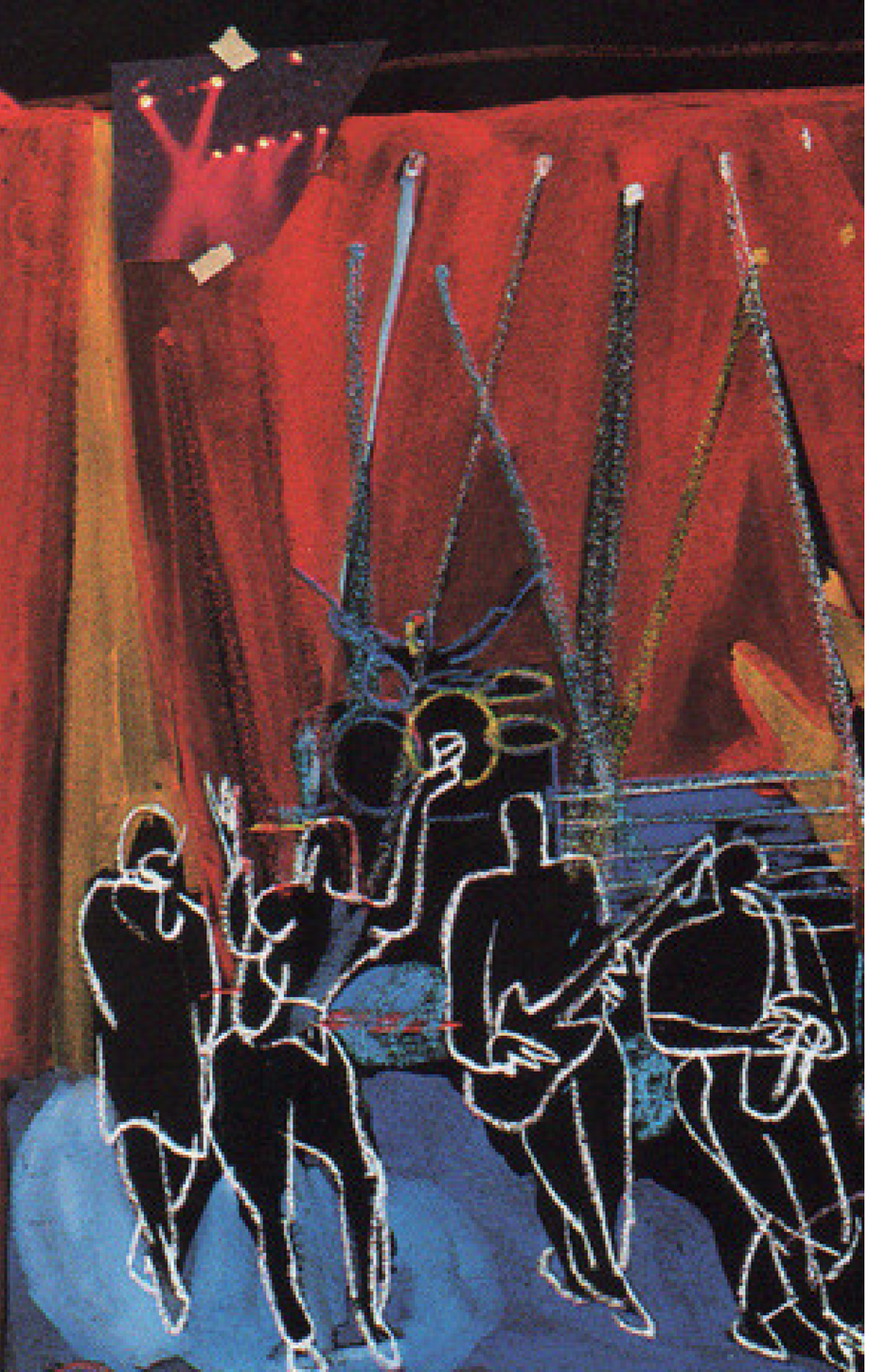


PHY-141

Macroscopic Properties and Microscopic Models

Luis Anchordoqui

Outline

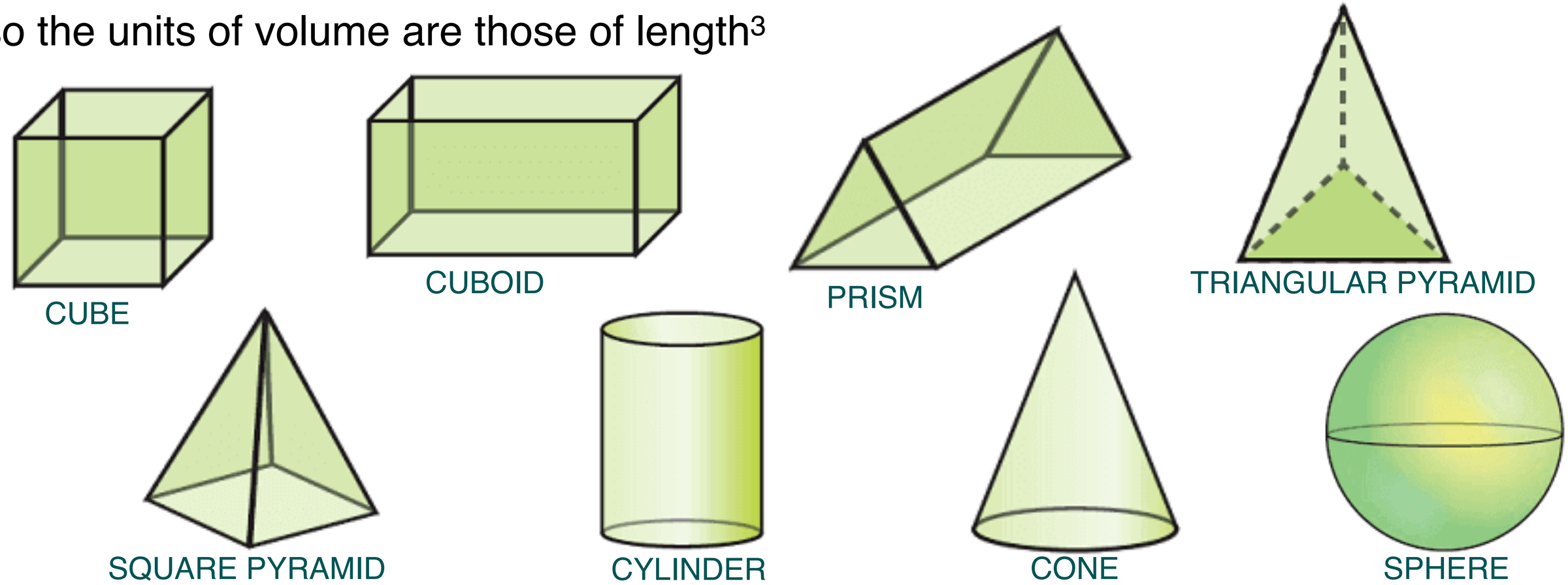
- Macroscopic properties (e.g., pressure, temperature, volume) describe the bulk, observable state of matter, while microscopic models (e.g., atomic, molecular) explain these behaviors based on individual particle interactions
- In today's class we will dive deeper into these concepts

KINETIC THEORY

- Kinetic theory bridges the gap between microscopic particle behavior and macroscopic bulk properties of matter (specifically gases) by explaining observables like pressure and temperature as results of molecular motion
- Microscopic models assume molecules are in constant, random motion, exerting forces through collisions, while macroscopic properties are averages of these actions

VOLUME

- The volume of a physical system is how much space it takes
- We generally refer to it with the symbol V
- The volume is usually obtained multiplying three different lengths for a given shape, so the units of volume are those of length^3

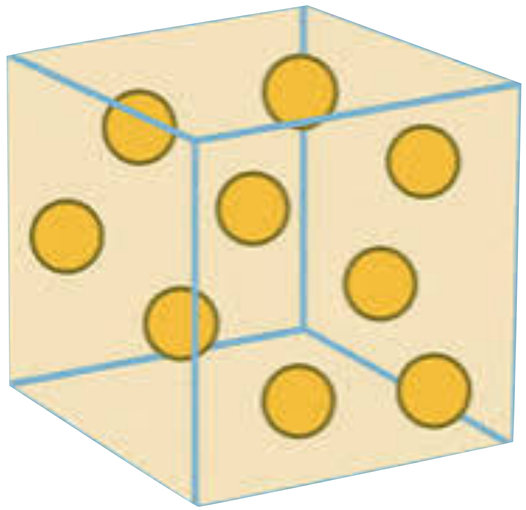


DENSITY

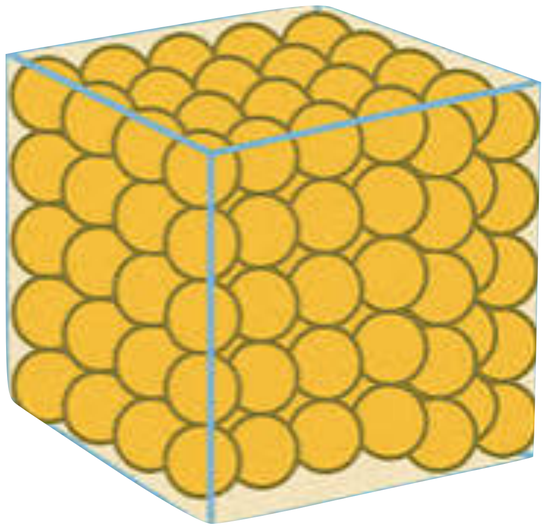
- Density is a measure of mass per unit volume, representing how tightly matter is packed within a substance

- It is calculated by dividing an object's mass by its volume

$$\text{density} \equiv \rho = m/V$$



LOW DENSITY

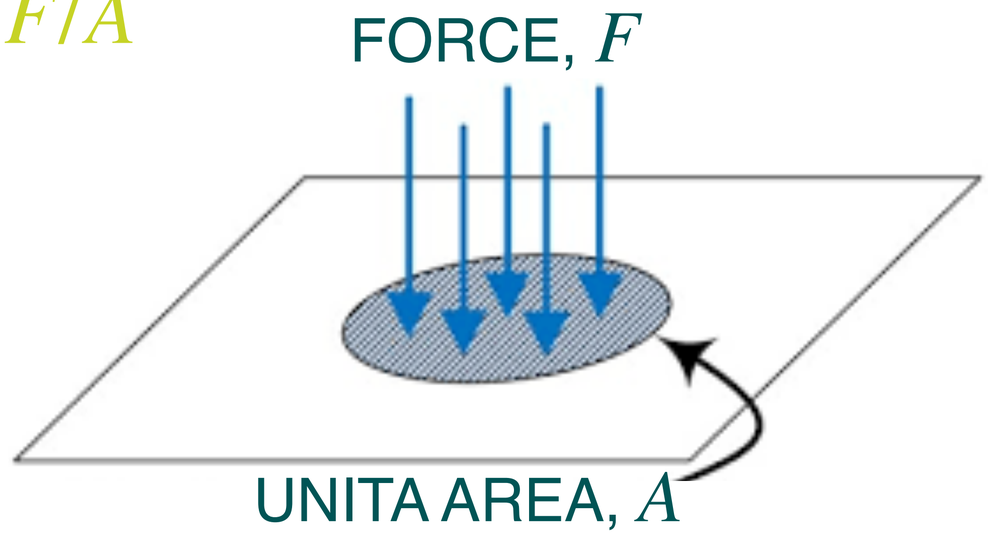


HIGH DENSITY

PRESSURE

- Pressure is the force exerted perpendicular to an object's surface per unit area A

$$\text{pressure} \equiv P = F/A$$



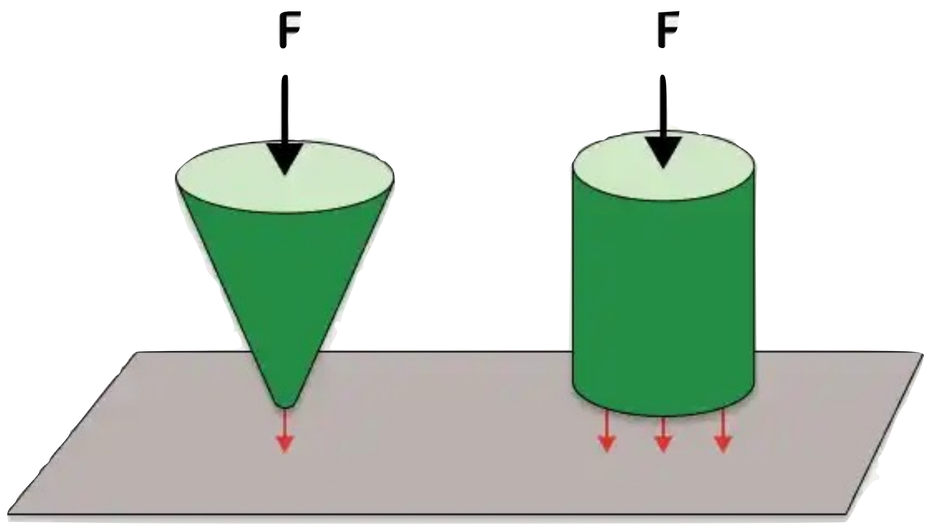
PRESSURE

- While internal gas pressure can cause outward expansion (like in a balloon), pressure generally measures force concentration in any direction —*inward, outward, or downward* — depending on the context

- Pressure acts in all directions at once

PRESSURE

- Note that pressure depends on both the amount of force (e.g., gravity, molecular motion) and the area it is spread over
- A smaller area results in higher pressure for the same force

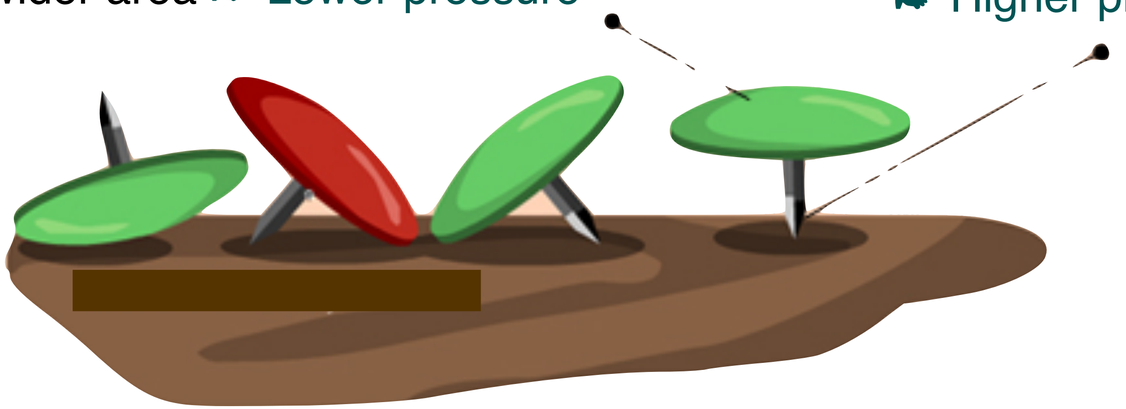


More Pressure
(As smaller area)

Less Pressure
(As higher area)

Force is distributed over
a wider area ☛ Lower pressure

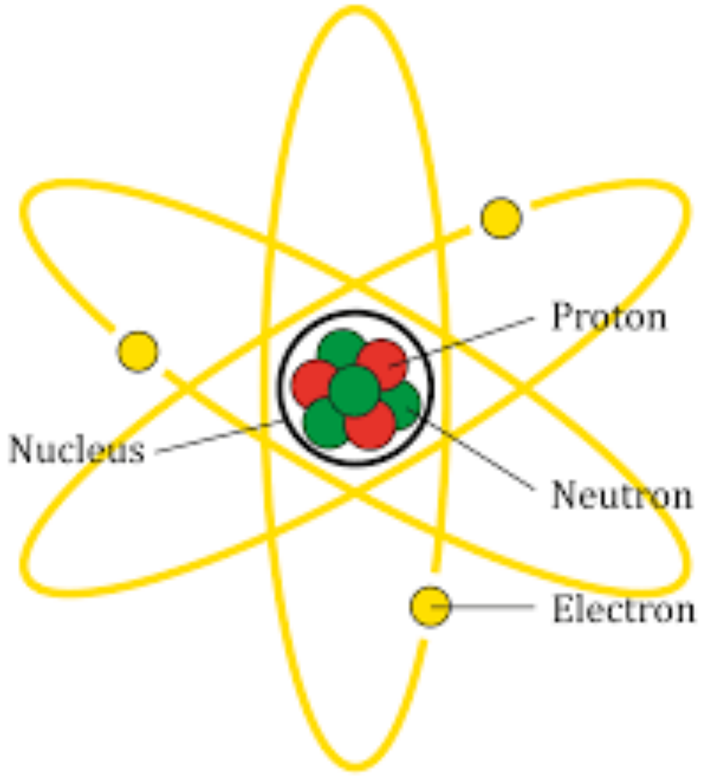
Force is directed to one point
☛ Higher pressure



Atomic Structure

- ATOMS are the fundamental building blocks of ordinary matter, consisting of a dense, central nucleus of positively charged protons and neutral neutrons, surrounded by a cloud of negatively charged electrons

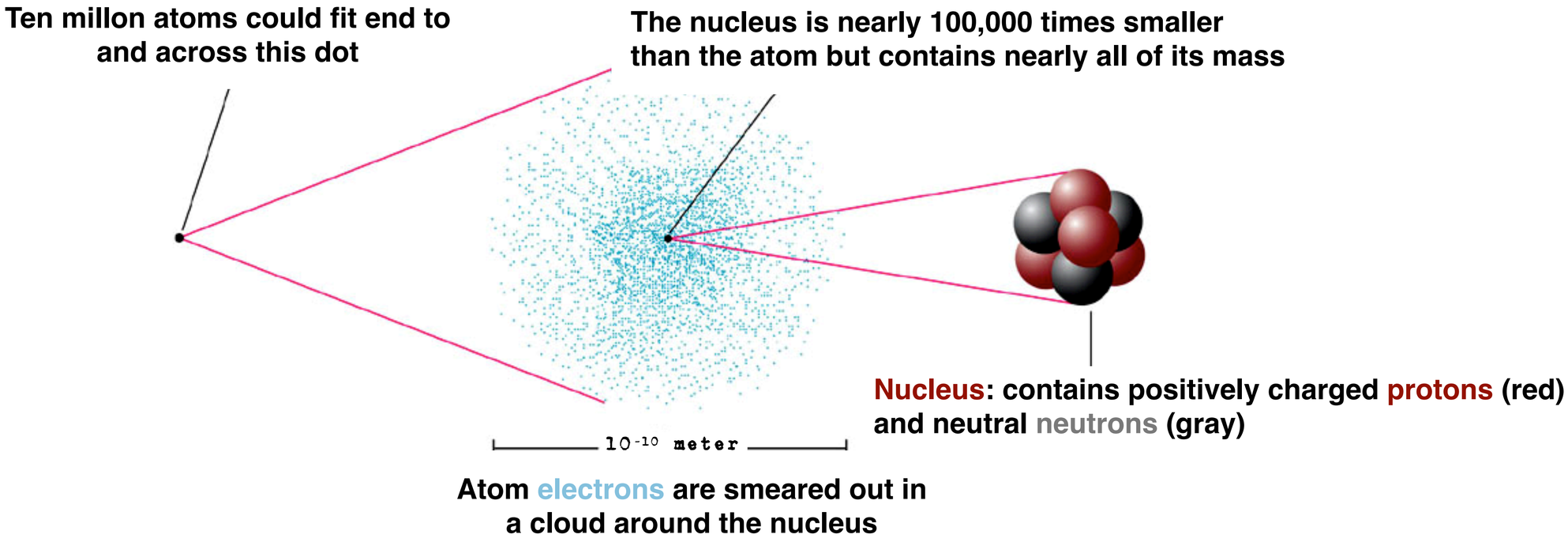
- Ranging in size around 10^{-10} m, they form the smallest unit of an element that retains its chemical properties



- The bodies that make up our everyday environment are made up of atoms that are attached to other atoms by bonds that hold them together, forming molecules

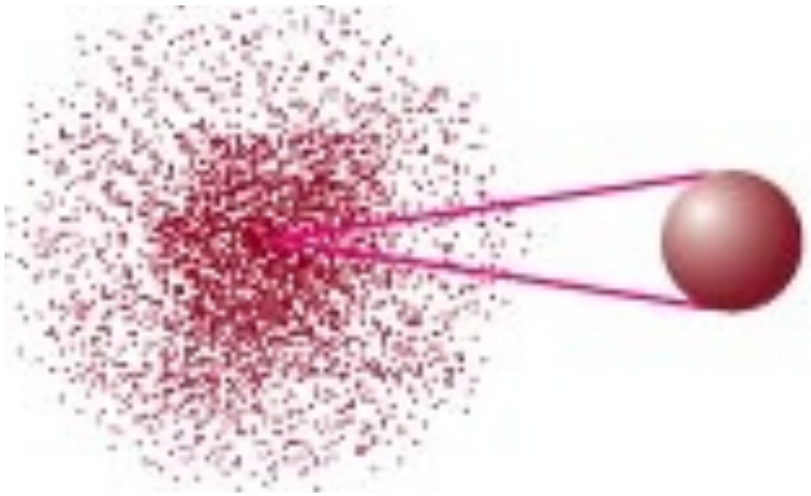
Atoms encompass big empty spaces

- **Protons and neutrons make up more than 99.9\% of the atomic mass, while electrons occupy most of the volume, which is primarily empty space**



HYDROGEN: SIMPLEST AND MOST COMMON

HYDROGEN (^1H)



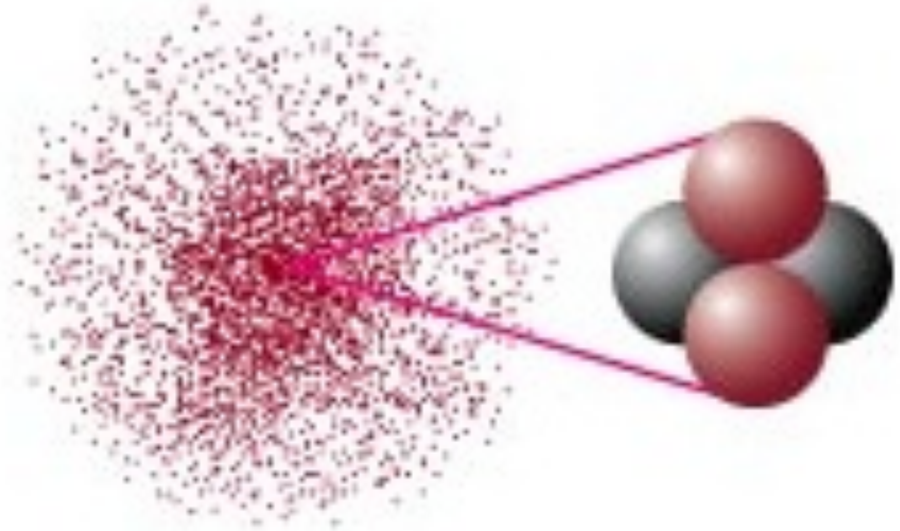
atomic number 1

atomic mass number 1

(1 electron)

HELIUM

HELIUM (^4He)



atomic number 2

atomic mass number 4

(2 electrons)

PERIODIC TABLE OF THE ELEMENTS

1 H																	2 He
3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
55 Cs	56 Ba	57–71 La–Lu	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
87 Fr	88 Ra	89–103 Ac–Lr	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt									
		Lanthanoids	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu	
		Actinoids	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr	

Atomic Number = # of protons in nucleus

Atomic Mass Number = # of protons + neutrons

ISOTOPES

- The number of protons (atomic number) characterizes a certain chemical element

- Mostly an atom will have certain normal number of neutrons along with the protons

- But occasionally, an atom will have a few more or less neutrons than normal
  This is called an *isotope* of that element

CARBON ISOTOPES

- Different isotopes of a given element contain the same number of protons, but different numbers of neutrons

carbon-12

^{12}C

6 protons
+
6 neutrons

carbon-13

^{13}C

6 protons
+
7 neutrons

carbon-14

^{14}C

6 protons
+
8 neutrons

What if an electron is missing?

Ion

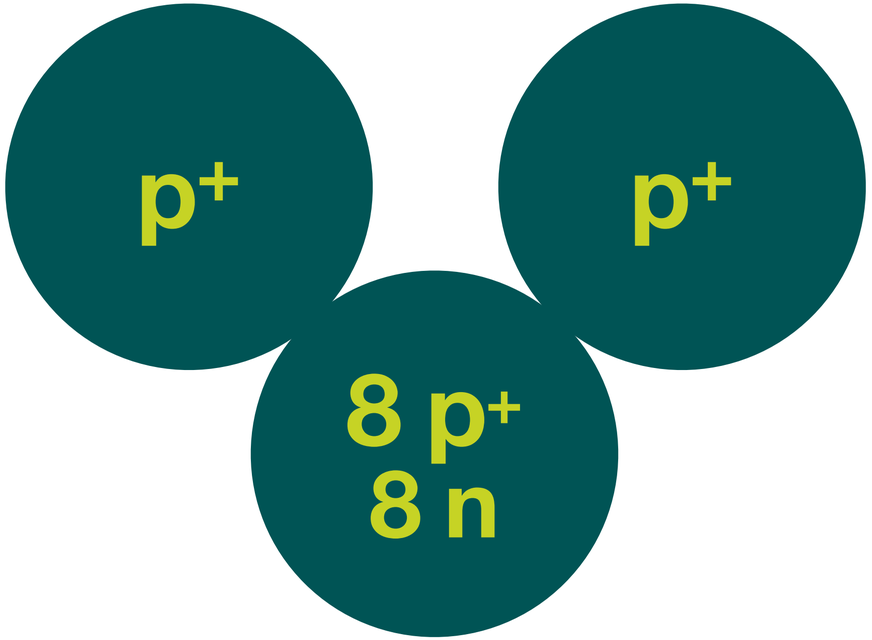
atomic number = 1

H^{+1}

atomic mass number = 1

What if two or more atoms combine to form a particle ?

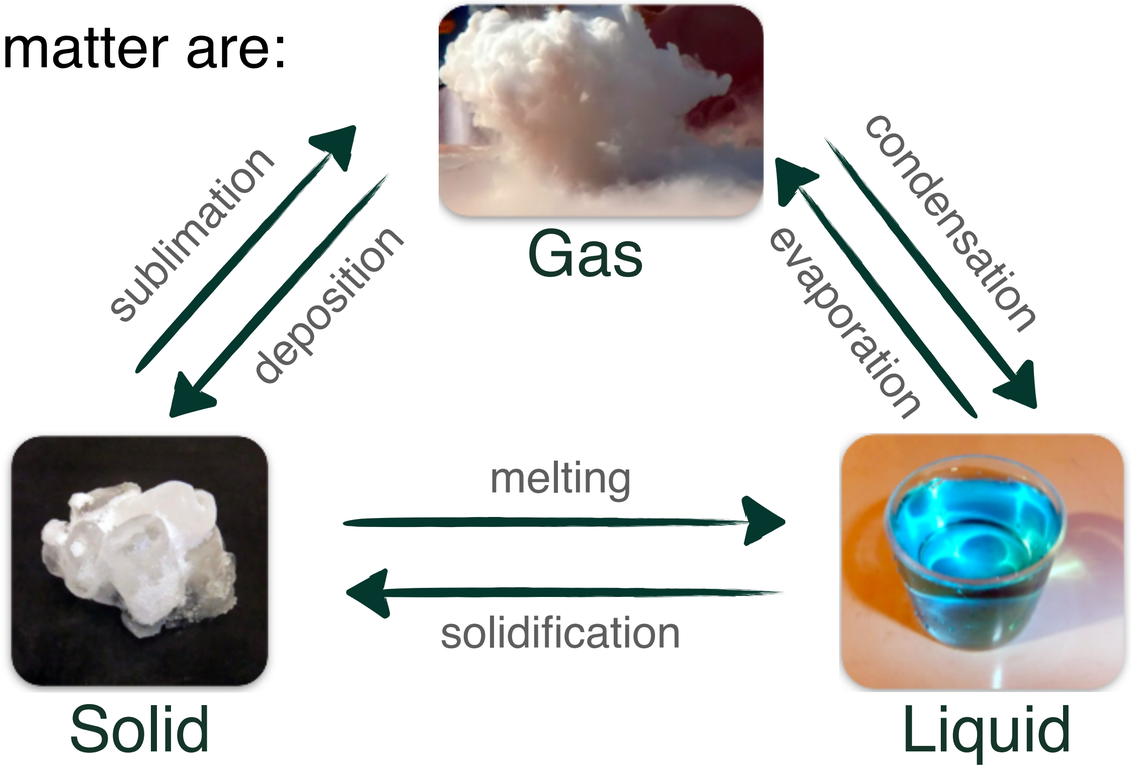
Molecule



H_2O water

PHASES OF MATTER

- Three common phases of matter are:

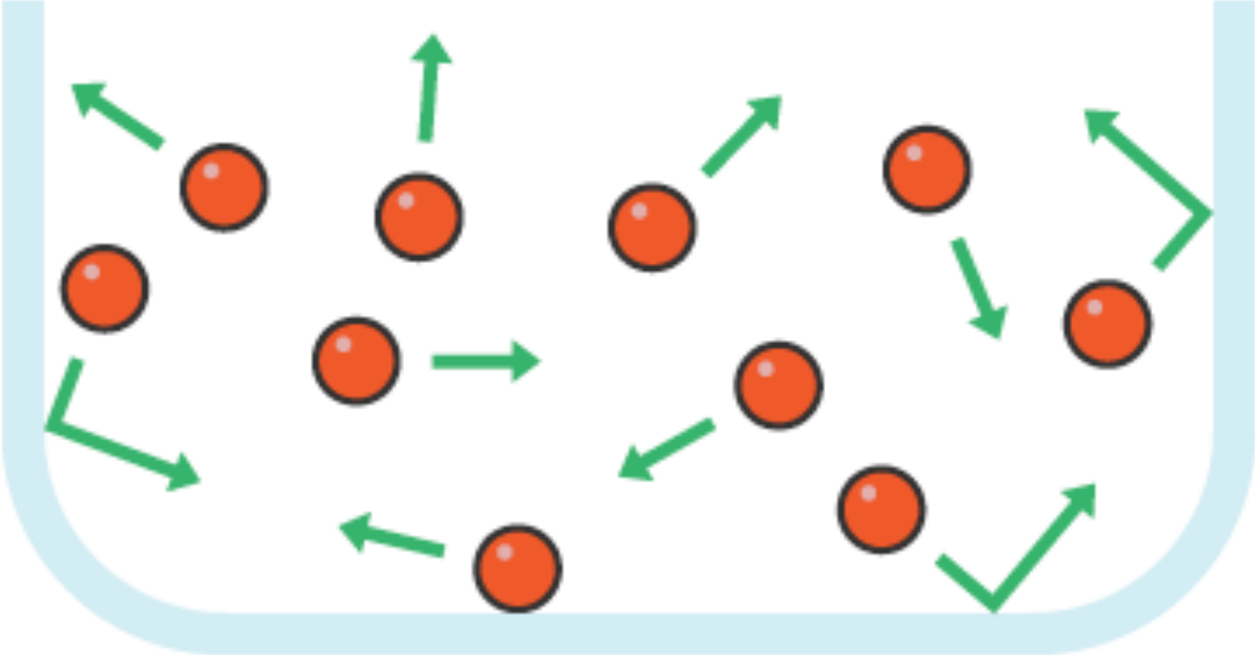


- Solid ☛ has a fixed shape and volume with tightly packed, vibrating molecules
- Liquid ☛ has fixed volume but can be any shape
- Gas ☛ has no fixed shape or volume

Liquids and gases both flow and are called fluids

GASES

- Gases contain particles (atoms or molecules) that move around very quickly
- The particles travel in straight lines until they bounce off another particle or a surface
- Particle collisions are assume to be elastic
- Gas particles are widely spaced and tend to be only slightly attracted to each other

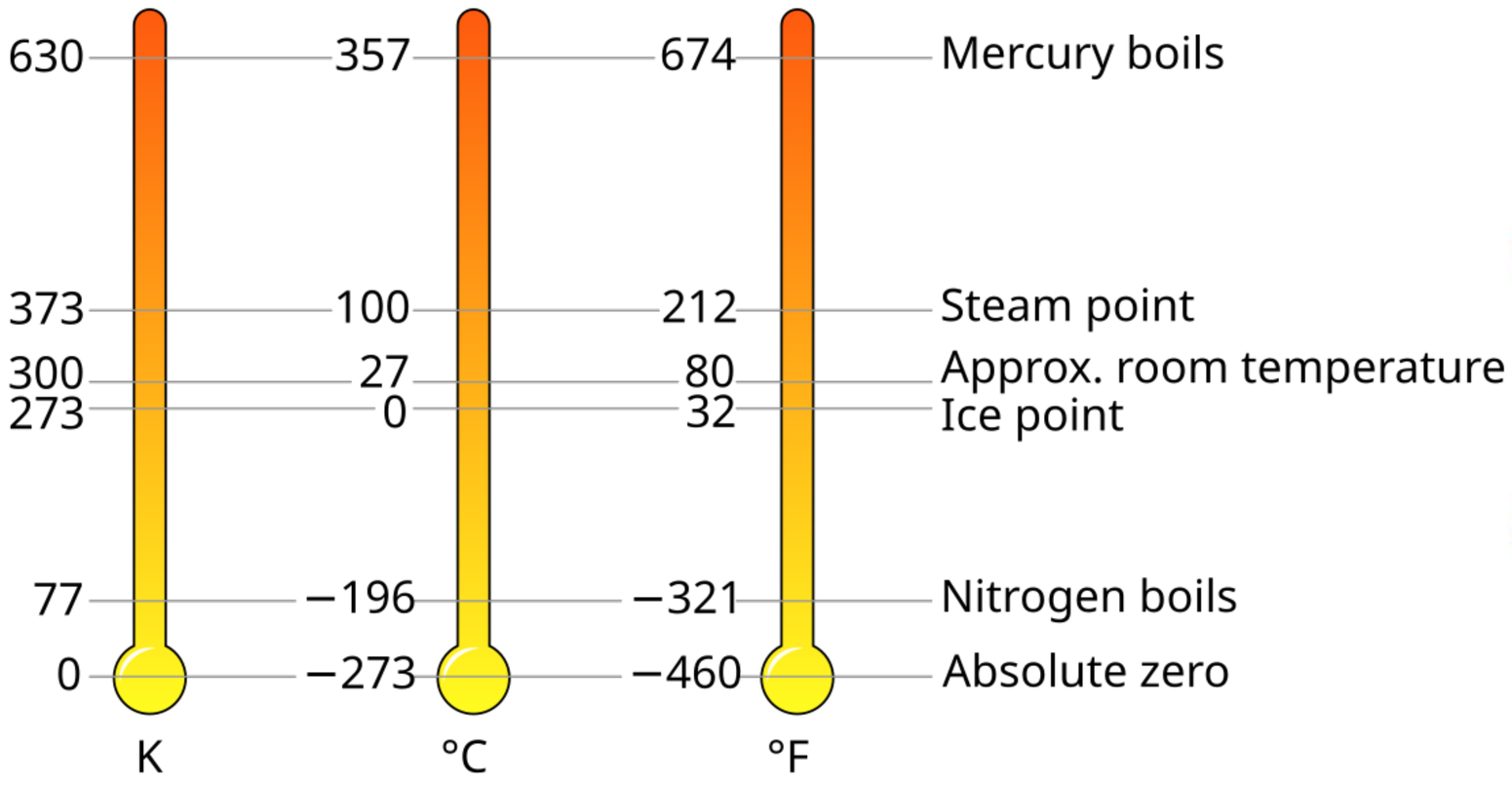


TEMPERATURE

- Temperature (T) is a macroscopic measure of the average kinetic energy of gas particles; increasing temperature increases molecular velocity
- While a single atom (or molecule) has energy, it does not have temperature;

  temperature only describes the collective, average motion of a large number of particles

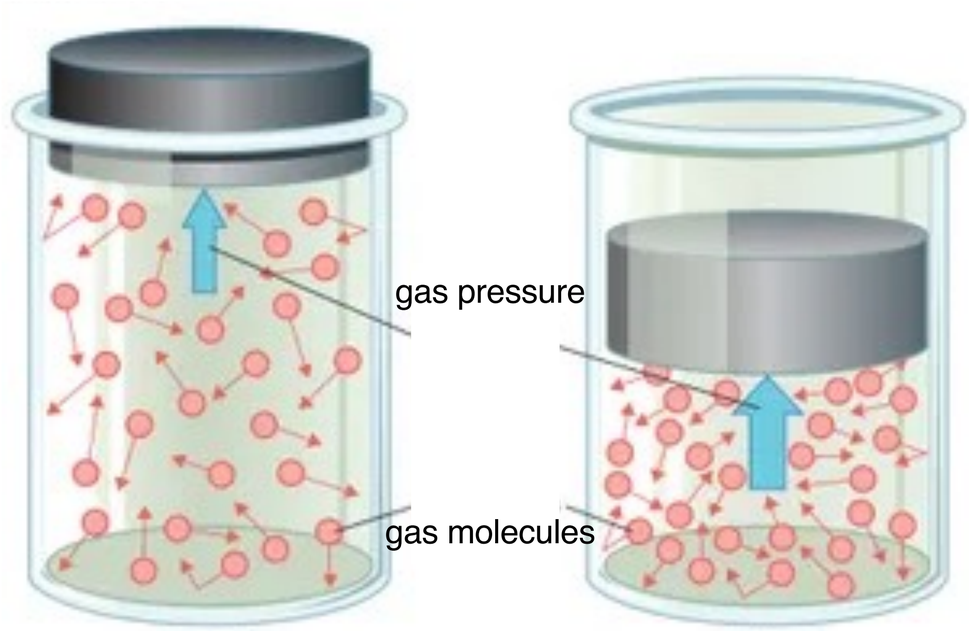
TEMPERATURE SCALES



Throughout we use Kelvin scale

IDEAL GAS LAW

- The properties of a gas are almost independent of its identity
- This implies that gas molecules behave as if no other molecules are present
- The ideal gas law ☛ $PV = Nk_{\mathrm{B}}T$



volume 1 volume 2

P ☛ pressure

V ☛ volume

N ☛ number of molecules

T ☛ temperature

k_B ☛ Boltzmann constant

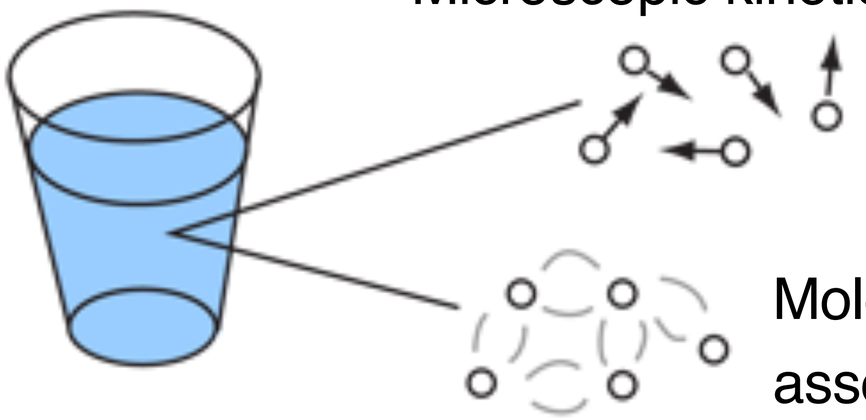
INTERNAL ENERGY

- The internal energy (U) of a substance, arising from the random or disorganized molecular motion, is primarily dependent on temperature
- The internal energy of a monatomic ideal gas is $U = \frac{3}{2} k_B T$ per molecule

Does a glass of water sitting on a table have any energy?

Microscopic kinetic energy is part of internal

No apparent energy of the glass of water on a macroscopic scale



Molecular attractive forces are associated with potential energy

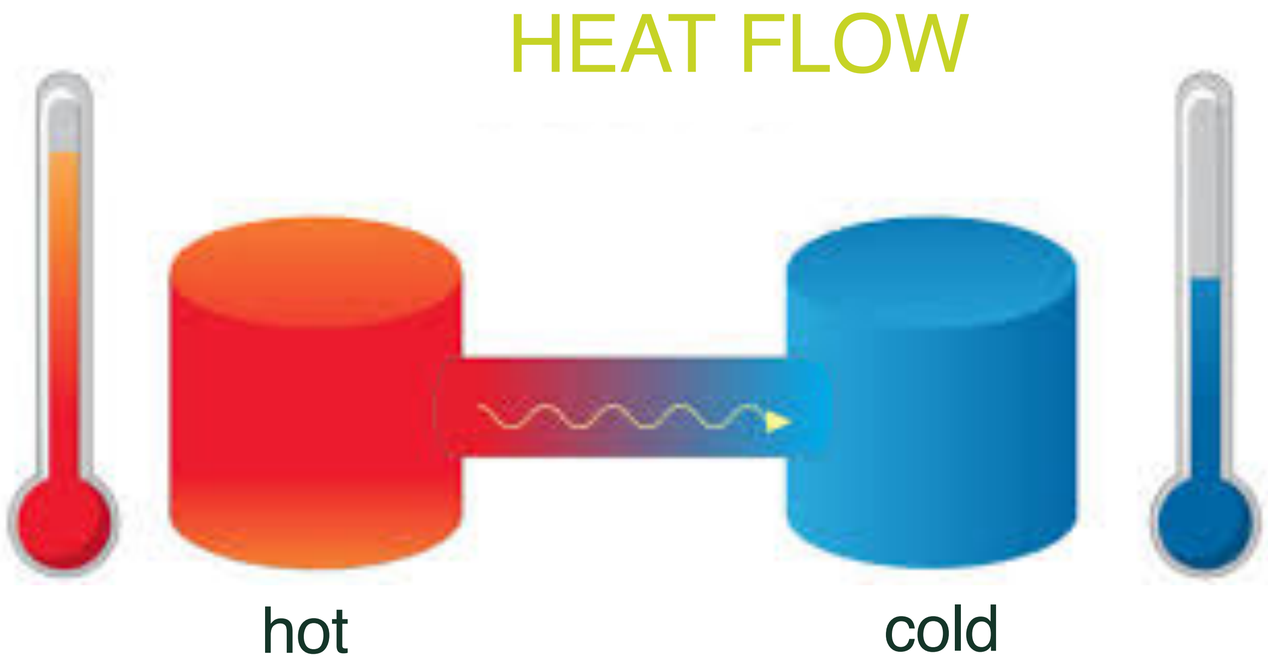
THERMODYNAMIC SYSTEM

- A thermodynamic system is a specific, defined portion of matter or radiation in the universe chosen for study, separated from its surroundings by real or imaginary boundaries
- It exchanges energy or matter with its environment, allowing analysis of properties like pressure, volume, and temperature via thermodynamic laws

Open System	Closed System	Isolated System
Heat and mass transfer	Only heat transfer	Nothing is transfer

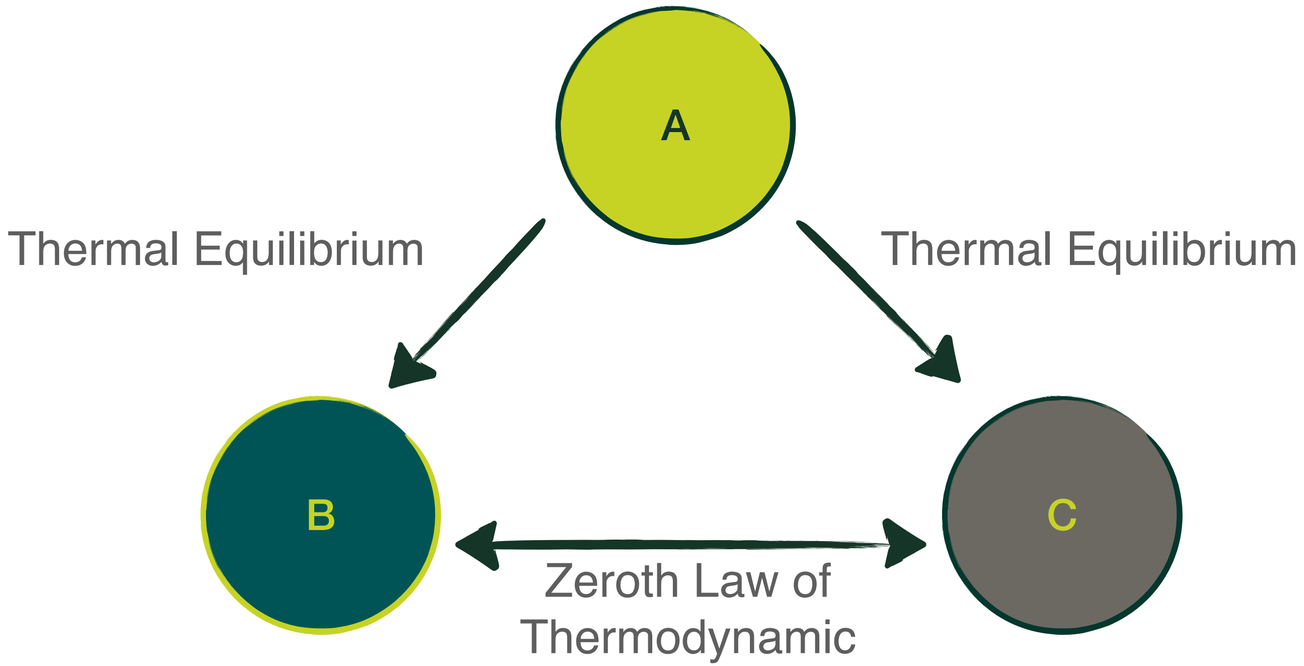
HEAT

- In thermodynamics, heat Q is defined as the transfer of energy between two systems or a system and its surroundings due to a temperature difference
- It is fundamentally energy in transit, moving from a hotter body to a cooler one until thermal equilibrium is reached, resulting in both bodies having the same temperature



ZEROTH LAW OF THERMODYNAMIC

- The zeroth law states that if two systems are both in thermal equilibrium with a third system, then they are in thermal equilibrium with each other
- This law provides the basis for measuring temperature



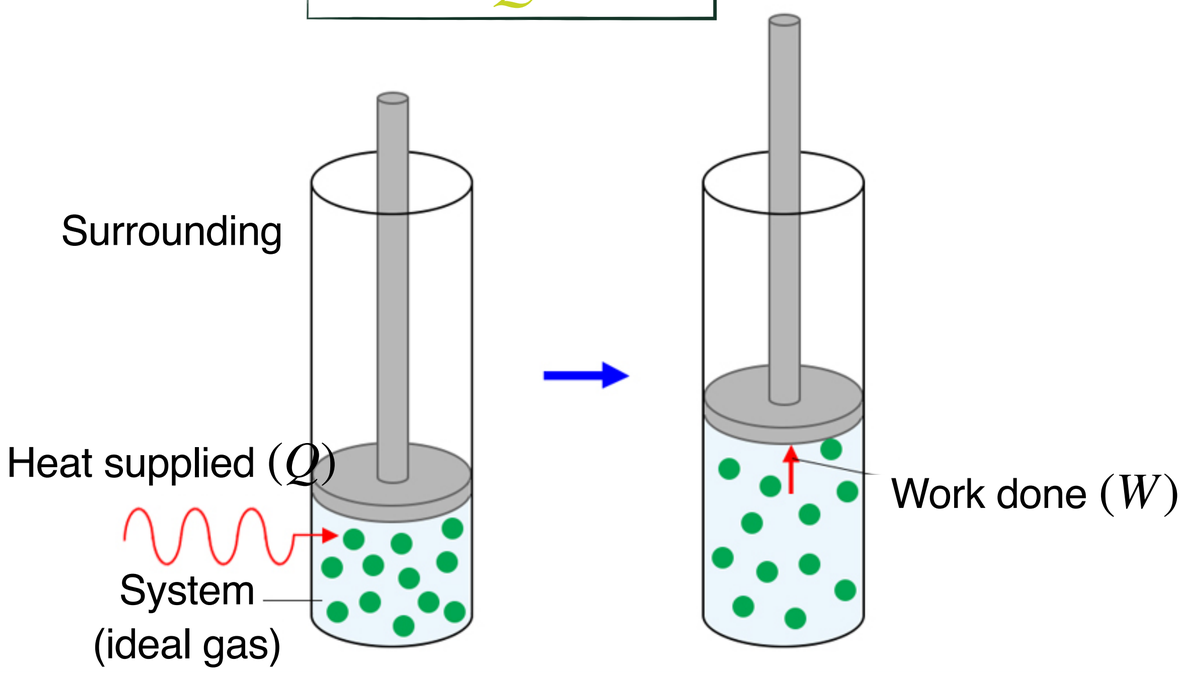
FIRST LAW OF THERMODYNAMIC

FIRST LAW OF THERMODYNAMIC

- The first law is a variation of the law of conservation of energy that is adapted for thermodynamic systems
- The total energy of an isolated system is constant, where energy can be transformed from one form to another but can be neither created or destroyed

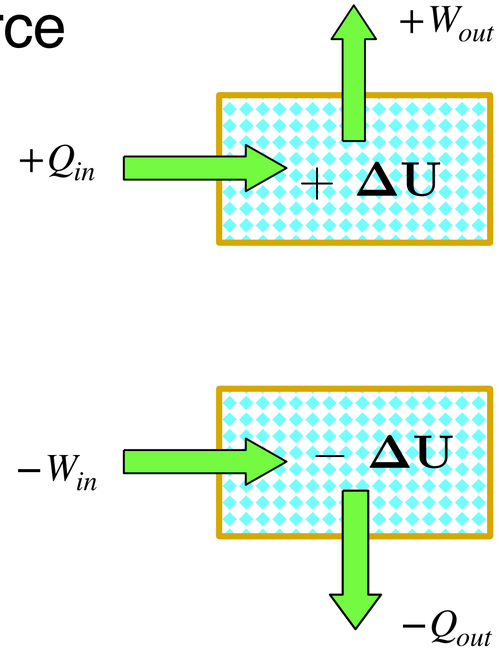
Change in internal energy of a system = Heat added to the system – Work done by the system

$$\Delta U = Q - W$$



FIRST LAW OF THERMODYNAMIC

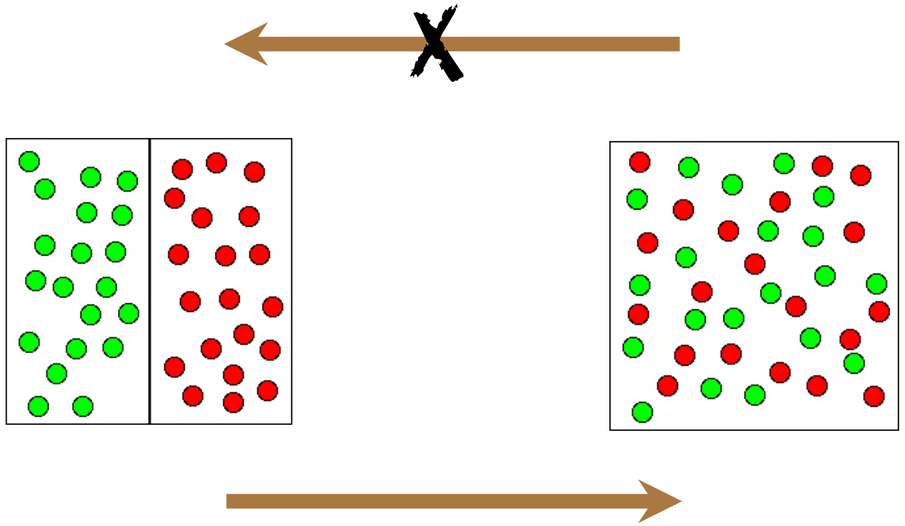
- The signs in $\Delta U = Q - W$ are critical and potentially confusing; thus, it is necessary to explicitly clarify that Q is positive if the heat is transferred to the system and negative if it is transferred from the system, whereas W is postive if the work is done by the system and negative if it is done on the system
- One of the implications of this law is that it is impossible to create perpetual motion machines that will produce work with no input of any energy source
- Perpetual motion machines are an impossibility



ENTROPY

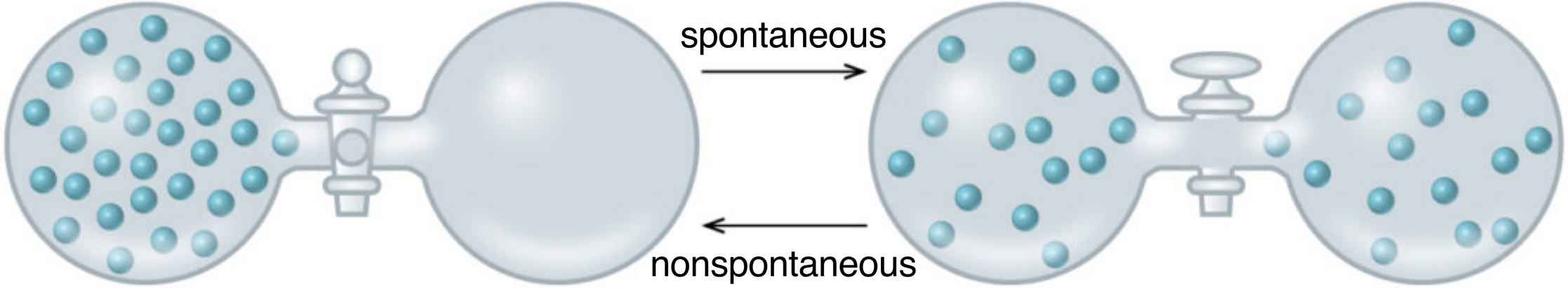
- A measure of the molecular disorder or energy dispersal in a system ☛ typically expressed in Joules per Kelvin (J/K).
- Systems tend to change from a state of low entropy to a state of higher entropy
- Change in entropy (ΔS) is defined as the heat transferred (Q) divided by the absolute temperature (T) at which the transfer occurs

$$\boxed{\Delta S = \frac{Q}{T}}$$



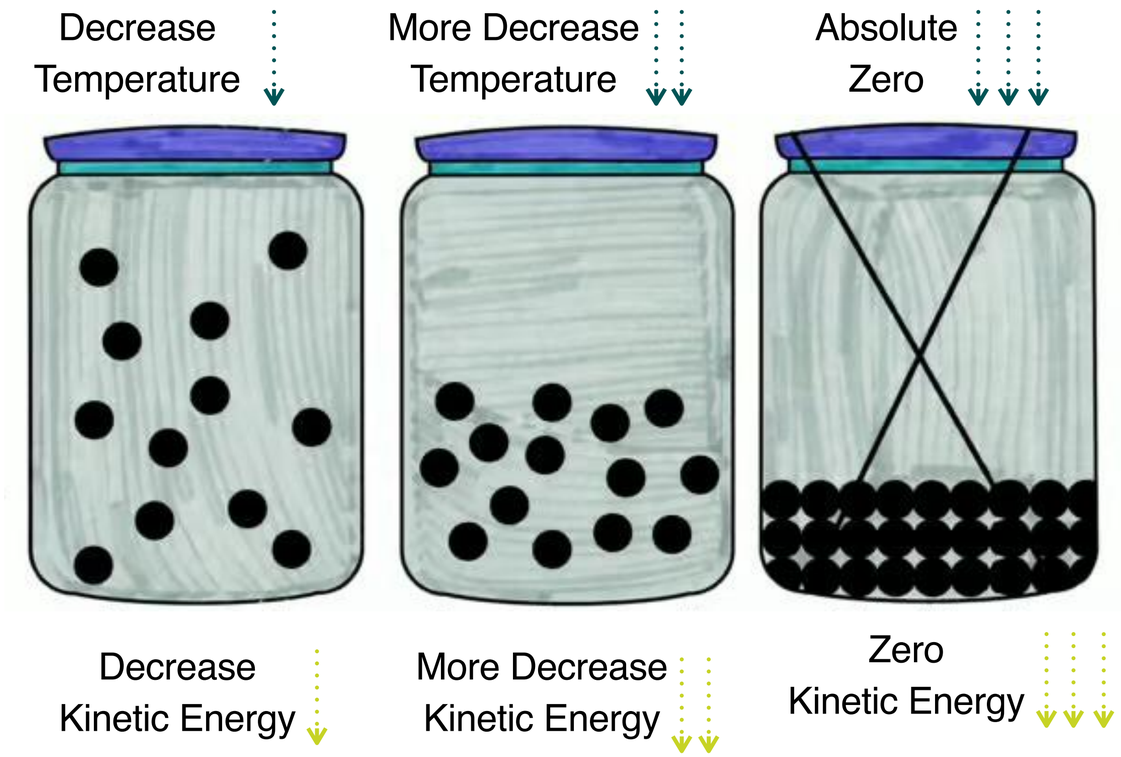
SECOND LAW OF THERMODYNAMIC

- The second law of thermodynamics states that in any spontaneous process, energy tends to disperse or spread out from a concentrated state to a more dilute, disordered, or lower-temperature state
- This inevitable dispersal increases the total entropy of the universe, meaning energy becomes less available to do useful work



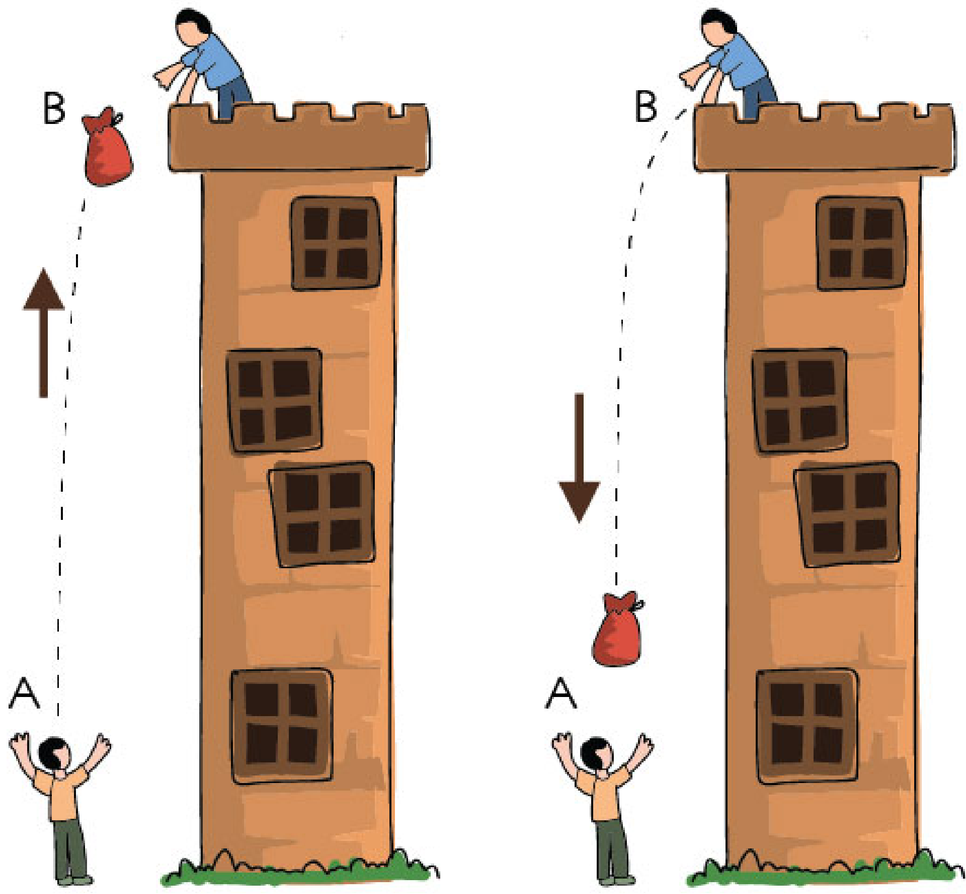
THIRD LAW OF THERMODYNAMIC

- The third law of thermodynamics states that the entropy of a system will approach a constant as the system gets closer to absolute zero
- The third law then implies that it is impossible for any system to ever reach absolute zero



Mr. GREEN & Mr. RED

- Consider Mr. Green is throwing a bag of coins to Mr. Red, who is up a tower
- As Mr. Green throws the bag from A to B, work is transferred from Mr. Green to the bag, which now has kinetic energy
- As the bag moves upward, kinetic energy decreases, and gravitational energy increases
- At the highest point B, the kinetic energy is zero and the gravitational potential energy is the highest
- As the bag did not get to Mr. Red, it starts falling from point B downwards due to gravity
- It starts falling slowly (kinetic energy is low) and then speeds up downwards
- At point A, the bag is at full speed and the kinetic energy is the highest, while gravitational energy is nearly lost
- When the bag of gold coins hits the ground, the kinetic energy is converted into heat and sound by the impact



Deuterium is an isotope of Hydrogen

Which of the following makes sense for the composition of Deuterium?

A. 1 proton, 0 neutrons, 1 electron

B. 2 protons, 0 neutrons, 2 electrons

C. 2 protons, 2 neutrons, 2 electrons

D. 1 proton, 1 neutron, 1 electron

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According to the kinetic theory, particles of matter are:

A. Stationary

B. Always fluid

C. In constant, random motion

D. Arranged in a fixed pattern

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B. Perfectly elastic

C. Resulting in energy loss

D. Causing particles to stick together

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Which of the following is NOT an assumption of the kinetic molecular theory of gases?

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B. There is very little empty space in a gas

C. Gas particles do not attract or repel each other

D. Kinetic energy depends on temperature

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Temperature is a measure of which property of gas molecules?

A. Average speed

B. Average kinetic energy

C. Total pressure

D. Particle masses

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Which postulate explains why gases are so easily compressed?

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B. Particles have perfectly elastic collisions

C. The volume of the particles is negligible compared to the container volume

D. Particles exert no force on each other

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What happens to the volume of a gas if the pressure is doubled while temperature remains constant?

A. It doubles

B. It is halved

C. It remains constant

D. It quadruples

[Hint: $PV = Nk_{\mathrm{B}}T$]

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Which unit of temperature MUST be used in all gas law calculations?

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B. Fahrenheit

C. Kelvin

D. Any of the above

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If you decrease the temperature of a gas in a sealed, rigid container, the pressure will:

A. Increase

B. Decrease

C. Stay the same

D. Fluctuate

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Which thermodynamic principle forms the basis for our ability to measure temperature?

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B. The First law

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A system that allows both energy and mass to cross its boundary is known as:

A. Closed system

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C. Open system

D. Audio system

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If a system absorbs 50 J of heat and does 20 J of work, what is the change in internal energy (ΔU)?

A. 30 J

B. 70 J

C. 20 J

D. 50 J

[Hint: $\Delta U = Q - W$]

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B. Remain zero

C. Increase or stay constant

D. Depend on pressure

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If 30 J of energy is added to water as heat at 300 K, what is the change in entropy of water?

A. 1.11 J/K

B. 0.1 J/K

C. 10 J/K

D. 0.01 J/K

[Hint: $\Delta S = \frac{Q}{T}$]

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A hot cup of coffee is kept on the table. After some time it attains a thermal equilibrium with the surroundings. By considering the air molecules in the room as a thermodynamic system, which of the following is true

A. $\Delta U > 0$ and $Q = 0$

B. $\Delta U > 0$ and $W < 0$

C. $\Delta U > 0$ and $Q > 0$

D. $\Delta U = 0$ and $Q > 0$

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