SINCE the enthalpy change does NOT depend on path, this means that we can use standard values for enthalpy to predict the heat change in reactions that we have not tested in a calorimeter.

THERMOCHEMICAL EQUATIONS

- is like a regular chemical equation, except that phase labels are REQUIRED and the enthalpy for the reaction is given along with the equation.

$$CH_3COCH_3(l) + 4O_2(g) \longrightarrow 3CO_2(g) + 3H_2O(l) \ ; \ \Delta H = -1800 \ kJ$$
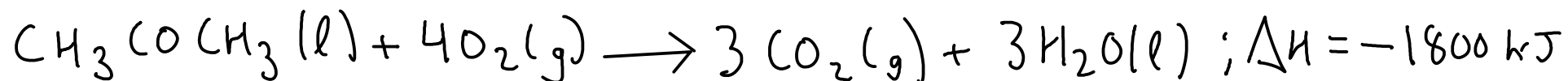
- Why are phase labels required? Because phase changes either absorb or release energy.

$\Delta H = -1800 \ kJ$ ... what does this mean?

$$1 \ mol \ CH_3COCH_3 = -1800 \ kJ$$

$$4 \ mol \ O_2 = -1800 \ kJ$$

$$3 \ mol \ CO_2 = -1800 \ kJ$$

$$3 \ mol \ H_2O = -1800 \ kJ$$

We treat the enthalpy change as if it's another product of the reaction!

$$CH_3COCH_3(\ell) + 4O_2(g) \longrightarrow 3CO_2(g) + 3H_2O(\ell) \; ; \Delta H = -1800 \, kJ$$

What would be the enthapy change when 25 g of water are produced by the reaction?

1 - Convert 25 g water to moles. Use FORMULA WEIGHT
2 - Convert moles water to entahalpy change. Use THERMOCHEMICAL EQUATION.

$H_2O : 18.016 \, g \, H_2O = mol \, H_2O \quad | \quad 3 \, mol \, H_2O = -1800 \, kJ$

$$25 \, g \, H_2O \times \frac{mol \, H_2O}{18.016 \, g \, H_2O} \times \frac{-1800 \, kJ}{3 \, mol \, H_2O} = \boxed{-830 \, kJ}$$

① ②

... which also equals Q, provided pressure is constant

This is an EXOTHERMIC reaction. The reaction mixture tranfers energy to the surroundings.
This shouldn't be surprising, as the reaction is a COMBUSTION.

A few more terms related to enthalpy:

- Enthalpy of vaporization / heat of vaporization: The enthalpy change on vaporizing one mole of a substance. (from liquid to vapor)

- Enthalpy of fusion / heat of fusion: The enthalpy change when a mole of liquid changes to the solid state.

Phase changes require energy, too!

Example problems:

2.016 32.00   18.02

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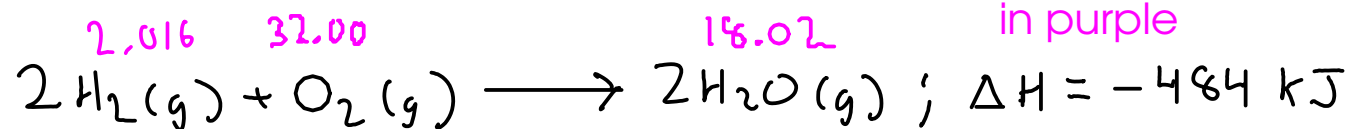
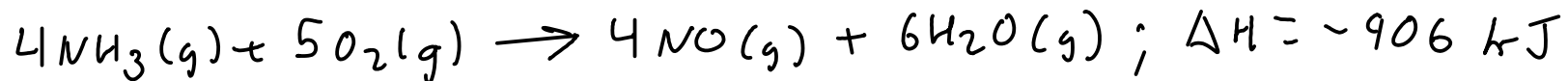Calculate the enthalpy change for the combustion of 1.00 kg of hydrogen gas.

---

1 - Convert mass hydrogen to moles using FORMULA WEIGHT. (And kg ->g conversion)
2 - Convert moles hydrogen to enthalpy change using THERMOCHEMICAL EQUATION

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

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

①

$$4 NH_3 (g) + 5 O_2 (g) \longrightarrow 4 NO (g) + 6 H_2O (g) \; ; \; \Delta H = -906 \; kJ$$

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 150 L NO to moles using IDEAL GAS EQUATION.
2 - Convert moles NO to enthalpy change using THERMOCHEMICAL EQUATION

① $PV = nRT$ | $P = 1.50 \; atm$ $V = 150. \; L$

$$n = \frac{PV}{RT} \quad \Big| \quad R = 0.08206 \frac{L \cdot atm}{mol \cdot k} \quad T = 25.0°C = 298.2 k$$

$$n = \frac{(1.50 \; atm)(150. \; L)}{\left(0.08206 \frac{L \cdot atm}{mol \cdot k}\right)(298.2 k)} = 9.194822849 \; mol \; NO$$
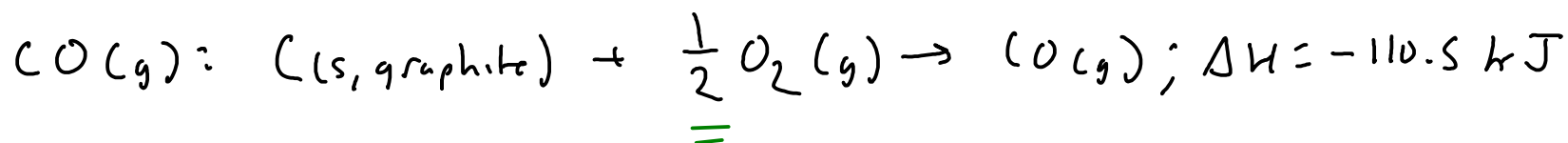
② $4 \; mol \; NO = -906 \; kJ$

$$9.194822849 \; mol \; NO \times \frac{-906 \; kJ}{4 \; mol \; NO} = \boxed{-2080 \; kJ}$$

FORMATION REACTIONS

- A reaction that forms <u>exactly one mole</u> of the specified substance from its elements at their STANDARD STATE at 25C and 1 atm pressure.

$$CO_2(g): \quad C(s, graphite) + O_2(g) \longrightarrow CO_2(g) \; ; \Delta H = -393.5 \, kJ$$
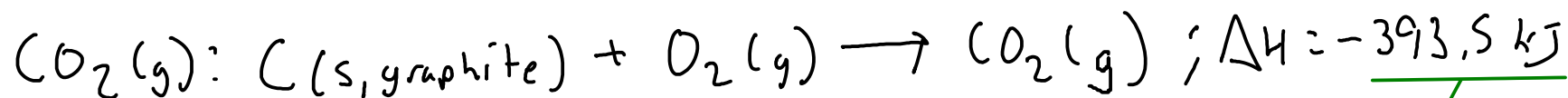
heat of formation of carbon dioxide ΔH_f° or ΔH_f
"enthalpy of formation"

$$CO(g): \quad C(s, graphite) + \tfrac{1}{2} O_2(g) \rightarrow CO(g); \Delta H = -110.5 \, kJ$$

you may see fractional coefficients in these formation reactions, because you MUST form exactly one mole of the product!

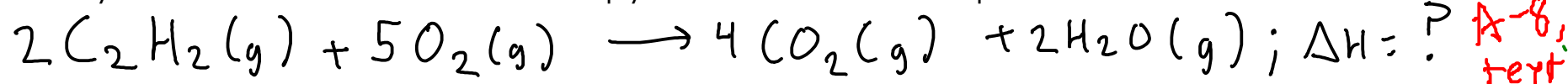- The heat of formation for an element in its standard state at 25C and 1 atm is ZERO.

$$\Delta H^{\circ}_{f, O_2(g)} = 0 \; kJ/mol$$
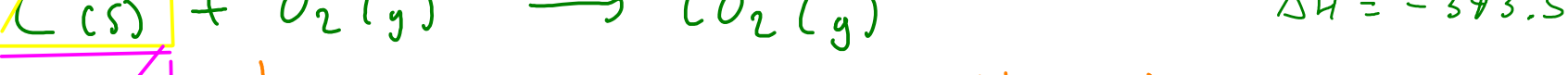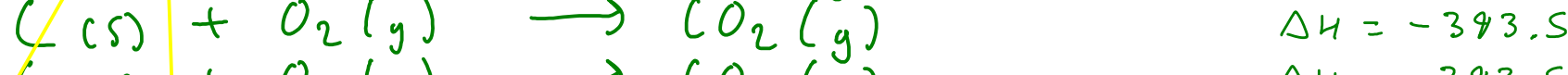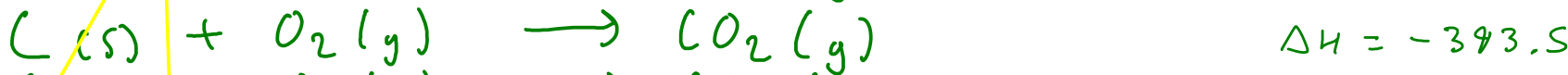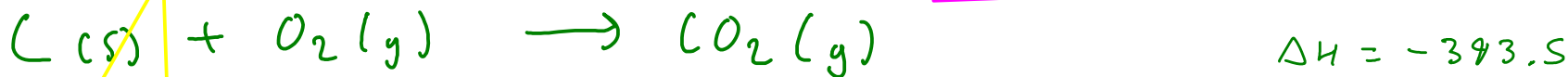
- What are formation reactions good for?

... finding enthalpies for more interesting reactions!

Let's say we would like to find the enthalpy of reaction for this equation:

$$2 C_2H_2(g) + 5 O_2(g) \longrightarrow 4 CO_2(g) + 2 H_2O(g); \quad \Delta H = ?$$

From A-8, text

Hess' Law: If you add two reactions to get a new reaction, their enthalpies also add.

C_2H_2: $\quad 2 C_{(s)} + H_2(g) \longrightarrow C_2H_2(g) \quad \Delta H = 226.7$

CO_2: $\quad C_{(s)} + O_2(g) \longrightarrow CO_2(g) \quad \Delta H = -393.5$

H_2O: $\quad H_2(g) + \frac{1}{2}O_2(g) \longrightarrow H_2O(g) \quad \Delta H = -241.8$

$C_2H_2(g) \longrightarrow 2 C_{(s)} + H_2(g) \quad \Delta H = -226.7$

$C_2H_2(g) \longrightarrow 2 C_{(s)} + H_2(g) \quad \Delta H = -226.7$

$C_{(s)} + O_2(g) \longrightarrow CO_2(g) \quad \Delta H = -393.5$

$C_{(s)} + O_2(g) \longrightarrow CO_2(g) \quad \Delta H = -393.5$

$C_{(s)} + O_2(g) \longrightarrow CO_2(g) \quad \Delta H = -393.5$

$C_{(s)} + O_2(g) \longrightarrow CO_2(g) \quad \Delta H = -393.5$

$H_2(g) + \frac{1}{2}O_2(g) \longrightarrow H_2O(g) \quad \Delta H = -241.8$

$H_2(g) + \frac{1}{2}O_2(g) \longrightarrow H_2O(g) \quad \Delta H = -241.8$

$$2 C_2H_2(g) + 5 O_2(g) \longrightarrow 4 CO_2(g) + 2 H_2O(\ell)$$

$$\Delta H = 2(-226.7) + 4(-393.5) + 2(-241.8) = \boxed{-2511 \text{ kJ}}$$

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Hess' Law using enthalpy of formation:

$$\Delta H = \sum \Delta H_{f, products} - \sum \Delta H_{f, reactants}$$

$$\overset{226.7}{2C_2H_2(g)} + \overset{0}{5O_2(g)} \longrightarrow \overset{-393.5}{4CO_2(g)} + \overset{-241.8}{2H_2O(g)}; \Delta H = ?$$
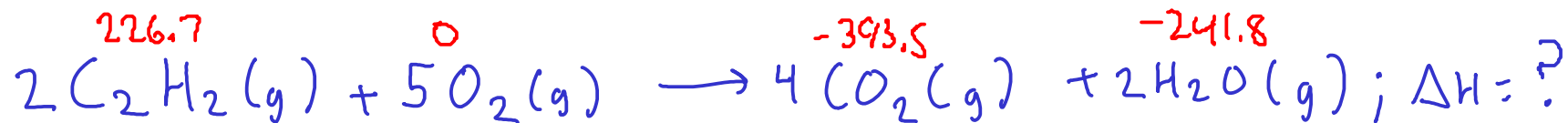
$$\Delta H = [4(-393.5) + 2(-241.8)] - [2(226.7) + 5(0)]$$

$$= -2511 \text{ kJ}$$

See Appendix C in the textbook for enthalpy of formation data:
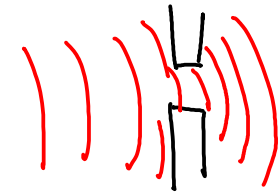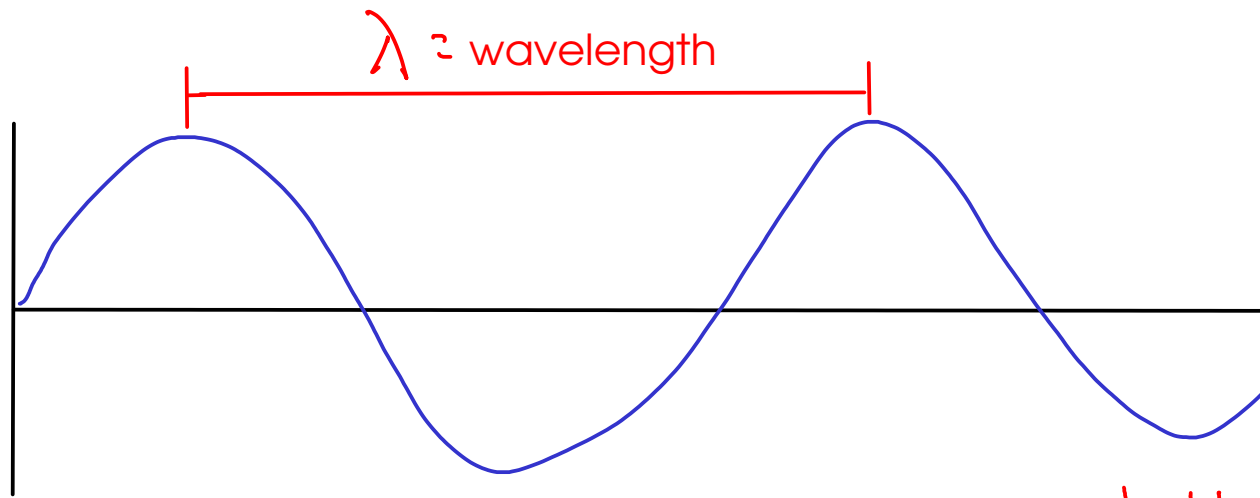p A-8 to A-11

* Remember:

- Multiply each enthalpy by its stoichiometric coefficient from the reaction

- Enthalpy of formation of an element at its standard state is zero

- Watch phase labels. You will usually find SEVERAL enthalpies of formation for a given substance in different phases!

- For ionic substances in solution, remember that they exist as free ions, so look up the aqueous IONS!

34.086g/mol

Heat of formation / enthalpy of formation!

$$-20.50 \qquad 0 \qquad\qquad -285.8 \qquad -296.8 \quad] \, \Delta H_f^0, \text{kJ/mol}$$

$$2H_2S(g) + 3O_2(g) \longrightarrow 2H_2O(l) + 2SO_2(g) \qquad (\text{Appendix C})$$

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

1 - Find the enthalpy change for the reaction as written using HESS'S LAW
2 - Convert 25.0 g hydrogen sulfide to moles using FORMULA WEIGHT
3 - Convert moles hydrogen sufide to enthalpy change using THERMOCHEMICAL EQUATION

$$\Delta H = \sum \Delta H_f^0, \text{products} - \sum \Delta H_f^0, \text{reactants}$$

$$= [2(-285.8) + 2(-296.8)] - [2(-20.50) + 3(0)] = -1124.2$$

So the thermochemical equation is ...

$$2H_2S(g) + 3O_2(g) \longrightarrow 2H_2O(l) + 2SO_2(g) \,; \Delta H = -1124.2 \, kJ \; ①$$

$$34.086 \, g \, H_2S = \text{mol} \, H_2S \quad \Big| \quad 2 \, \text{mol} \, H_2S = -1124.2 \, kJ$$

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

②   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:
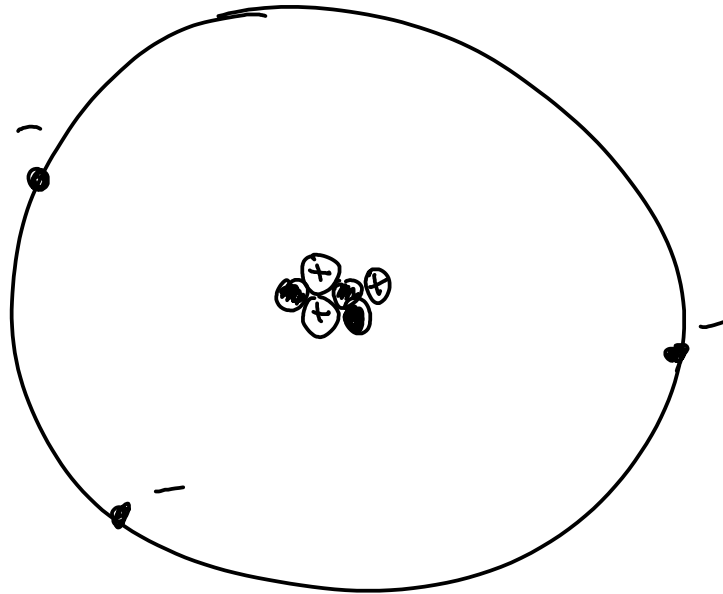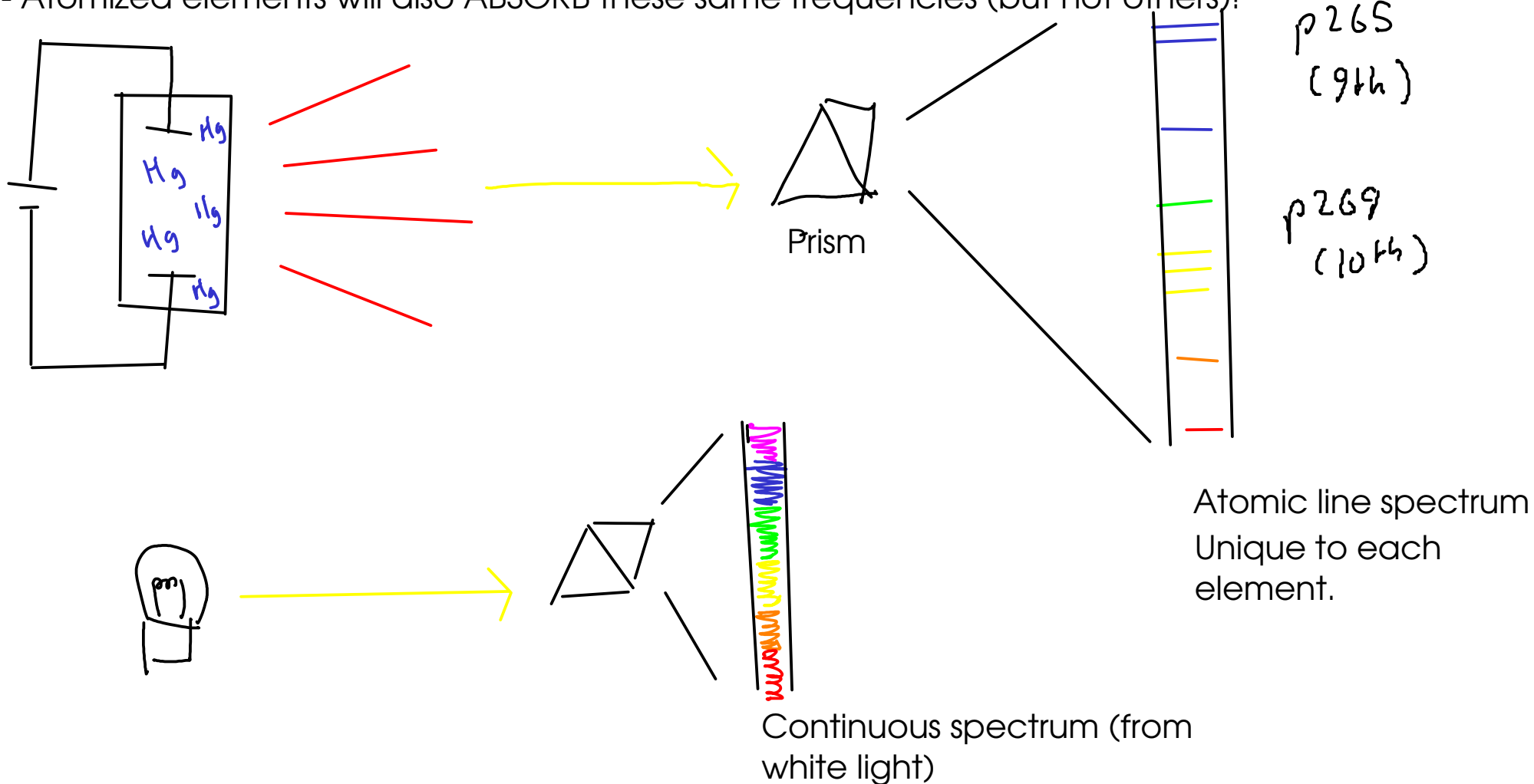

Nuclear model:

- 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 ...

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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)

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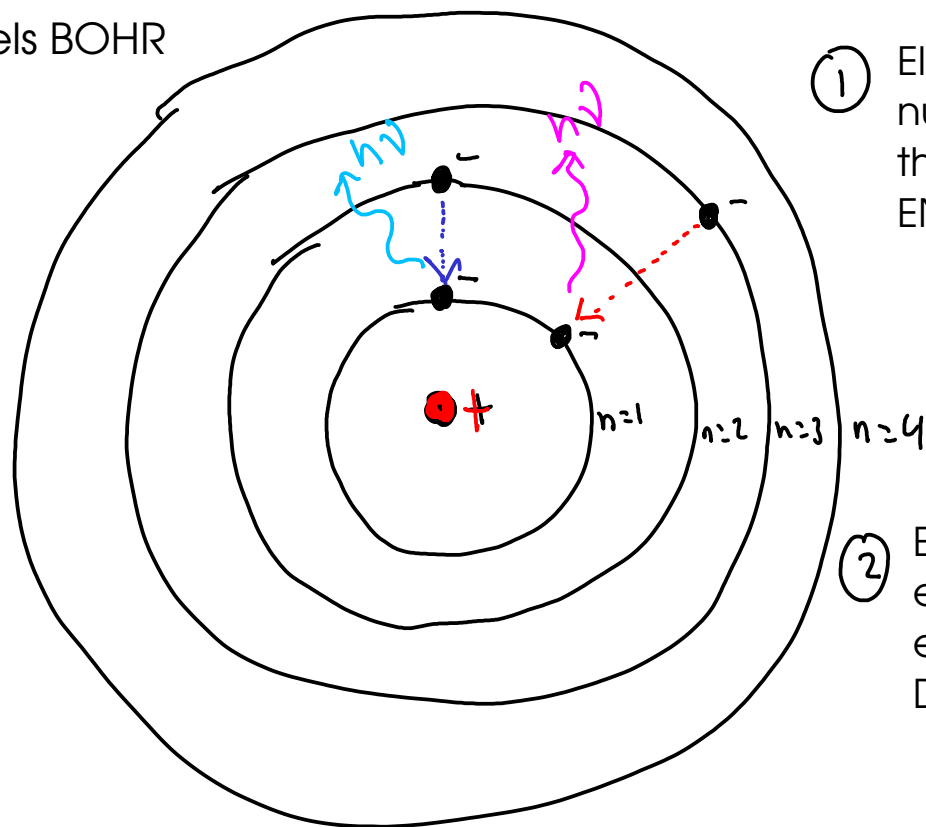
① Electrons can't be just ANYWHERE around a nucleus. They can exist only at certain distances from the nucleus. These distances correpsond to certain ENERGIES and are called ENERGY LEVELS!

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.
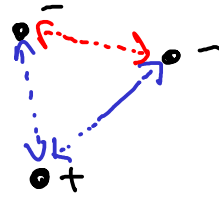
Multi-electron atoms have interactions between electrons, not just interactions between electrons and nucleus!

- 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.