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.

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

- 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 enthalpy change.

---

① H_2O - H : 2 x 1.008
O : 1 x 16.00
18.016 g H_2O = mol H_2O

② 3 mol H_2O = −1800 kJ

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

Notes: Notice the negative sign. This is an EXOTHERMIC process. (Like other combustions)
Reminder ... This number (-830 kJ) also equals Q, provided pressure remains constant.

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:

FORMULA WEIGHTS in g/mol in purple

2.016 32.00 18.02

$$2H_2(g) + O_2(g) \longrightarrow 2H_2O(g) \; ; \; \Delta H = -484 \text{ kJ}$$

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.
2 - Convert moles hydrogen gas to enthalpy change. Use THERMOCHEMICAL EQUATION

① H_2 - $2 \times 1.008 = 2.016 \text{ g } H_2 = \text{mol } H_2$ $\quad$ $\text{kg} = 10^3 \text{ g}$

② $2 \text{ mol } H_2 = -484 \text{ kJ}$

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

① ②

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

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. Use IDEAL GAS EQUATION.
2 - Convert moles NO to enthalpy change. Use THERMOCHEMICAL EQUATION

---

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

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

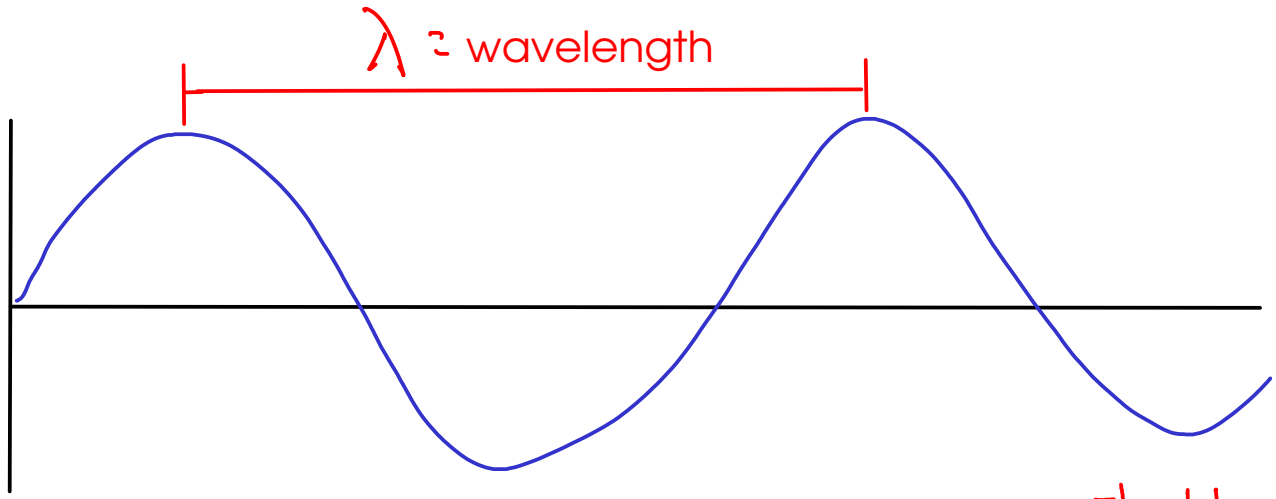
$$n_{NO} = \frac{(1.50\ atm)(150.\ L)}{\left(0.08206 \frac{L \cdot atm}{mol \cdot K}\right)(298.2\ K)} = 9.194822849\ mol\ NO$$

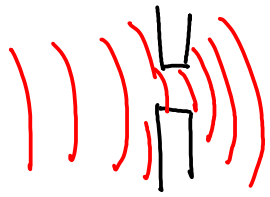
---

② $4\ mol\ NO = -906\ kJ$

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

LIGHT





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!

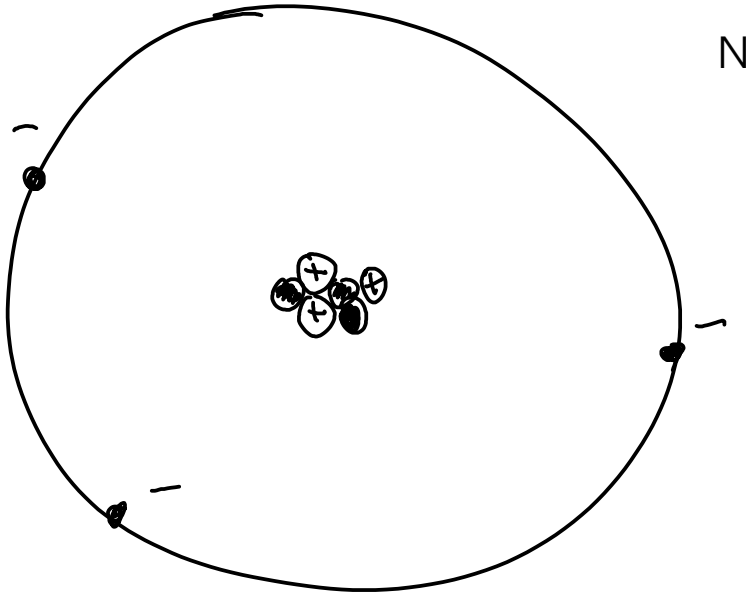
$$E_{photon} = h\nu$$

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:

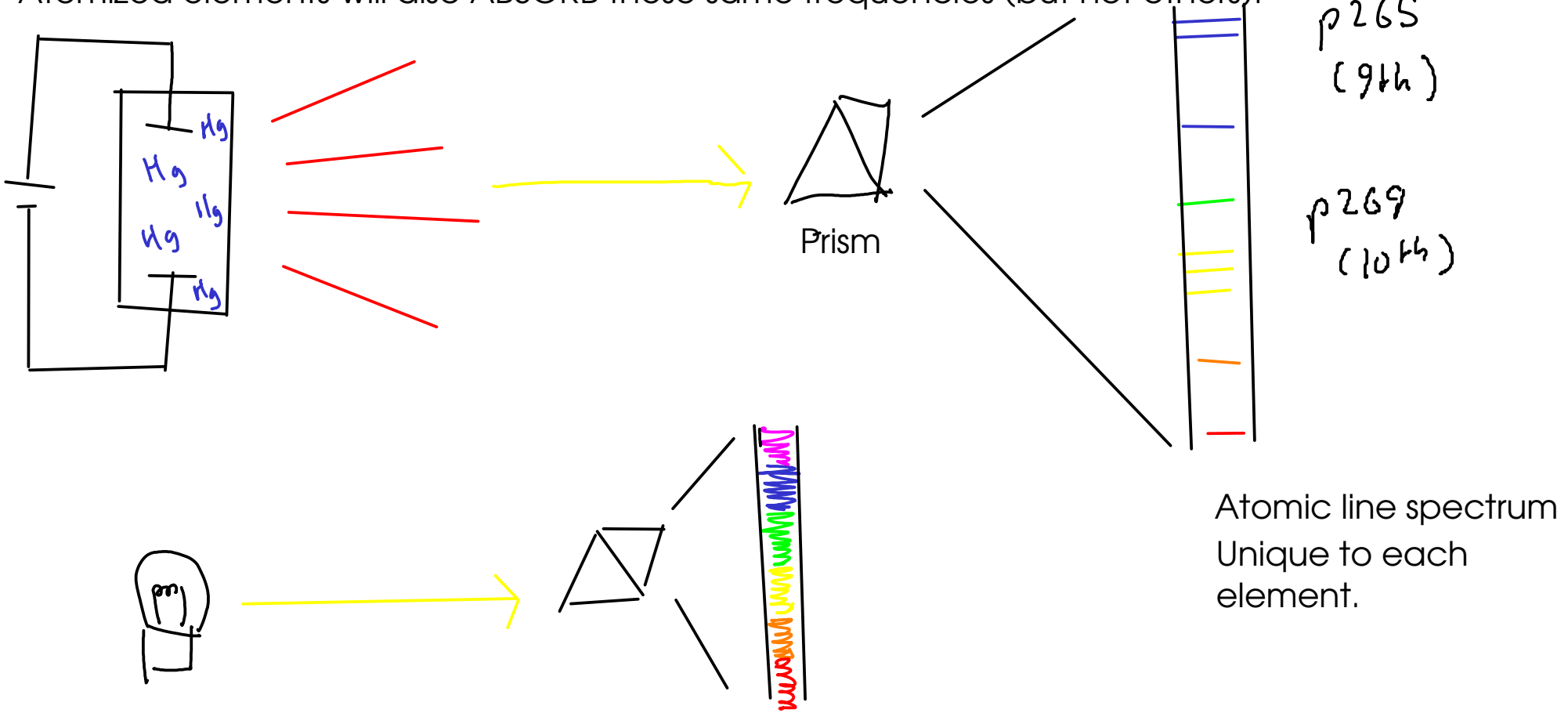
- Protons and neutrons in a dense NUCLEUS at center of atom
- Electrons in a diffuse (mostly empty) ELECTRON CLOUD surrounding NUCLEUS.

... 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)!



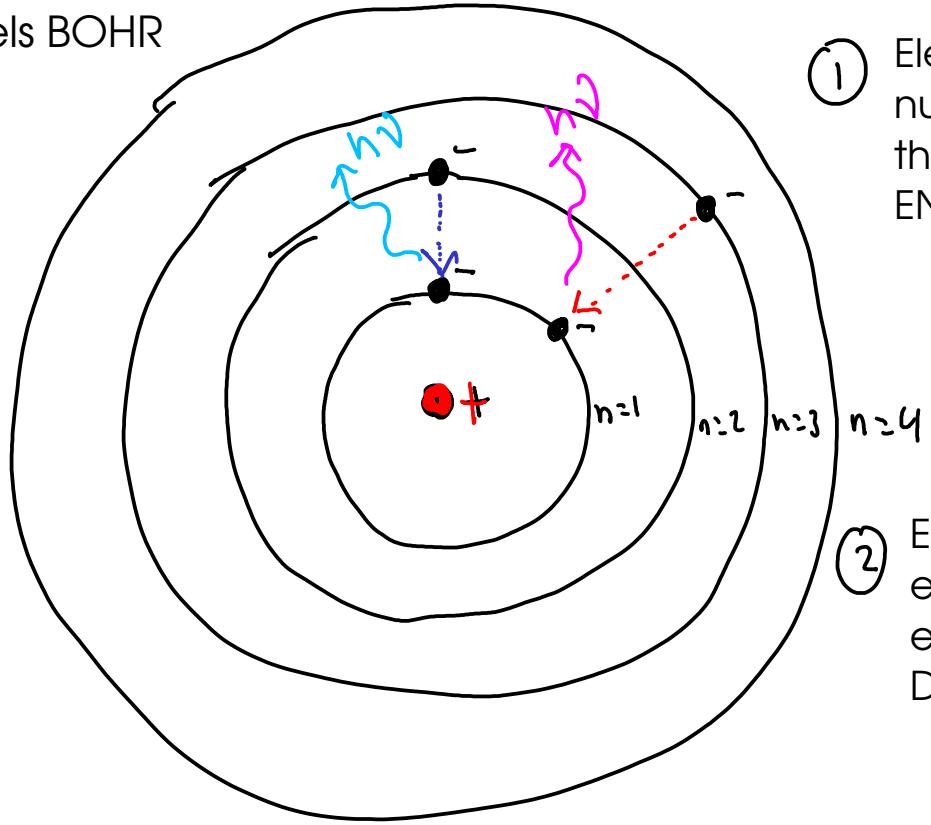
Atomic line spectrum
Unique to each element.

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

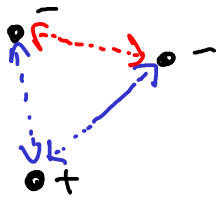


1. Electrons can't be just ANYWHERE around a nucleus. They can exist only at certain distances from the nucleus. These distances correpsond to certain ENERGIES and are called ENERGY LEVELS!

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

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

- λ: wavelength
- m: mass
- V: velocity (m/s)
- h: Planck's constant

Calculates the WAVELENGTH of ... matter?

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