Example problems:

$$\overset{2.016}{2H_2(g)} + \overset{32.00}{O_2(g)} \longrightarrow \overset{18.02}{2H_2O(g)} ; \Delta H = -484 \, kJ$$
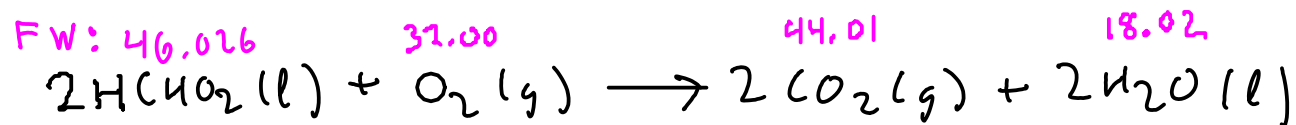
Calculate the enthalpy change for the combustion of 1.00 kg of hydrogen gas.

---

1 - Convert 1 kg hydrogen gas to moles. Use formula weight (and kg -> g conversion)
2 - Convert moles hydrogen gas to enthalpy change using thermochemical equation.

$$2.016 \, g \, H_2 = mol \, H_2 \quad | \quad kg = 10^3 g \quad | \quad 2 \, mol \, H_2 = -484 \, kJ$$

$$1.00 \, kg \, H_2 \times \frac{10^3 g}{kg} \times \frac{mol \, H_2}{2.016 \, g \, H_2} \times \frac{-484 \, kJ}{2 \, mol \, H_2} = \boxed{-120000 \, kJ \text{ per } kg \, H_2}$$

①   ②

FW: 46.026   32.00   44.01   18.02

$$2HCHO_2\,(l) + O_2\,(g) \longrightarrow 2CO_2\,(g) + 2H_2O\,(l)$$

If 50.3 kJ of heat was released when 5.48 g of formic acid are burned at constant pressure, then what is the enthalpy change of this reaction per mole of formic acid?
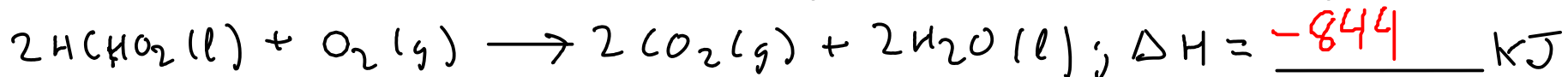
$$Q = -50.3\,kJ \;;\; \Delta H = \frac{Q \text{ constant pressure}}{\text{mol } HCHO_2}$$

So we just need to calculate the moles of formic acid:

$$5.48\,g\ HCHO_2 \times \frac{\text{mol } HCHO_2}{46.026\,g\ HCHO_2} = 0.11906313\,82\ \text{mol } HCHO_2$$

$$\Delta H = \frac{-50.3\,kJ}{0.11906313\,82\ \text{mol } HCHO_2} = \boxed{-422\ \frac{kJ}{\text{mol } HCHO_2}}$$

Based on the calculation above, can we complete this thermochemical equation?

$$2HCHO_2\,(l) + O_2\,(g) \longrightarrow 2CO_2\,(g) + 2H_2O\,(l) \;;\; \Delta H = \underline{-844}\ kJ$$

Since the equation above is based on TWO MOLES of formic acid reacting, and our calirometry answer was calculated per mole, we need to multiply the calculated value by two to get the correct enthalpy for the thermochemical equarion.

$$4NH_3(g) + 5O_2(g) \longrightarrow 4NO(g) + 6H_2O(g) \; ; \; \Delta H = \sim 906 \, kJ$$
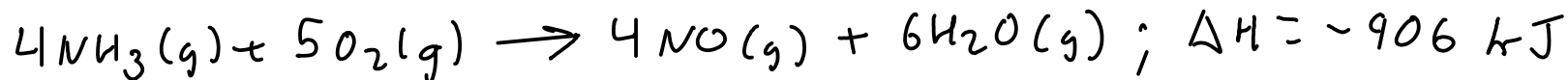
What is the enthalpy change when 150. L of nitrogen monoxide are formed by this reaction at 25.0 C and 1.50 atm pressure?

1 - Convert 150L of NO gas to moles using ideal gas equation.
2 - Convert moles NO to enthalpy change using thermochemical equation.

$$PV = nRT \qquad P = 1.50 \, atm \qquad V = 150. \, L$$
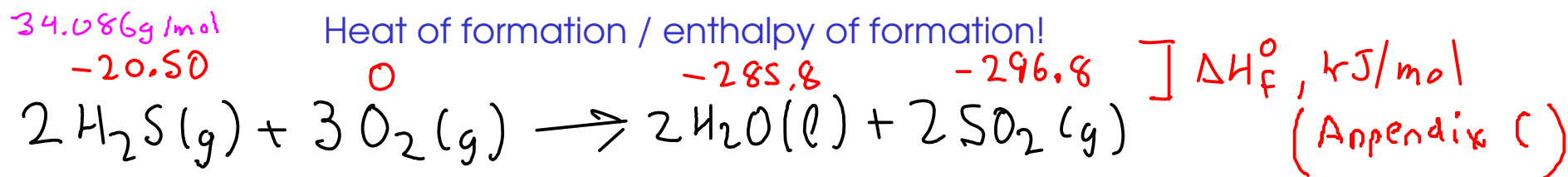
$$n = \frac{PV}{RT} \qquad R = 0.08206 \frac{L \cdot atm}{mol \cdot K} \qquad T = 25.0° = 298.2 \, k$$

$$① \; n_{NO} = \frac{(1.50 \, atm)(150. \, L)}{\left(0.08206 \frac{L \cdot atm}{mol \cdot K}\right)(298.2 \, k)} = 9.194022849 \, mol \; NO$$

$$4 \, mol \; NO = -906 \, kJ$$

$$9.194022849 \, mol \; NO \times \frac{-906 \, kJ}{4 \, mol \; NO} = \boxed{-2080 \, kJ}$$

34.086g/mol

Heat of formation / enthalpy of formation!

$$2H_2S(g) + 3O_2(g) \longrightarrow 2H_2O(l) + 2SO_2(g)$$

-20.50 0 -285.8 -296.8 $]\, \Delta H_f^\circ,\ kJ/mol$

(Appendix C)

What is the enthalpy change at standard conditions when 25.0 grams of hydrogen sulfide gas is reacted?

1 - Calculate the enthalpy change of the reaction as written using Hess' Law.
2 - Convert 25.0 g hydrogen sulfide to moles using formula weight.
3 - Convert moles hydrogen sulfifde to enthalpy change using thermochemical equation.

$$\Delta H = \sum \Delta H_{f,\ products}^\circ - \sum \Delta H_{f,\ reactants}^\circ \quad \text{<-- Hess' Law}$$

① $= \left[2(-285.8) + 2(-296.8) \right] - \left[2(-20.50) + 3(0) \right]$

$$= -1124.2\ kJ$$

So, the thermochemical equation is

$$2H_2S(g) + 3O_2(g) \longrightarrow 2H_2O(l) + 2SO_2(g);\ \Delta H = -1124.2\ kJ$$
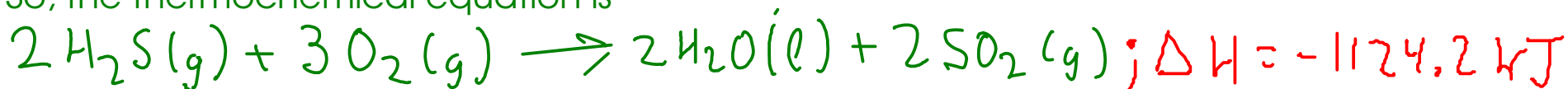
$$34.086\,g\ H_2S = mol\ H_2S \left| 2mol\ H_2S = -1124.2\ kJ \right.$$

$$25.0\,g\ H_2S \times \frac{mol\ H_2S}{34.086\,g\ H_2S} \times \frac{-1124.2\ kJ}{2mol\ H_2S} = \boxed{-412\ kJ}$$

②   ③

propane

$$C_3H_8(g) + 5O_2(g) \rightarrow 3CO_2(g) + 4H_2O(g) \; ; \Delta H = -2043 \; kJ$$
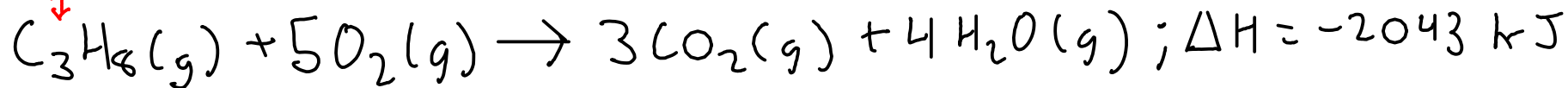
Calculate the volume of propane gas at 25.0 C and 1.08 atm required to provide 565 kJ of heat using the reaction above.

1 - Convert energy requirement to moles PROPANE
2 - Convert moles propane to volume using ideal gas equation.

$$mol \; C_3H_8 = -2043 \; kJ$$

$$-565 \; kJ \times \frac{mol \; C_3H_8}{-2043 \; kJ} = 0.2765540871 \; mol \; C_3H_8 \;\; ①$$

Since the reaction is providing the energy, the energy requirement has a NEGATIVE sign. From the point of view of the reaction, this is an energy loss.

$$PV = nRT$$
$$V = \frac{nRT}{P}$$

$$n = 0.2765540871 \; mol \; C_3H_8 \qquad T = 25.0\,^\circ C = 298.2 K$$

$$R = 0.08206 \frac{L \cdot atm}{mol \cdot K} \qquad P = 1.08 \; atm$$

$$V = \frac{(0.2765540871 \; mol \; C_3H_8)(0.08206 \frac{L \cdot atm}{mol \cdot K})(298.2 K)}{(1.08 \; atm)} =$$

$$= \boxed{6.27 \; L \; propane \; @ \; 1.08 \; atm, \; 25.0\,^\circ C} \;\; ②$$

END OF CHAPTER 6

LIGHT
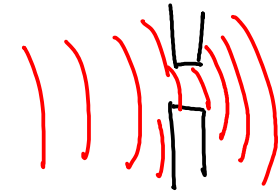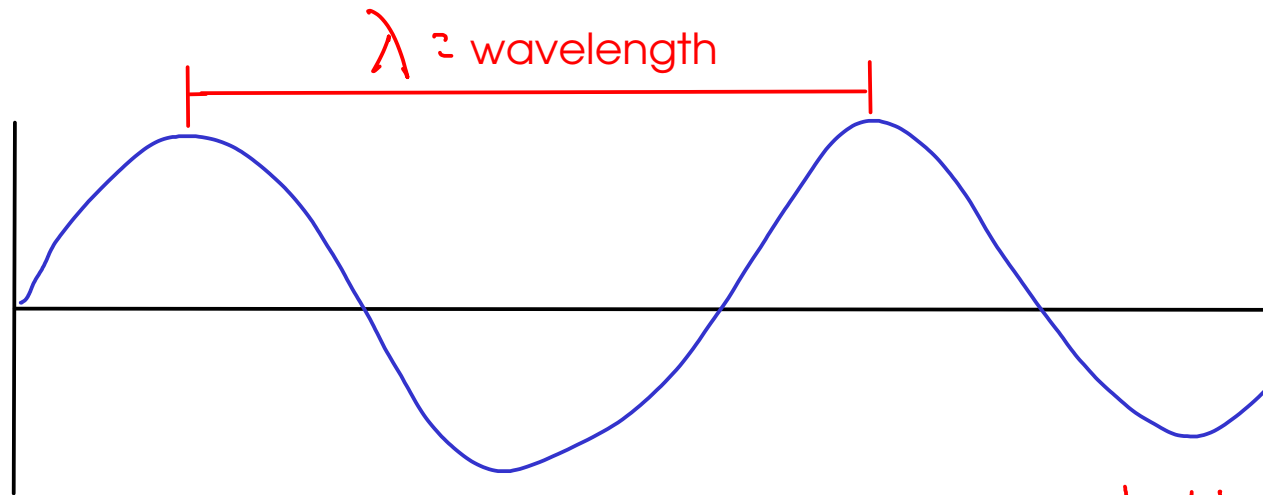
λ = wavelength

Diffraction

frequency = wavelengths / time = ν s^{-1} : Hertz, Hz

- Light has properties of WAVES such as DIFFRACTION (it bends around small obstructions).

- Einstein noted that viewing light as a particle that carried an energy proportional to the FREQUENCY could explain the PHOTOELECTRIC EFFECT!

$$E_{photon} = h\,\nu$$

Planck's constant: 6.63×10^{-34} J·s

photon = particle or packet of light

(The photoelectric effect is the emission of electrons from a metal caused by exposure to light. Einstein discovered that if the light were not of the correct FREQUENCY, increasing the INTENSITY of the light would not cause electron emission. He concluded that individual photons must have enough energy to excite an electron - i.e. they must have the appropriate frequency.)

The photoelectric effect and Einstein's ideas about the energy content of light led us to discover a new model for the atom! How? Let's start with the nuclear model:
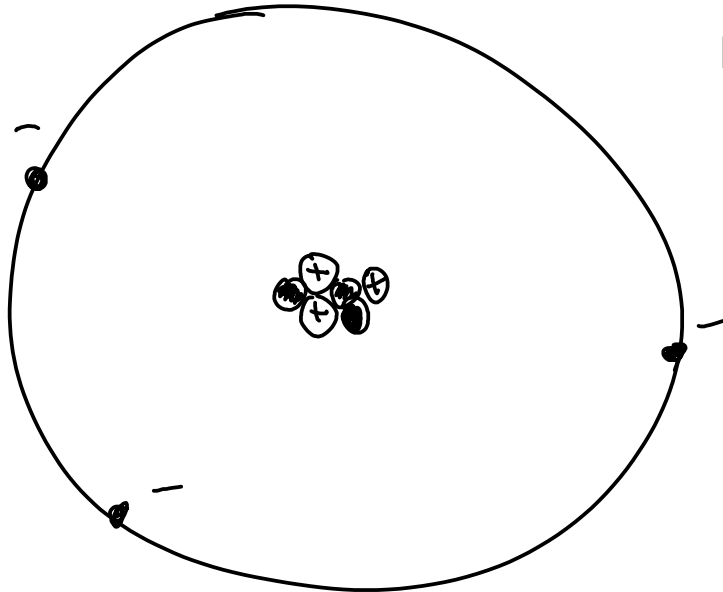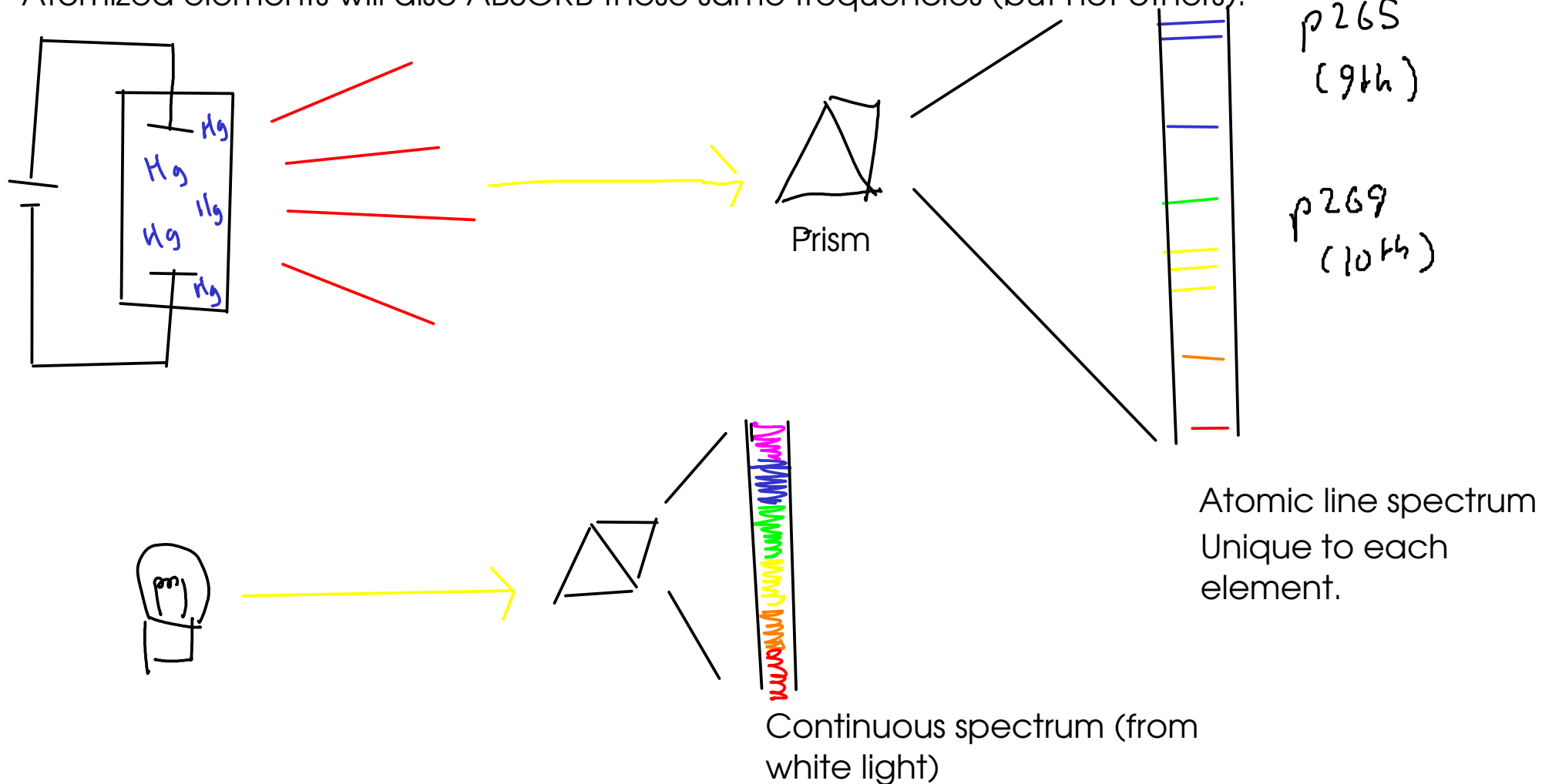

Nuclear model:

- Protons and neutrons in a dense NUCLEUS at center of atom
- Electrons in a diffuse (mostly empty) ELECTRON CLOUD surrounding NUCLEUS.

... so what's wrong with the nuclear model? Among other things, it doesn't explain ...

ATOMIC LINE SPECTRA

- if you take element and ATOMIZE it, if excited by energy it will emit light at unique frequencies. The set of emitted frequencies is called an ATOMIC LINE SPECTRUM.

- Atomized elements will also ABSORB these same frequencies (but not others)!

p265
(9th)

p269
(10th)

Hg
Hg
Hg
Hg
Hg

Prism

Atomic line spectrum
Unique to each
element.

Continuous spectrum (from
white light)

... so, why don't atoms by themselves emit continuous spectra like a flashlight would?

- The regular patterns of emission and absorption of light by atoms suggest that the electron cloud has some sort of regular structure. The specific frequencies of light emitted and abosrbed relate to specific values of ENERGY in the electron cloud.

Niels BOHR
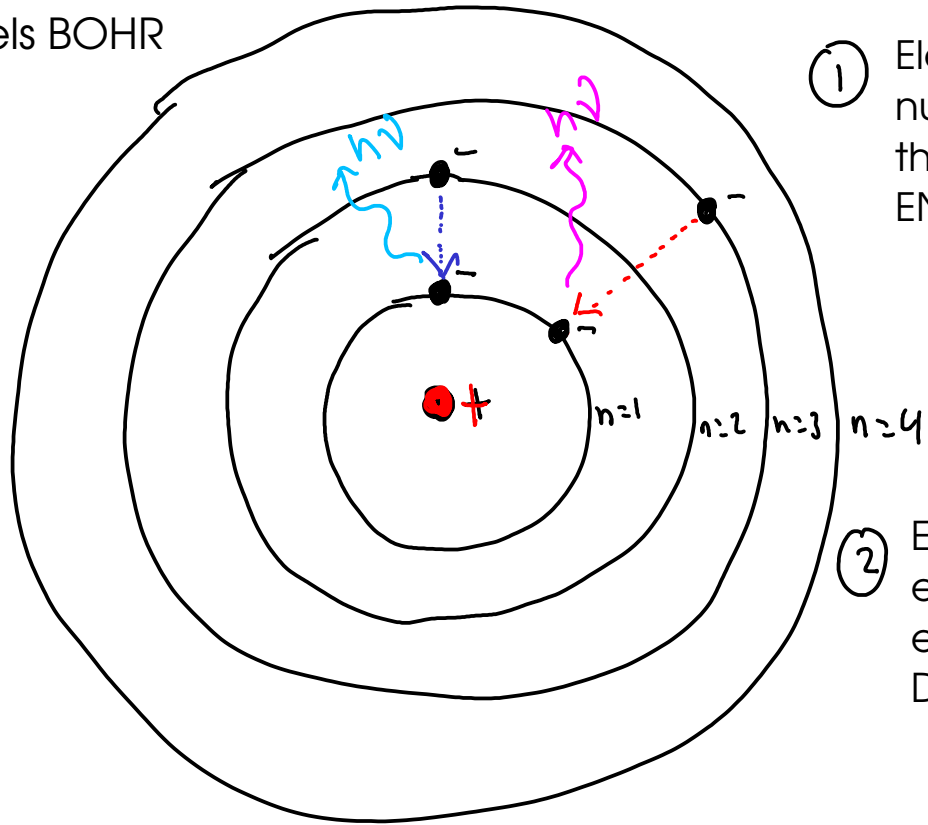
① Electrons can't be just ANYWHERE around a nucleus. They can exist only at certain distances from the nucleus. These distances correpsond to certain ENERGIES and are called ENERGY LEVELS!

② Electrons CAN move (transition) between different energy levels by gaining or losing exactly enough energy to get into the new energy level. This was a DIRECT transition .

Bohr's model was the first proposal that predicted the existence of atomic line spectra, and it exactly predicted the spectra of hydrogen and "hydrogen-like" (i.e. one-electron) species.

The spectra were "off" for multi-electron atoms.
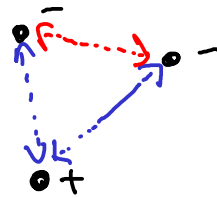
Multi-electron atoms have interactions between electrons, not just interactions between electrons and nucleus!

- The additional interactions in multi-electron atoms introduced added complexity to the model of the atom! Bohr's model was too simple.

- Improvements in Bohr's model came from treating electrons as WAVES.

de Broglie relationship

Planck's constant

$$\lambda = \frac{h}{m \times V}$$

Calculates the WAVELENGTH of ... matter?

velocity (m/s)

mass

wavelength

... for very large particles, the wavelength is very small.

Quantum mechanics treats the electrons as waves and models THAT behavior!

- To describe the electrons, we use WAVEFUNCTIONs - which are mathematical descriptions of the behavior or electrons.

- The wavefunction describes the probability of finding an electron in a given space

- For larger objects, the wave behavior isn't very important .... and quantum mechanics becomes traditional Newtonian physics.

When we talk about describing electrons ... we will talk about the PARAMETERS that go into this WAVEFUNCTION ... without doing the actual math.

- There are FOUR of these parameters. (the Bohr model had only one!)

- The parameters are called "quantum numbers"

(1) Principal quantum number

(2) Angular momentum quantum number

(3) Magnetic quantum number

(4) Spin quantum number