the surface

C. Stay at whatever depth it is pushed to





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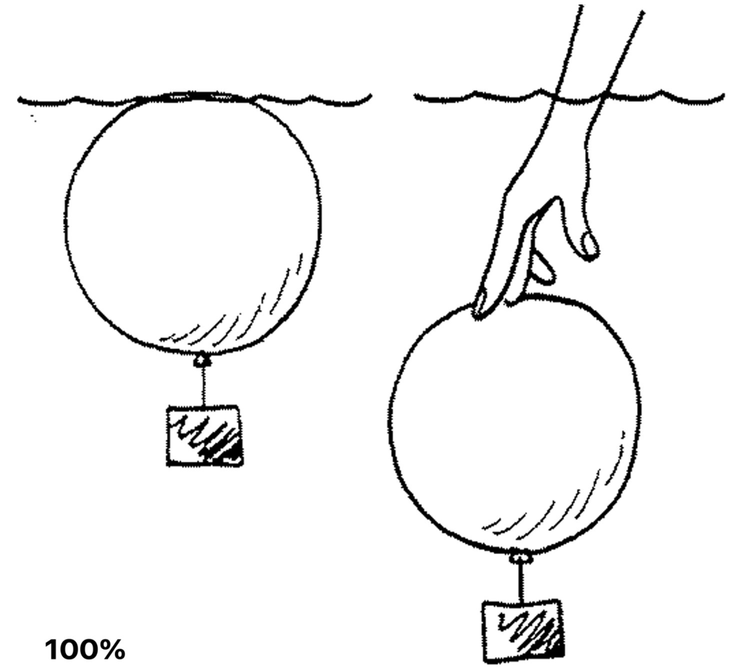
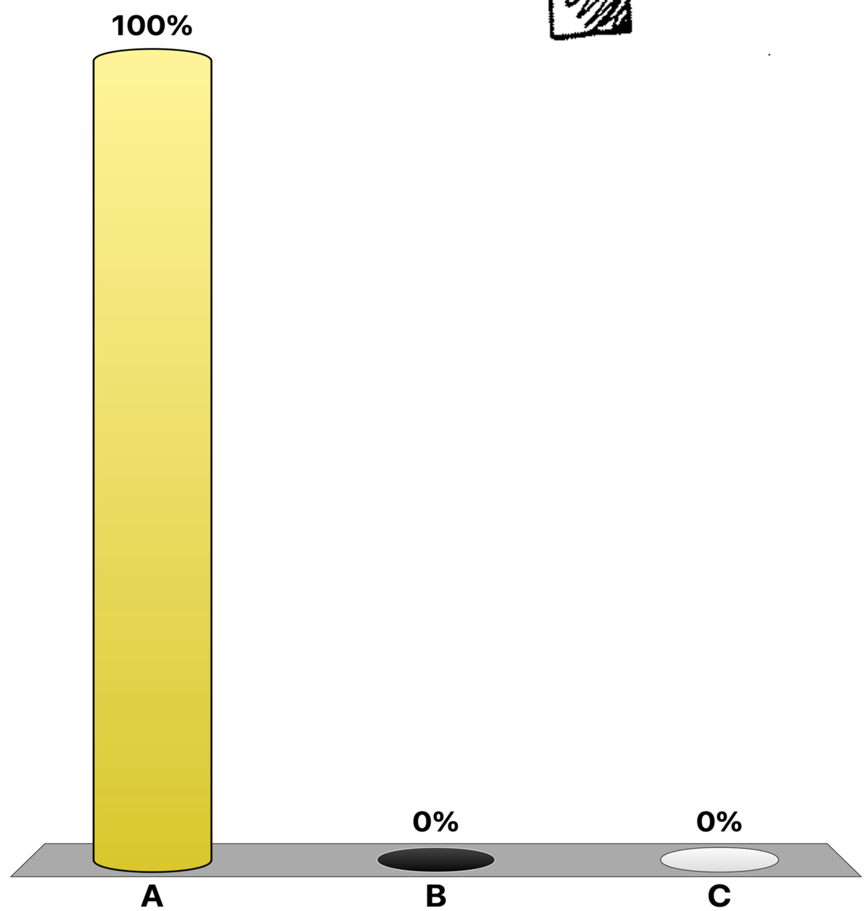
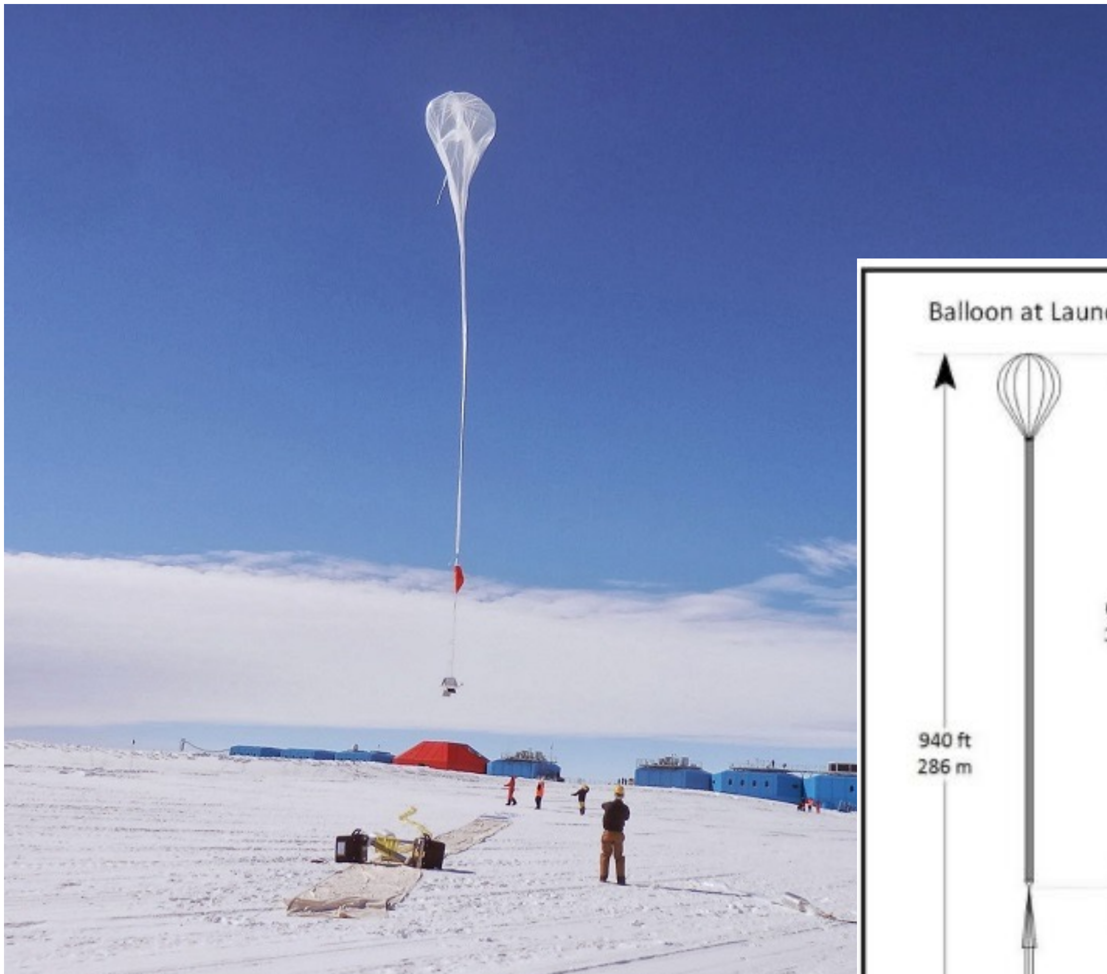


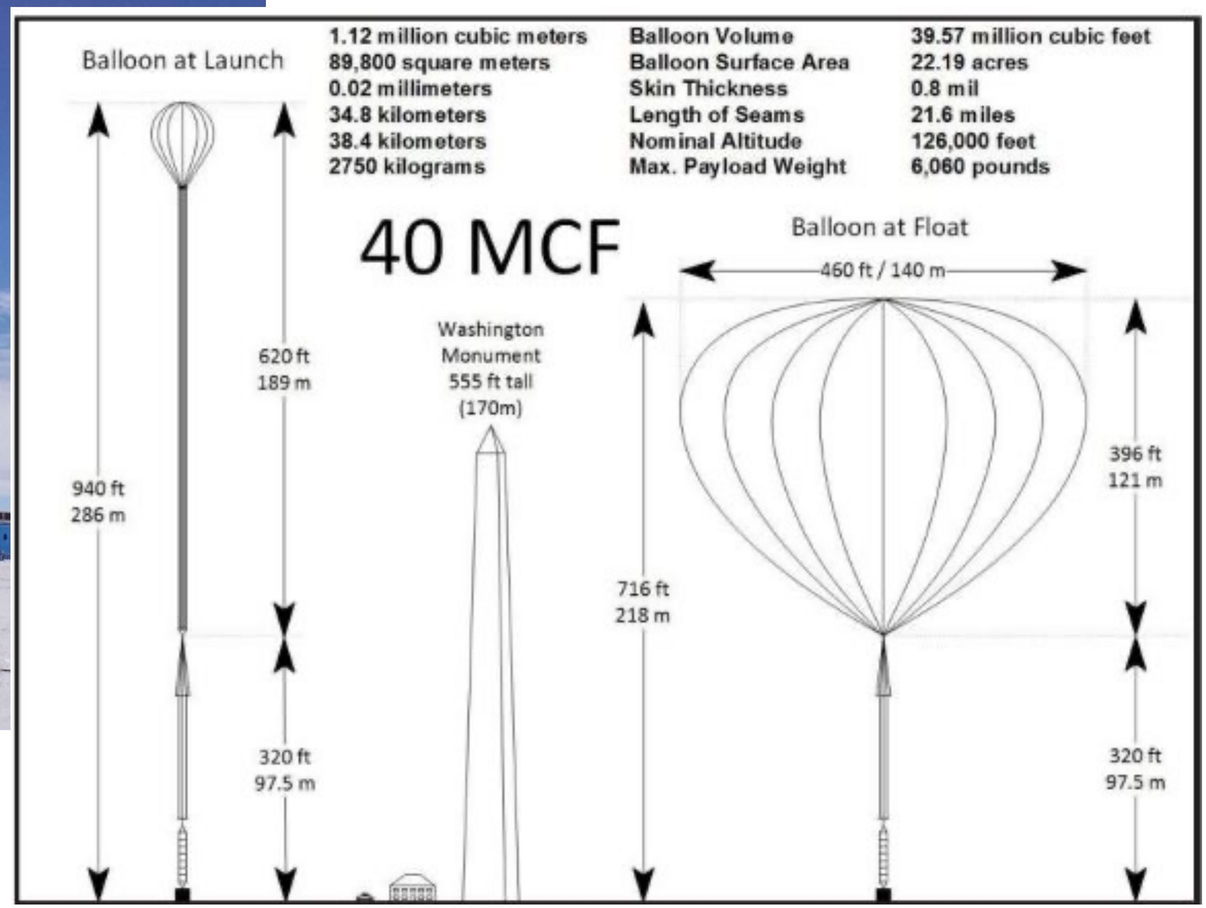


Similarly: Scientific Balloon



NASA Balloon Launch

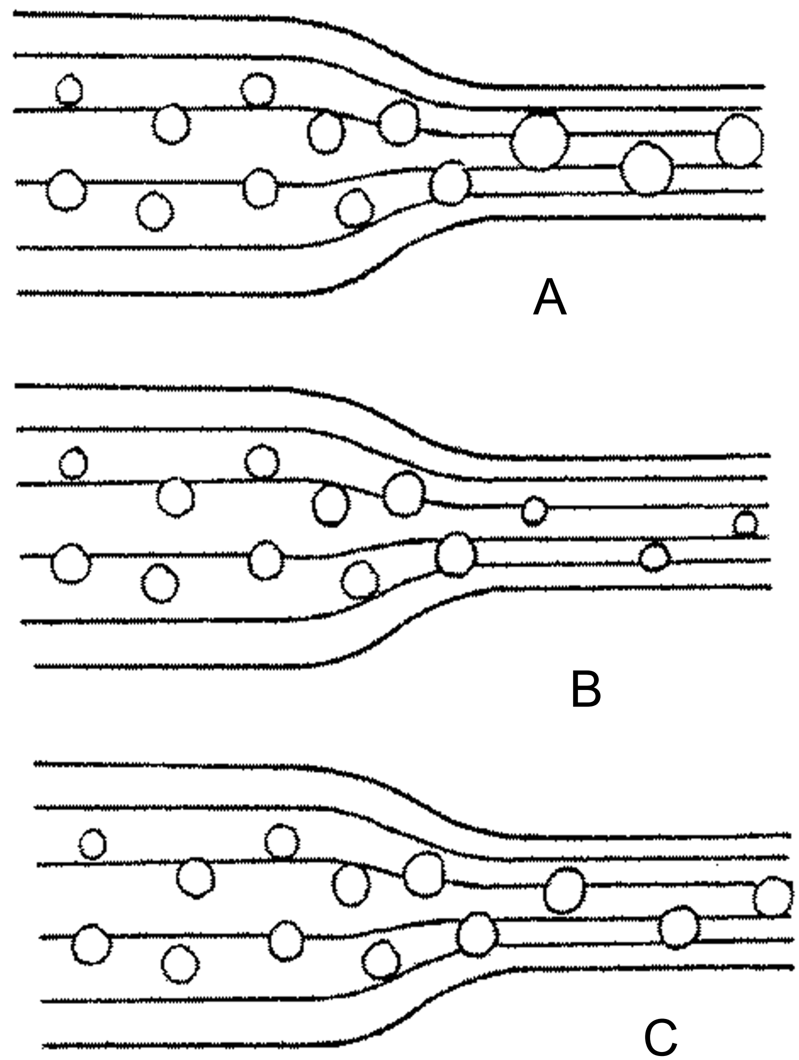
http://www.ltaflightmagazine.com/frequent-flights-of-science/



Q1

Water with air bubbles flows through a pipe that becomes narrower. In the narrow region the water gains speed and the bubbles are

A. Larger
B. smaller
C. the same size



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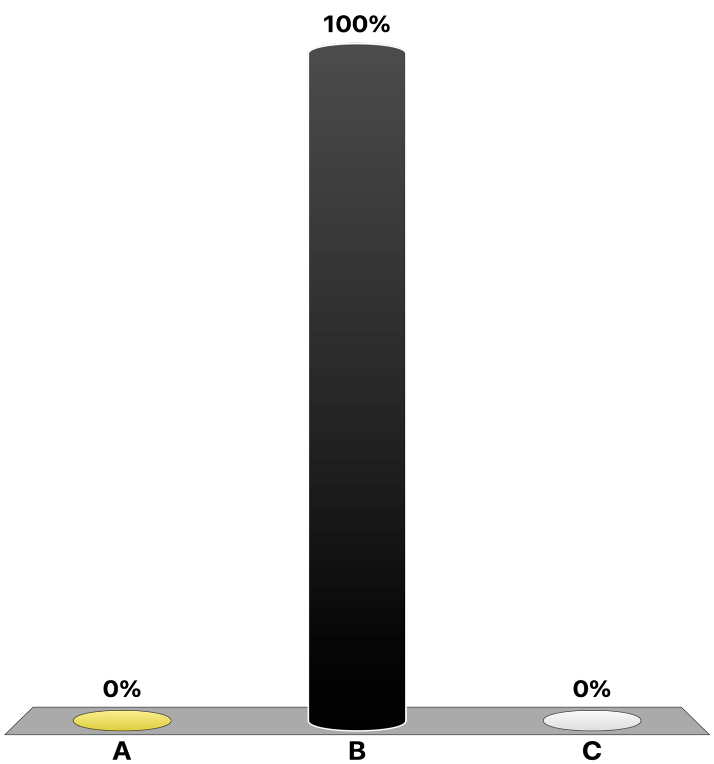
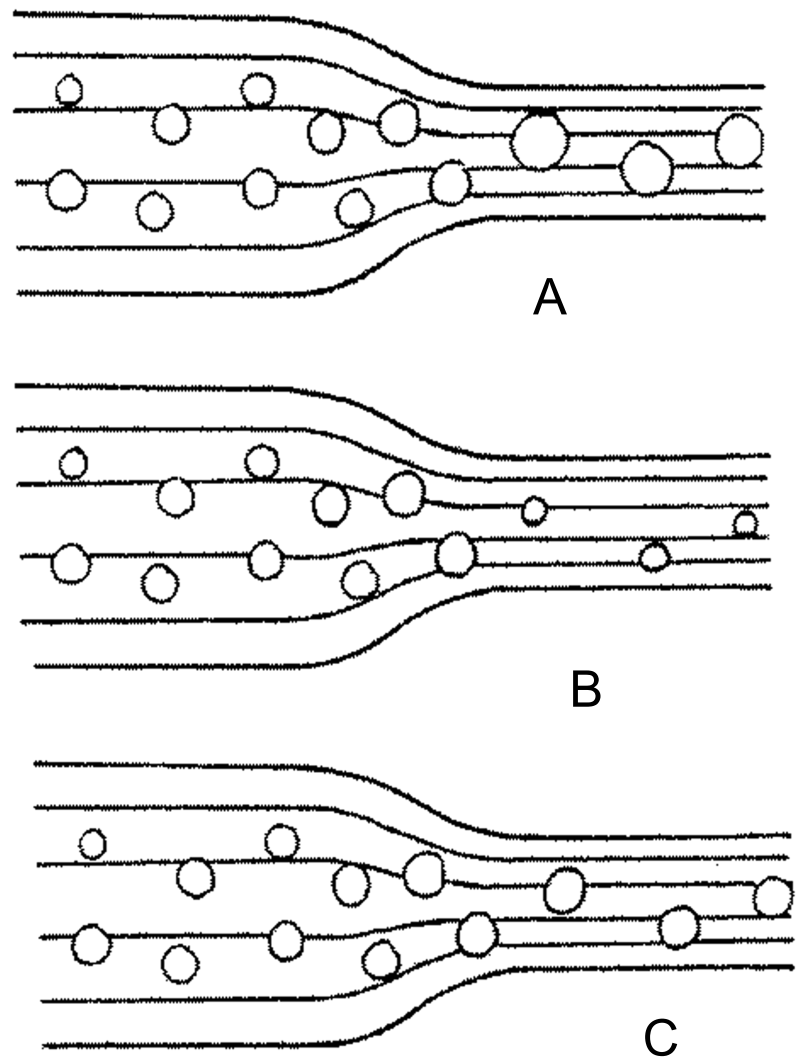




Temperature - what is it?

- Something you can "feel"
  - **Hot** and **cold** objects, liquids, atmosphere, …
- Something you can observe
  - Shrinking and expanding of objects, liquids and gases
  - Radiation ("white hot", "**red glow**", radio noise)
  - Phase changes (ice - water - steam)
- Something that gets increased by energy transfer
  - Rubbing (friction!), collision, burning, radiation, μwave, heating
- Something you measure with thermometers
- Something that tends to even out between objects, liquids or gases in contact

=> Temperature has to do with average (kinetic) energy of atoms/molecules in substance

Temperature - what is it?

- Something you can "feel"
  - Hot and cold objects… - nerves pick up "wiggling" of molecules in your skin
- Something you can observe
  - Shrinking and expanding of objects, liquids and gases - wiggling takes room!
  - Radiation - shaken electrons and ions give off electromagnetic radiation
  - Phase changes - heavier wiggling breaks solids apart, liberates single atoms
- Something that gets increased by energy transfer - Duh!
  - Rubbing (friction!), collision, burning, radiation, μwave; **heating**: see later!
- Something you measure with thermometers - thermometers take on temperature of surroundings, indicate their own temperature by expanding liquid/solid (or other effects like electric resistance, voltage, …)
- Something that tends to even out between objects, liquids or gases in contact - fast objects get slowed down in collisions (billiard analogy)

⇒Temperature has to do with average kinetic energy of atoms in substance, **BUT**: Only random motion counts (fast cars aren't *really* "hotter" than slow ones) => **Internal** Energy

Temperature Scales

- Fahrenheit: Based on "feel"
  - 0^{O} F: "Really, really cold weather"
  - 100^{O} F: "Really hot person", slight fever
- Celsius ("Centigrade"): Based on observation
  - 0^{O} C: Water freezes at normal atmospheric pressure
  - 100^{O} C: Water boils at normal atmospheric pressure
- Kelvin: Based on fundamental Physics
  - 0 K: Absolutely lowest possible temperature; no transferable internal energy left
  - 1 K increase = 1^{O} C increase => Water freezes at 273 K and boils at 373 K; 0 K = -273.16^{O} C

Heat vs. Internal Energy

- 2 ways to increase temperature of a system:
  - Do work on system in a way that spreads to all particles of the system, resulting in random motion (friction, impact…)
  - bring system into contact with another, **HOTTER** system: Heat will be transferred until both have same temperature
  - both ways increase **internal energy**
  - **work** and **heat** are something that gets **transferred** - not something a system **has**
- Temperature $\propto$ internal energy/particle *) => You need **more** heat to increase temperature of **larger** amount of material $\left(\text{Heat needed} = c \cdot m \cdot \Delta T\right)$
  - **Units for heat:** J(oule), calories (1 calorie = 4.2 J; 1 food calorie yields 1000 calories = 1kcalorie = 4200 J if burned)

*) really: average internal energy per *degree of freedom*

**) c = specific heat capacity (J per degree and per kg)

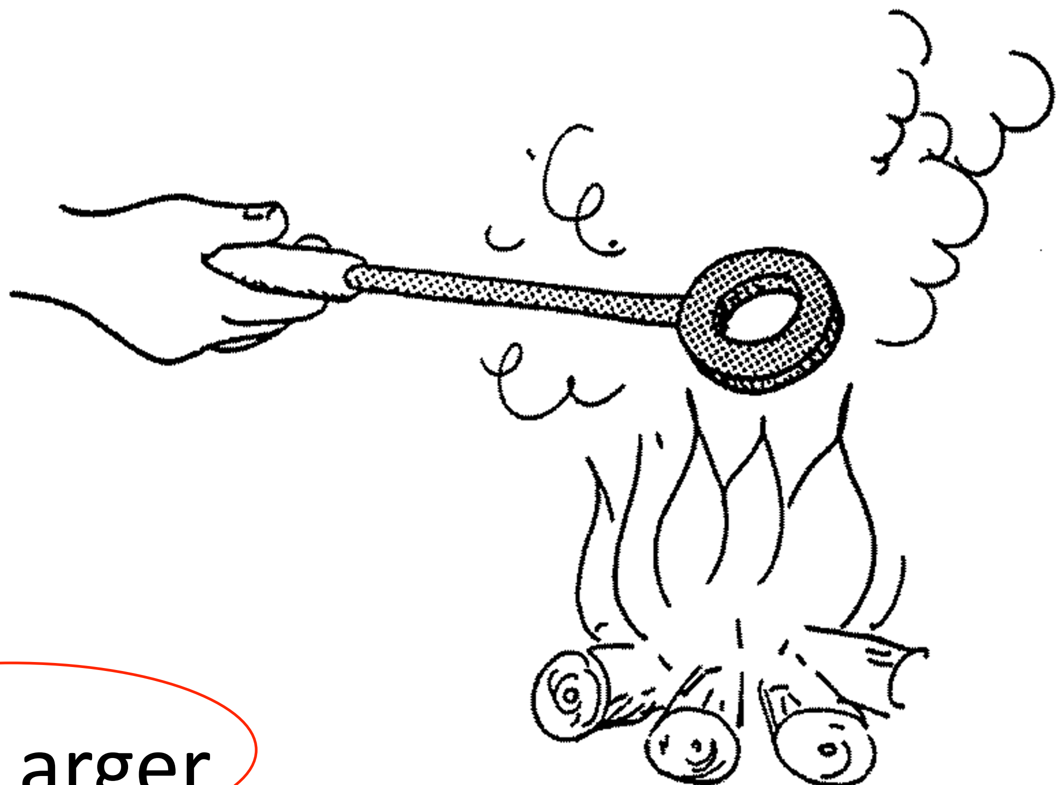
Examples

- Specific Heat Capacity has a huge range
  - air: 1001 J/^{0}C/kg
  - Al: 902, Iron: 450, Copper: 385, Gold: 129 J/^{0}C/kg
- The amazing properties of water
  - huge specific heat capacity: 4179 J/^{0}C/kg
  - shrinks from ice to 0^{O}C liquid to 4^{0}C
  - > Many consequences:
    - Climate difference between Costs and Plains
    - Large cooling power
    - Constant temperature at bottom of lakes; icebergs

Intrinsic ("Intensive") vs. Extensive Variables

- Intrinsic Variables describe properties of material; vary smoothly from point to point; don't (necessarily) increase with amount of material
  - Density ρ
  - Pressure P
  - Temperature T
  - Specific heat capacity c
- Extensive Variables describe "amount of": Doubling the amount of material (keeping all of its properties the same) doubles their values
  - Volume, Mass, number of mols V, m, n
  - Weight F=gm
  - Internal energy E
  - Total heat capacity $C = c{\cdot}m$

When the temperature of a metal ring increases, does the hole become larger? Smaller? Or remain the same size?



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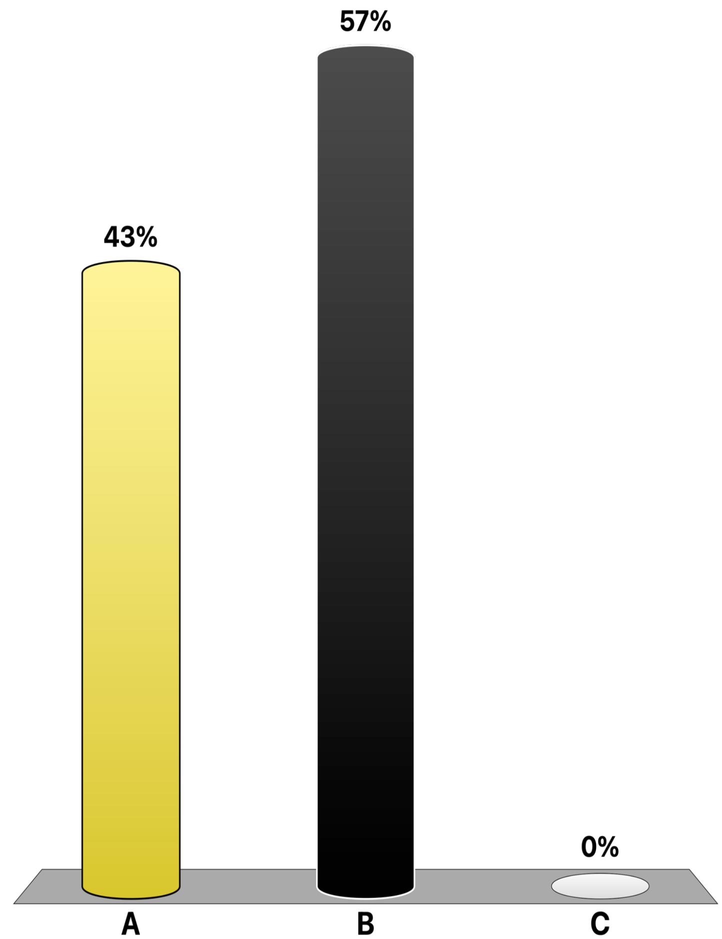
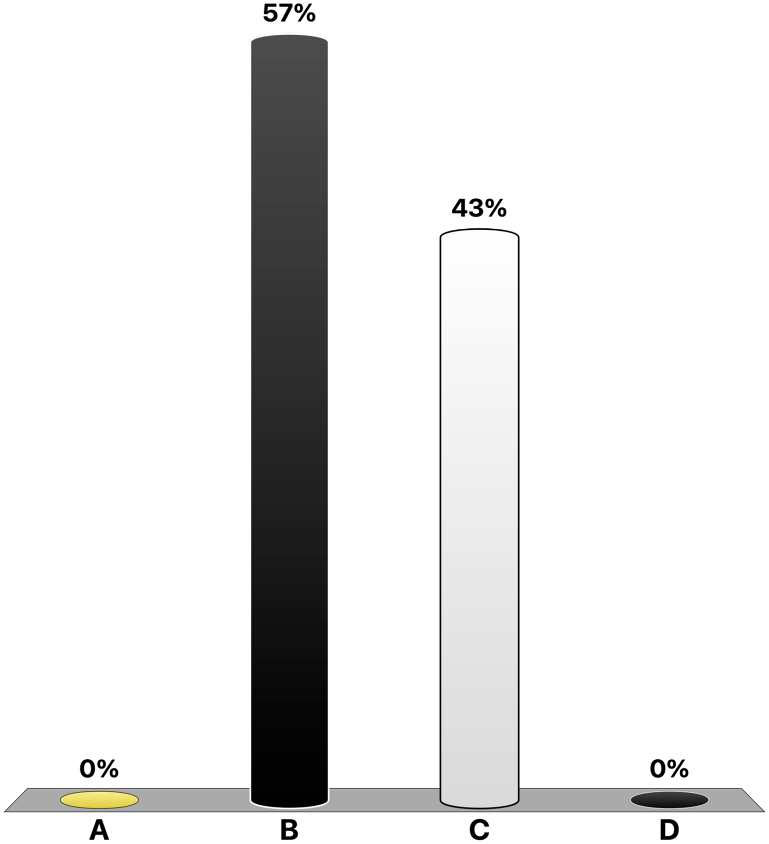


Q2

A glass of water with a few ice cubes swimming on top is filled to the brim. If you wait until all the ice melts, what will happen:

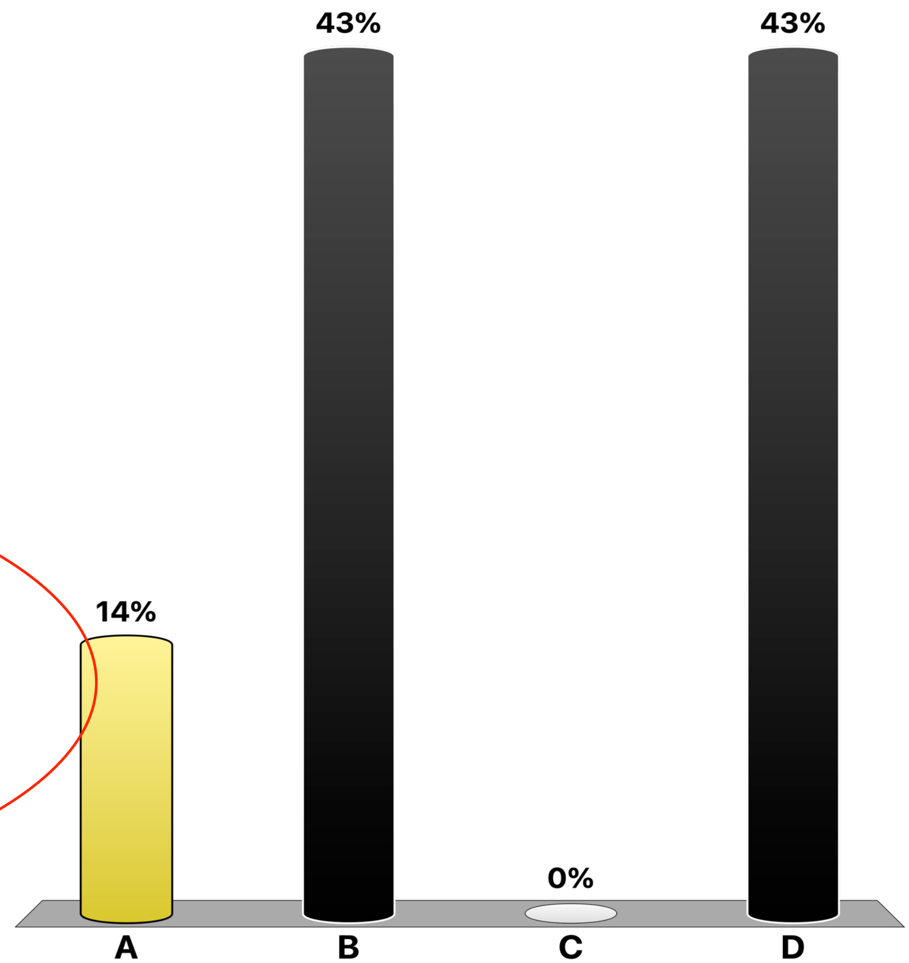
A. The glass will overflow
B. The water level will stay the same
C. The water level will first stay the same but the glass will eventually overflow if you wait until it reaches room temperature.
D. The water level will sink below the rim



Q3

With a gas burner, I first warm up a 2 kg piece of copper from 10^{O}C to 15^{O}C.
Then I warm a second piece of copper, with 1 kg mass, from 20^{O}C to 27^{O}C.
Afterwards, which piece of copper will contain more heat?

A. The first one
B. The second one
C. Both the same
D. Neither "contains" any heat – but it took more heat to warm up the first one



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