Atomic Physics

- Remember that the size of an atom is on the order of 10^{-10} m

- Prior to about 1900, physics was generally concerned with describing *macroscopic* phenomena.

    macroscopic – large scale, generally observable with the naked eye

    classical or Newtonian Physics

- After 1900, physics began to explore the world of the very, very small (or *microscopic*)

    modern physics

    -*atomic physics* – deals mainly with phenomena involving the electrons in atoms

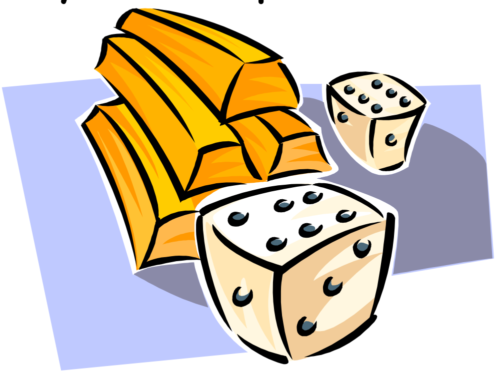
    -*nuclear physics* – deals with the central core, or nucleus, of the atom

    -*quantum mechanics* – describes atoms and electrons using properties of the wave

<u>Atomic Physics</u>

- *<u>Atomic Theory of Matter</u>*: All matter is made of tiny particles, too small to be seen

- Idea was first suggested by the Greeks – Leucippus and his student Democrittus – "thought experiment", an imagined experiment that seemed possible in principle but difficult to carry out in practice



- Matter is either *continous – divisible without limits*, or *discrete – made up of particles that cannot be divided*

- Concluded that matter is made up of small, "*a-tomic*" (Greek for *not divisible*), particles - atoms

Atomic Physics – How do we know?

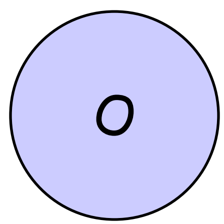
- Greeks had no direct evidence for existence of atoms. Democritus had some indirect evidence, odor

- First specific evidence was discovered by John Dalton around 1800.

- John Dalton: Chemical combinations of atoms occur in accordance with fixed ratios.

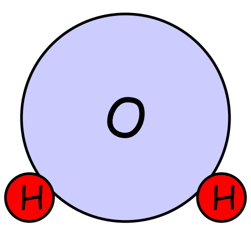
Consider water (H_2O):

Hydrogen – atomic weight 1



Oxygen – atomic weight 16

Water – H_2O



ratio of the weights of H : O in water is:

$$\frac{\text{Mass of all H atoms in a sample of water}}{\text{Mass of all O atoms in a sample of water}} = \frac{2}{16} = \frac{1}{8}$$

DOES THIS PROVE THE EXISTENCE OF ATOMS?

Atomic Physics – How do we know? more evidence

- Robert Brown – botanist, observed under a microscope that tiny pollen grains suspended in liquid move around erratically even though the liquid had no motion

- Brown first hypothesized that the pollen could be alive! lifeless pollen showed the same behavior

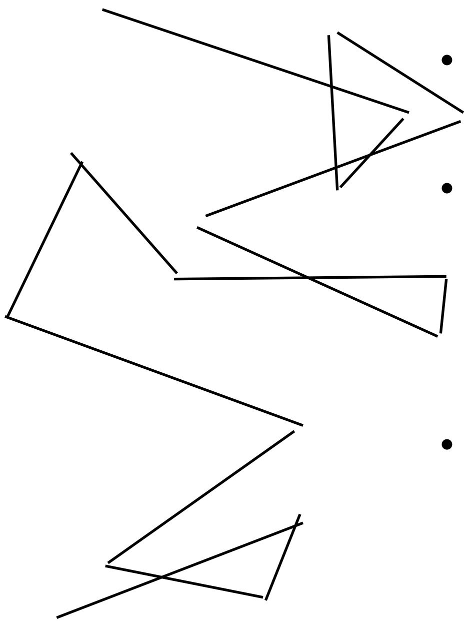


diagram of erratic pollen grain path

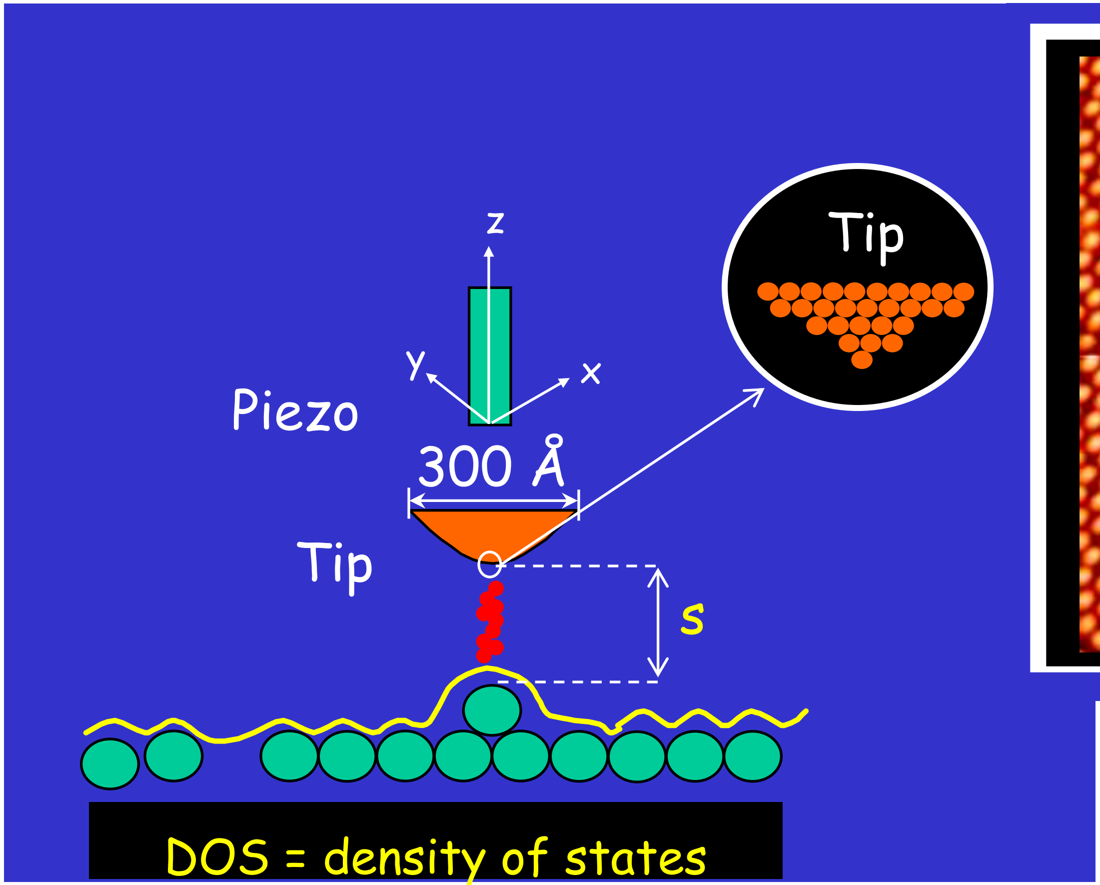
- Atomic theory could explain this motion

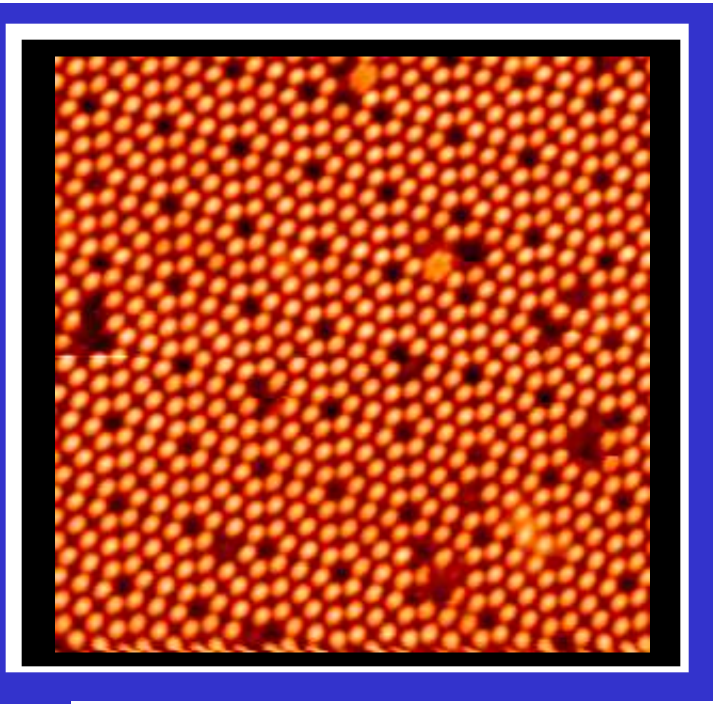
- Atoms in constant motion and that the dust grains were jostled or knocked around by this motion

- 1905 an unknown physicist named Albert Einstein was able to calculate the rate at which a collection of pollen grains would spread out (diffuse)

Atomic Physics – How do we know? more evidence

- Today we have the strongest evidence, thanks to the strongest microscope in the world called the Scanning Tunneling Microscope (STM) – uses *quantum mechanical tunneling* to achieve high resolution images





Atomic Physics

• *chemical decomposition* – any process that changes a single substance into two or more other substances. $H_2O \rightarrow 2H + O$

• Roughly 100 substances that are fundamental and cannot undergo chemical decomposition, these are known as the *chemical elements*

• Today we know of 112 different elements, 90 occur naturally and the others are made in laboratories

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 La	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 Ac	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Uun								

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
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

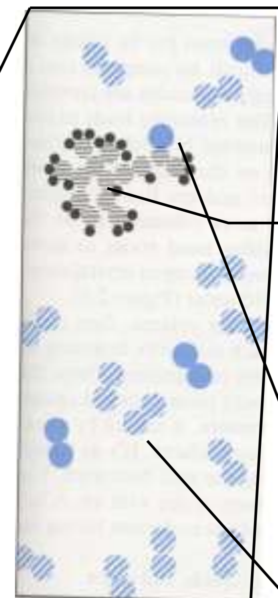
• combinations of these different elements result in *chemical compounds*

• the smallest particle of a compound that still has the characteristics of that compound is called a molecule

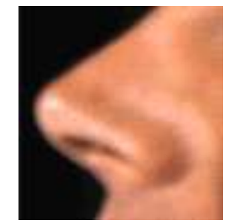
Atomic Physics

- the odor of violets, making connections between the microscopic and the macroscopic

- air is made of atoms – wind, air has weight
- Brownian motion, that atoms in a liquid are constantly moving, same for atoms in air



odor-of-violets molecule are made up of carbon, hydrogen, and oxygen molecules



odor molecules must break loose from the violet

- once in the air, moving air molecules knock odor molecules around, just like Brownian Motion

- causes molecules to spread out or *diffuse*

Atomic Physics –states of matter

- atomic theory is helpful in understanding state of matter
- Water comes in three states: solid, liquid, and gas state
- Macroscopically the three states can be distinguished by their shapes in a closed container – solid maintains its shape
  - liquid spreads out over the bottom
  - gas fills the volume

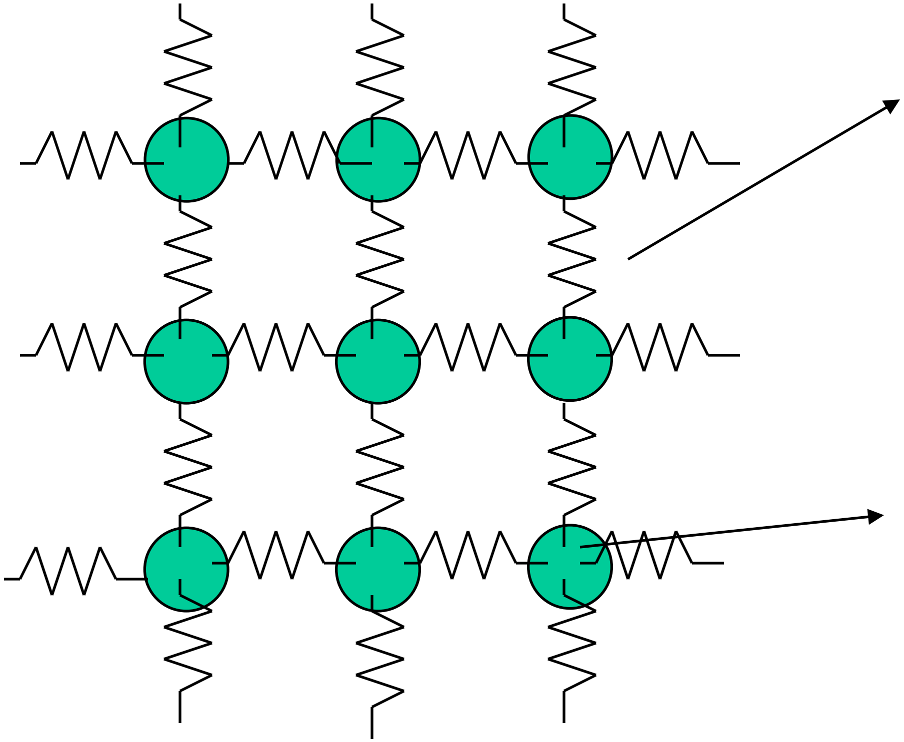
solid

liquid

gas

Atomic Physics –states of matter

solids (less motion → lower temperature)



interatomic forces (sort of like springs)

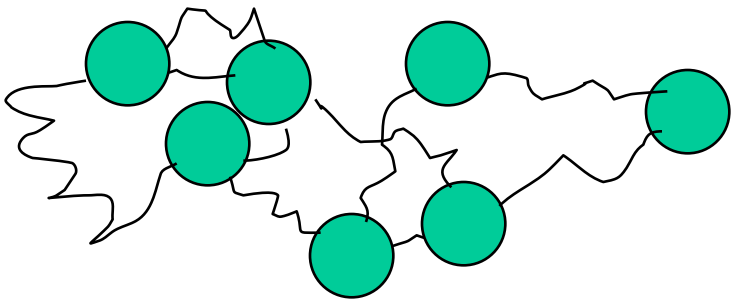
Solids have the strongest interatomic forces

atoms "shake in place"

- solids maintain fixed shape – molecules must be locked into a fixed arrangement
- solids are difficult to compress – their molecules must be crowded against one another

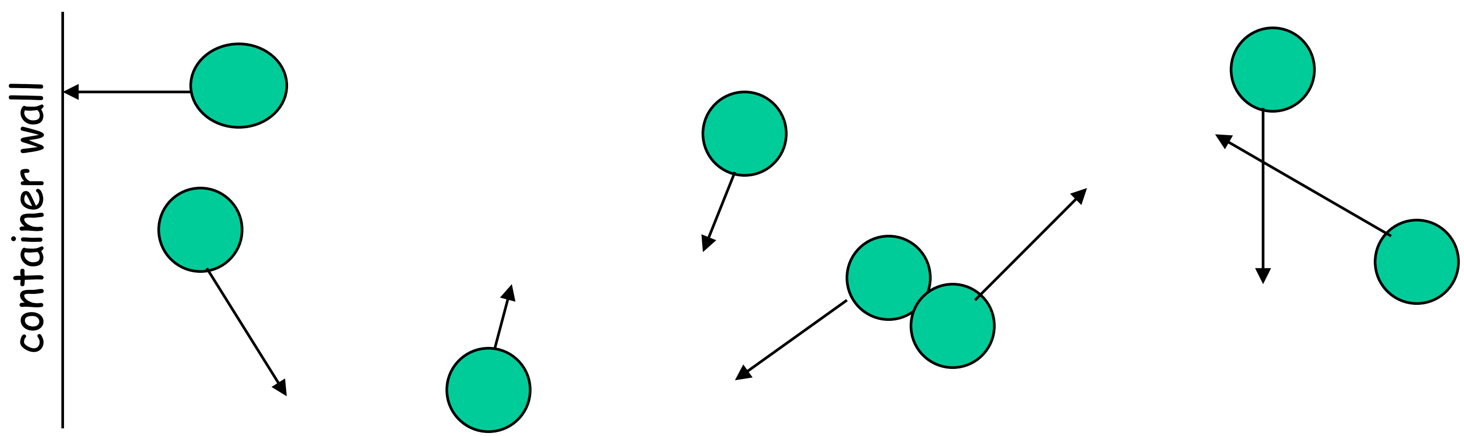
Atomic Physics –states of matter

liquid (intermediate motion → intermediate temperature)



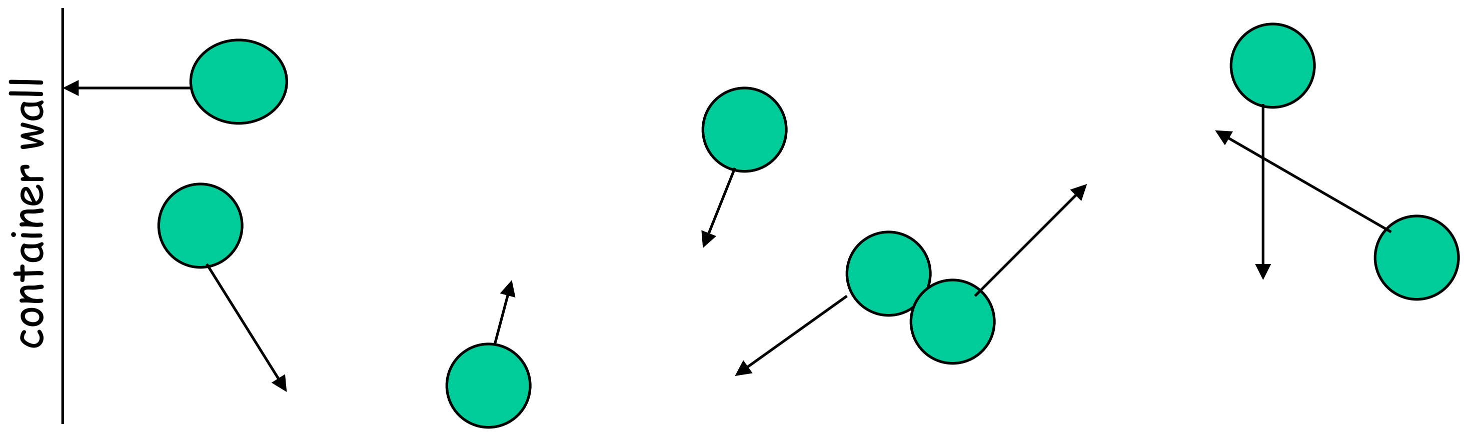
- forces are not weak and not well understood
- no fixed positions for atoms
- atoms can flow around one another
- not compressible (not very easy)

gas (lots of motion → higher temperature)



- interatomic forces are very weak
- atoms zip around and smash into things/each other – gas pressure, caused by gas molecules hitting the walls (3 Liter bombs)
- easily compressible (do LN2 demo here)

Atomic Physics –states of matter



- atoms zip around and smash into things/each other – *gas pressure, caused by gas molecules hitting the walls*

- mean free path – average distance an atom can travel before it collides with another atom . Mean free path is directly related to pressure

Normal atmospheric pressures → 1 billionth of a meter (try writing this number using scientific notation)

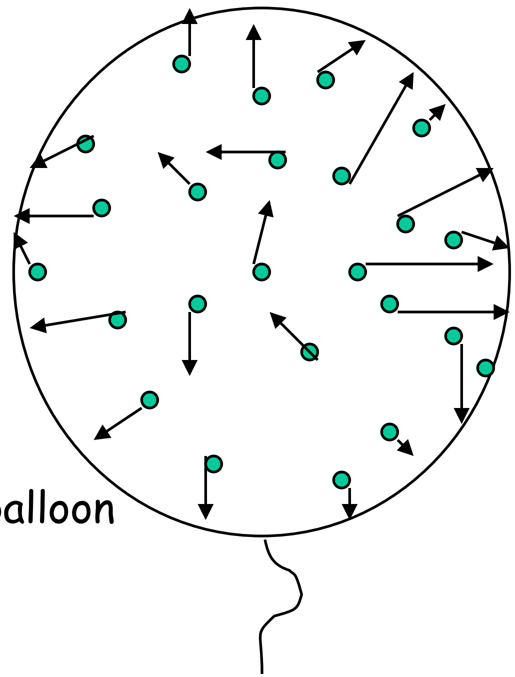
When the pressure is reduce the mean free path increases. In outer space the mean free path is ~ 1km

Vacuum – a complete absence of air and all other forms of matter

Atomic Physics –pressure, temperature

- using our knowledge of solids, liquids, and gasses let's try to answer the following questions:
  - what happens if we increase the temperature of the gas inside?
  - what happens if we increase the number of atoms inside? GO TO HITT

what gives the balloon its shape?

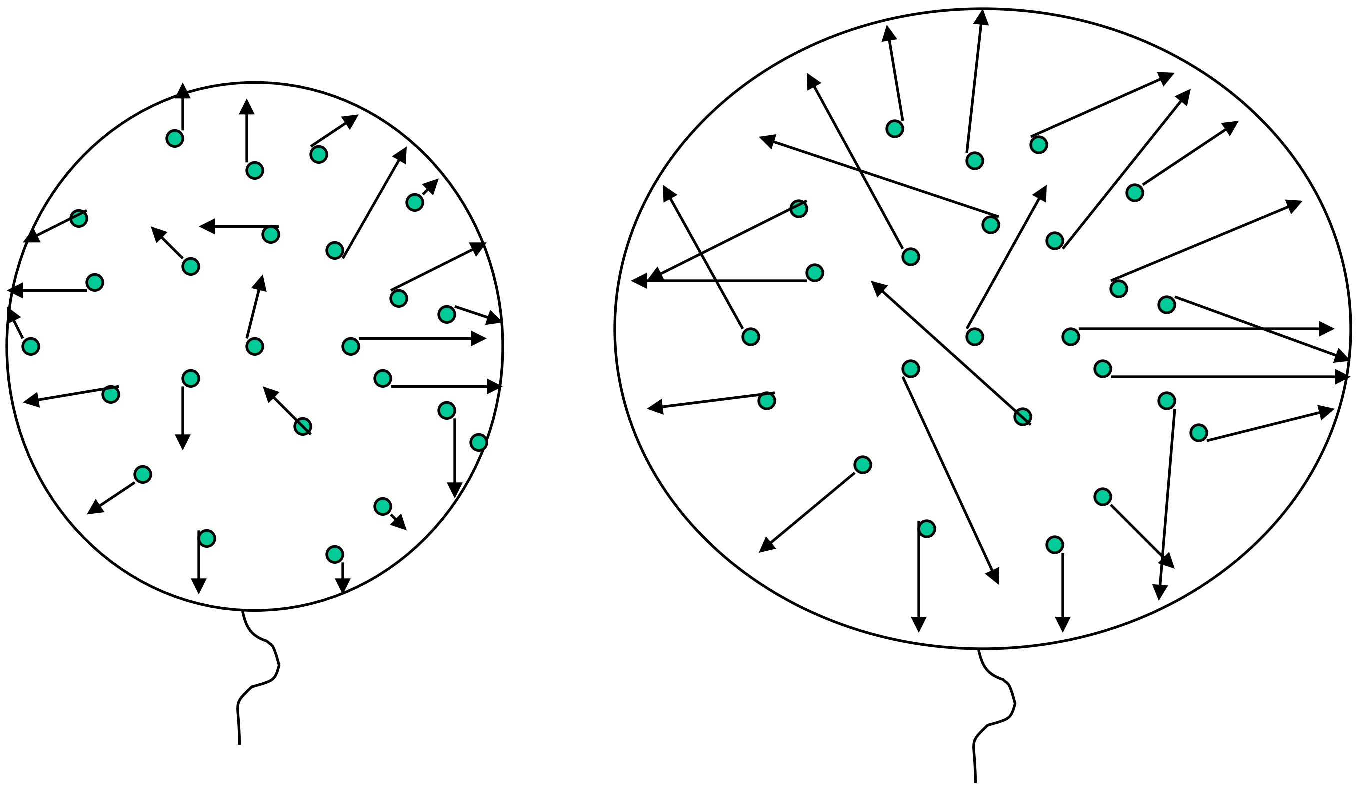


air filled balloon

Atomic Physics –pressure, temperature

- what happens if we increase the temperature of the gas inside?

NOTE: the number of molecules inside the balloon remains constant in this example



- As the temperature increases there is an increase in motion of the atoms, molecules
- more motion leads to an increase in the frequency (or ofteness) of collisions
- more pressure on the inside!

Atomic Physics –pressure, temperature

- now lets take it another step.
- we just learned that as temperature increases $\rightarrow$ pressure increases and the converse is true: temperature decreases $\rightarrow$ pressure decreases

temperature (T) ~ Pressure (P)

what about volume? how is it related to temperature and pressure?

- well this is a well known law called the "ideal gas Law"

$$\frac{pressure \times volume}{temperature} = cons\ tant$$

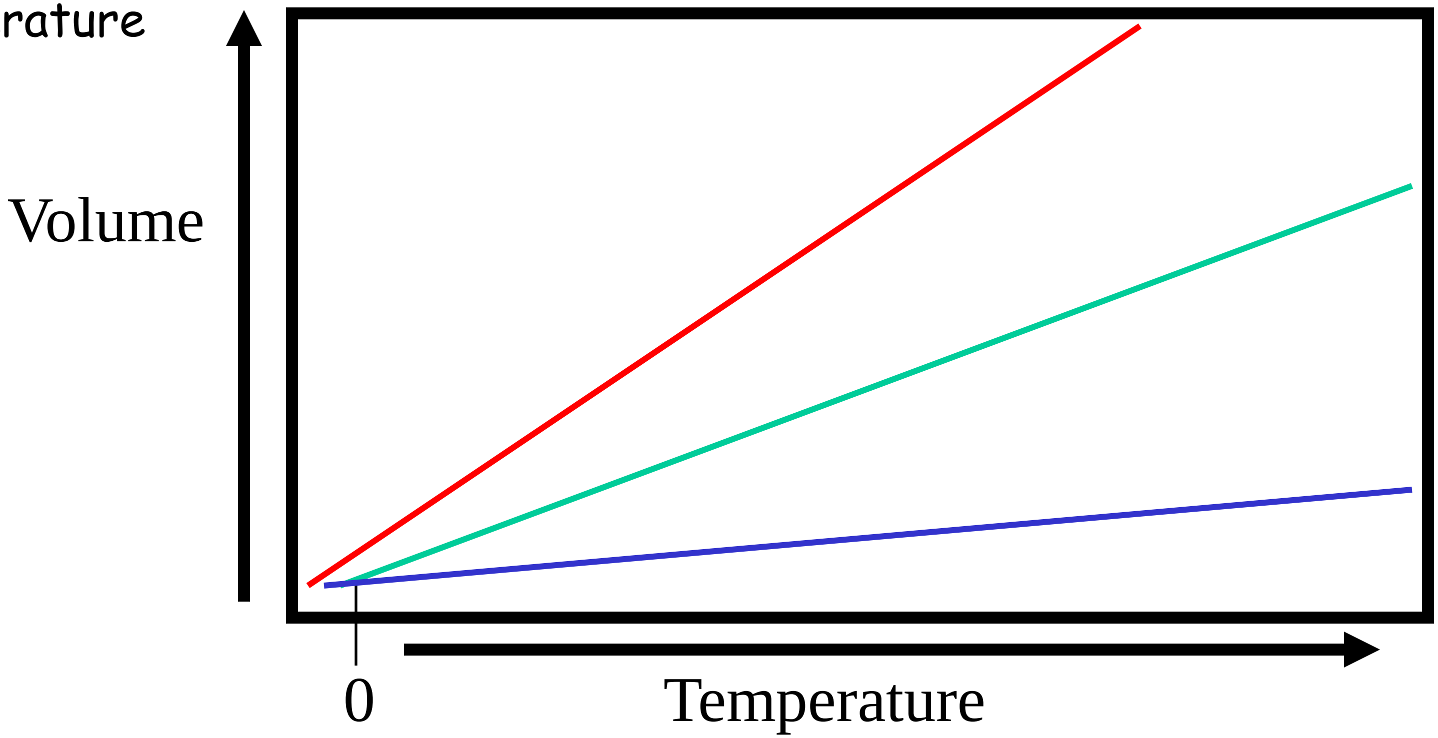
$$\frac{PV}{T} = cons\ tant$$

- the ideal gas law allows us to predict the behavior of the gas molecules when we change different parameters

Atomic Physics –pressure, temperature

Volume ~ Temperature

- Charles's Law- if we do not change the number of gas atoms/molecules and we don't change the pressure then the volume of gas will increase with increasing temperature



$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$

Atomic Physics –pressure, temperature

$$\text{Volume} \sim \frac{1}{\text{Pressure}}$$

- Boyle's Law- if we do not change the number of gas atoms/molecules and we don't change the temperature then the volume of gas will increase with decreasing pressure and decrease with increasing pressure

$$P_1 V_1 = P_2 V_2$$

An initial volume of gas experiences an increase in pressure by a factor of 3x (i.e. $P_2 = 3\ P_1$). What is the new volume?

$$P_1 V_1 = P_2 V_2 \rightarrow \frac{P_1 V_1}{P_2} = \frac{P_2 V_2}{P_2}$$

$$\frac{P_1 V_1}{P_2} = V_2 \rightarrow \frac{P_1 V_1}{3P_1} = V_2$$

$$\frac{V_1}{3} = V_2$$

Atomic Physics –pressure, temperature

Pressure ~ Temperature

- Constant Volume Law- if we do not change the number of gas atoms/molecules and we don't change the volume then the pressure of gas will increase with increasing temperature

$$\frac{P_1}{T_1} = \frac{P_2}{T_2}$$

A volume of gas experiences an increase in pressure by a factor of 3x (i.e. $P_2 = 3 P_1$). What is the new temperature?

$$\frac{P_1}{T_1} = \frac{P_2}{T_2} \rightarrow (T_2)\frac{P_1}{T_1} = \frac{P_2}{T_2}(T_2)$$

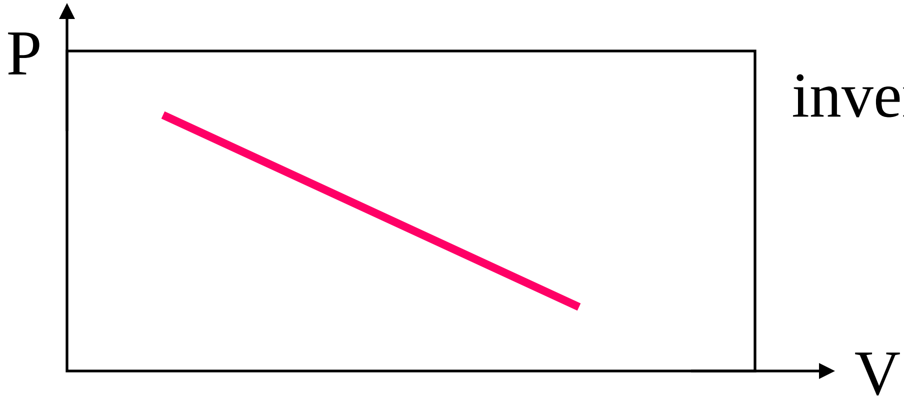
$$T_2\frac{P_1}{T_1} = P_2 \rightarrow (T_1)T_2\frac{P_1}{T_1} = P_2(T_1)$$

$$T_2 P_1 = P_2 T_1 \rightarrow \frac{T_2 P_1}{P_1} = \frac{P_2 T_1}{P_1}$$

$$T_2 = \frac{P_2 T_1}{P_1} = \frac{3P_1 T_1}{P_1} = 3T_1$$

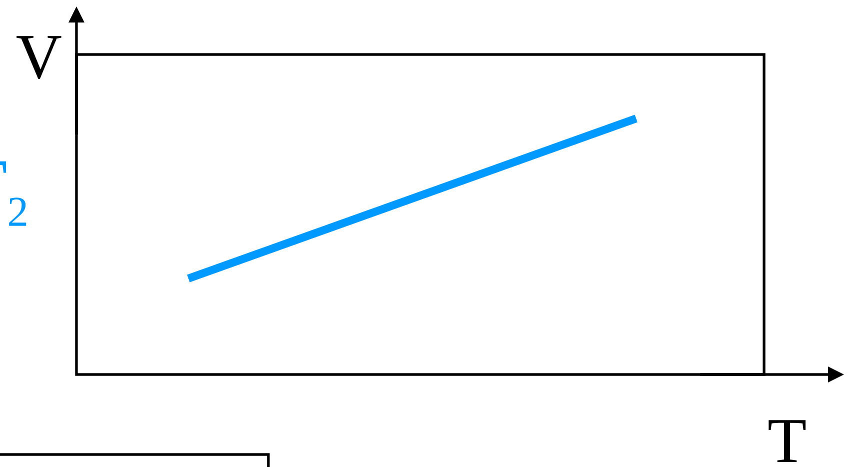
Gas Relationships

$P_1V_1 = P_2V_2$

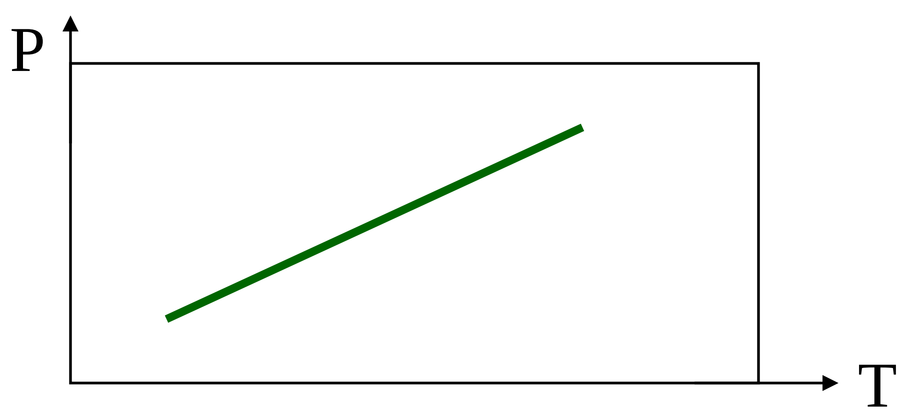


inversely proportional

$V_1/T_1 = V_2/T_2$



directly proportional

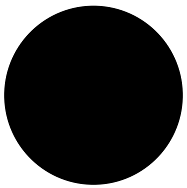


$P_1/T_1 = P_2/T_2$

Three atomic models: Greek, Planetary, Quantum

Greek Model: little indivisible chunks of matter. For example, Peas are composed of little chunks that have all the properties of a pea.

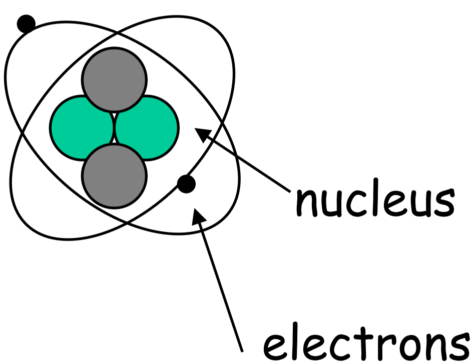
Explanatory Power: 1. All physical reactions (air pressure, odor of violets)
2. Chemical Stoichiometry (ratios of different elements)



small, indivisible solid,
most likely spherical

Planetary Model: offered detail about the structure of the atom
1897-1900 – discovery of the electron
1911 – discovery of the nucleus
nucleus composed of protons, and neutrons

Explanatory Power: 1. All physical reactions (air pressure, odor of violets)
2. Chemical Stoichiometry – Chemical Reaction, bonding



Three atomic models: Greek, Planetary, Quantum

Quantum Model: detailed structure of the "chunk" that is the atom

1920s – new experiments involving electrons contradicted the planetary model

-cannot be visualized or drawn

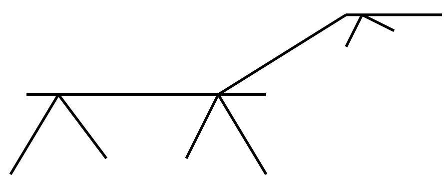
-*uncertainty principle* – every particle has an uncertainty associated with its position and speed

Artist's rendition

Another Artist's rendition

$$i\,\frac{\partial\Psi}{\partial t}=\left[-i\alpha\frac{\partial}{\partial x}+\beta-\frac{Z\alpha}{r}\right]\Psi$$

Another Artist's rendition



Another Artist's rendition