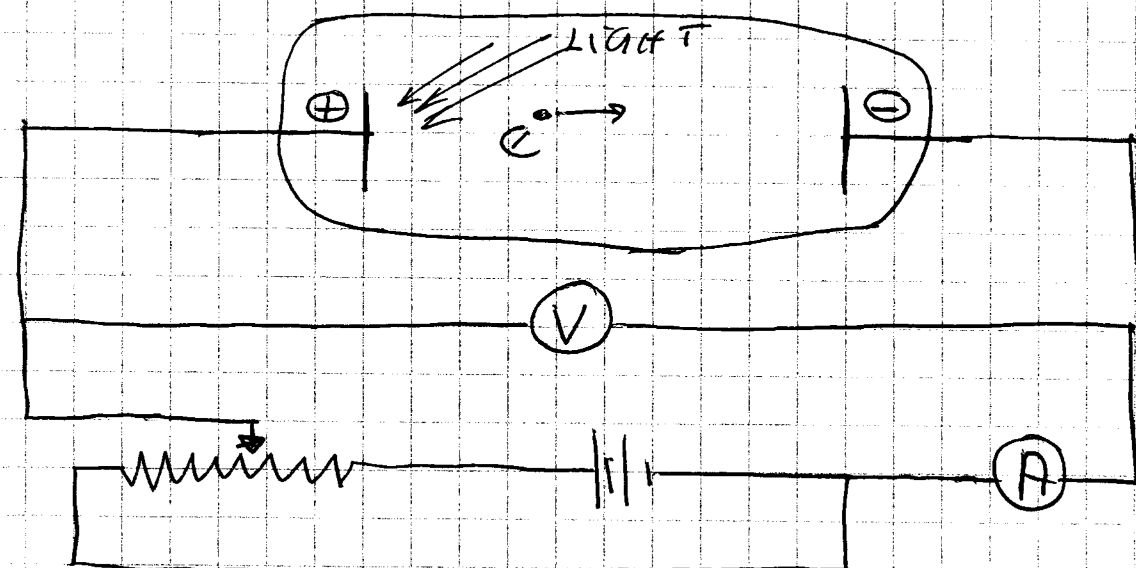
PHOTOELECTRIC EFFECT

LATE IN THE 19^{th} CENTURY A SERIES OF EXPERIMENTS REVEALED THAT electrons ARE EMITTED FROM METAL SURFACES WHEN LIGHT OF SUFFICIENT HIGH FREQUENCY FALLS UPON IT. THIS IS KNOWN AS THE PHOTOELECTRIC EFFECT



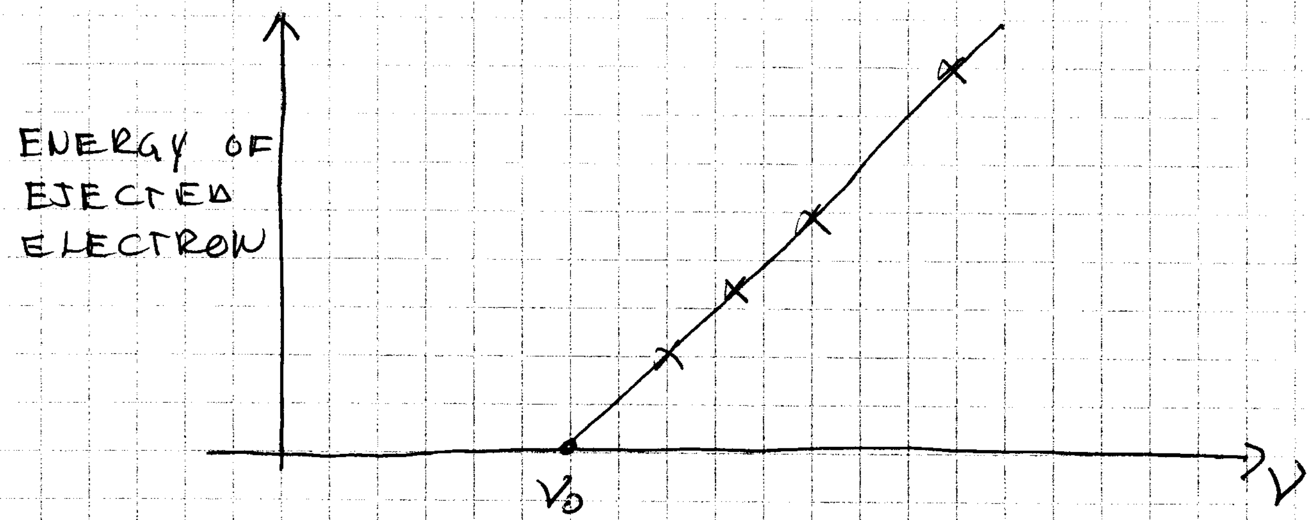
CLASSICAL THEORY

a) THE ENERGY OF THE EJECTED ELECTRON IS PROPORTIONAL TO THE INTENSITY OF THE LIGHT.

b) ELECTRONS ARE EJECTED FOR ANY FREQUENCY (RADIATION).

BOTH PREDICTIONS ARE WRONG

THERE IS A THRESHOLD FREQUENCY, ν_0



$$KE = h\nu - h\nu_0$$

WHERE

$$\phi \equiv h\nu_0$$

is CALLED THE WORK FUNCTION.

EINSTEIN IN 1905 ASSUMED THAT EM RADIATION CONSISTS OF LITTLE PACKETS (PHOTONS-1926) OF ENERGY

$$\epsilon = h\nu.$$

IF THIS IS TRUE, THE KE OF THE EJECTED electron IS GIVEN BY

$$KE = \frac{1}{2}mv^2 = h\nu - \phi,$$

WHERE ϕ IS THE WORK FUNCTION. NOTICE THAT THE TRESHOLD FREQUENCY, ν_0, IMPLIES NO KE

$$h\nu_0 = \phi$$

AND

$$h\nu \geq \phi.$$

ACTUALLY IN THE EXPERIMENT, ONE MEASURES THE STOPPING POTENTIAL, V_s

$$|e|V_s = KE = h\nu - h\nu_0.$$

THIS RELATION IS A STRAIGHT LINE WITH SLOPE h.

ϕ IS USUALLY EXPRESSED IN electron VOLTS (eV)

$$1 \text{ JOULE} = (1 \text{ COULOMB})(1 \text{ VOLT})$$
$$1|e|V = (1.602 \times 10^{-19} C)(1 \text{ VOLT})$$
$$= 1.602 \times 10^{-19} \text{ JOULE}$$

<u>PROBLEM</u> FOR Li IT IS KNOWN

$$V_s = 1.83 \text{ V} \quad \text{FOR } \lambda = 300 \text{ nm}$$
$$V_s = 0.80 \text{ V} \quad \text{FOR } \lambda = 400 \text{ nm}$$

CALCULATE h, ν_0 AND ϕ

$$|e|V_s^{(1)} = h\nu^{(1)} - \phi \Rightarrow \phi = h\nu^{(1)} - |e|V_s^{(1)}$$

$$|e|V_s^{(2)} = h\nu^{(2)} - \phi \Rightarrow \phi = h\nu^{(2)} - |e|V_s^{(2)}$$

$$h = \frac{|e|(V_s^{(1)} - V_s^{(2)})}{\nu^{(1)} - \nu^{(2)}} = \frac{|e|(1.83 - 0.80)V}{\left(\frac{1}{\lambda^{(1)}} - \frac{1}{\lambda^{(2)}}\right)c}$$

$$h = \frac{|e|\,1.03\,V}{\left(\frac{1}{300} - \frac{1}{400}\right)\frac{c}{nm}} = \frac{1.03\ eV}{\frac{\cancel{100}}{12000\cancel{0}}\ \frac{c}{nm}}$$

$$h = 1.03\ eV\ 1200\ \frac{nm}{c}$$

$$= 1.03\ 1.602 \times 10^{-19}\ Kg\ \frac{m^2}{s^2}\ \frac{12\cancel{00} \times 10^{-9}\ m}{3\cancel{00} \times 10^{6}\ \frac{m}{s}}$$

$$= (1.03)(1.602)(4.00) \times 10^{-34}\ J \cdot s$$

$$\boxed{h = 6.60 \times 10^{-34}\ J \cdot s}$$

$$\phi = h\nu^{(1)} - |e|V^{(1)} = \frac{hc}{\lambda'} - 1.83\ eV$$

$$hc = 1.98 \times 10^{-25}\ J \cdot m$$

$$= \frac{1.98 \times 10^{-25}\ eV}{1.602 \times 10^{-19}}\ 10^{9}\ nm$$

$$hc = 1.24 \times 10^{3}\ eV\ nm$$

$$\phi = \frac{1.24 \times 10^{3}\ eV\ nm}{300\ nm} - 1.83\ eV$$

$$\boxed{\phi = 4.13\ eV - 1.83\ eV = 2.30\ eV}$$

$$\nu_0 = \frac{\phi}{h} = \frac{2.30 \times 1.602 \times 10^{-19}\ J}{6.60 \times 10^{-34}\ J\ s}$$

$$\boxed{\nu_0 = 5.58 \times 10^{14}\ s^{-1}}$$

$$\lambda_0 = \frac{c}{\nu_0} = \frac{3 \times 10^{8}\ m\ s^{-1}}{5.58 \times 10^{14}\ s^{-1}}$$

$$\lambda_0 = 5.37 \times 10^{-7}\ m$$

$$\boxed{\lambda_0 = 537\ nm}$$

REYDBERG FORMULA AND ATOMIC SPECTRA

A HEATED SOLID EMITS RADIATION IN WHICH ALL WAVELENGTHS ARE PRESENT WITH DIFFERENT INTENSITIES. THIS IS A COLLECTIVE BEHAVIOR OF A GREAT MANY INTERACTING ATOMOS RATHER THAN THE CHARACTERISTIC BEHAVIOR OF INDIVIDUAL ATOMS.

IF WE CONSIDER A RAREFIED GAS, WE HAVE A SYSTEM WHERE ATOMS OR MOLECULES ARE SO FAR APART THAT THEIR INTERACTION OCCURS DURING OCCASIONAL COLLISIONS. THEN THE SPECTRA (EMITTED RADIATION) WILL GIVE US INFORMATION OF THE INDIVIDUAL ATOMS OR MOLECULES, WHEN SUBJECTED TO HIGH TEMP OR ELECTRICAL DISCHARGE

$h = 6.62618 \times 10^{-34}\ J \cdot s = 4.13568 \times 10^{-15}\ eVs$

$eV = 1.6022 \times 10^{-19}\ J$

$eV\ mol^{-1} = 9.6484 \times 10^{4}\ J\ mol^{-1}$

$= 96.484\ KJ\ mol^{-1}$

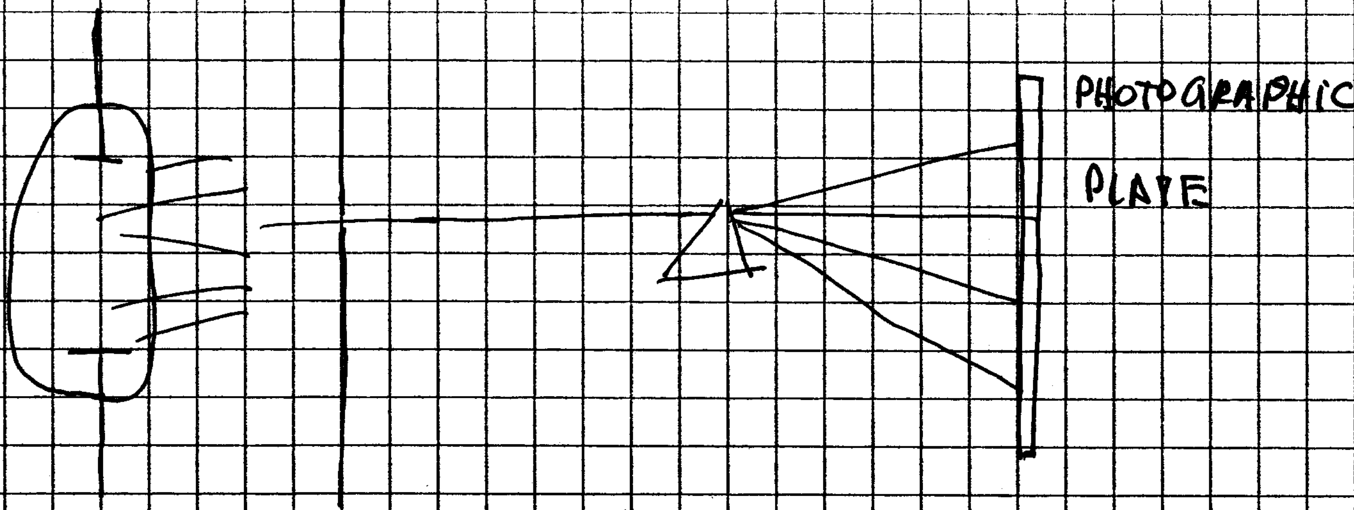
$= 23.05\ Kcal\ mol^{-1}$

$h = 4.13568 \times 10^{-15}\ eVs$

$hc = 1.2407 \times 10^{4}\ eV\ A^{o} = 12407\ eV\ A^{o}$

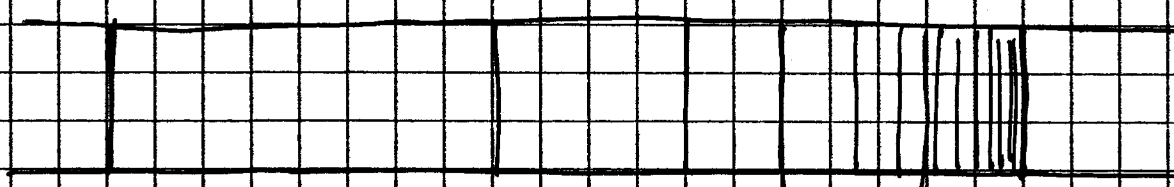
$\hbar c = 1.974 \times 10^{3}\ eV\ A^{o} = 197.4\ MeV\ f$

$f = \text{fermi} = 10^{-15}\ m$



RAREFIED GAS
EXCITED BY
ELECTRICAL
DISCHARGED

BALMER SERIES (HYDROGEN)



λ	656.3 nm	364.7 nm
ν	$4.6 \times 10^{14}\ s^{-1}$	$8.2 \times 10^{14}\ s^{-1}$
$\bar{\nu}$	15 237 cm^{-1}	27419 cm^{-1}
	1.9 eV	3.41 eV

EVERY ELEMENT DISPLAYS A UNIQUE SPECTRUM. BUT THE EMISSION SPECTRA WERE NOT UNDERSTOOD (1900).

BALMER DISCOVERED AN EMPIRICAL RELATION

$$\frac{1}{\lambda} = \bar{\nu} = 109\,680 \left(\frac{1}{2^2} - \frac{1}{n^2} \right) cm^{-1}$$

$$n = 3, 4, 5, \ldots$$

IN 1911, RUTHERFORD PROPOSED THAT THE ATOM WAS CONSTITUTED OF A STRONG + OR − CENTRAL CHARGE, RADIUS $< 3 \times 10^{-12}$ cm AND SURROUNDED BY A "SPHERE OF ELECTRIFICATION" OF THE OPPOSITE CHARGE WHICH SPENDS UP TO 10^{-8} cm.

ACCORDING TO CLASSICAL THEORY, THIS SYSTEM CANNOT BE STABLE, SINCE ACCELERATED PARTICLES RADIATE E+M WAVES.

1913 BOHR POSTULATES

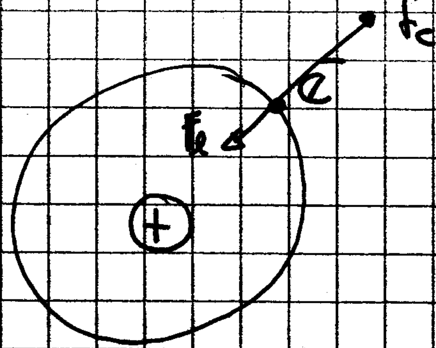
I.- ATOMOS CAN EXIST IN STATIONARY STATES W/OUT RADIATING ENERGIES

II.- TRANSITIONS BETWEEN THESE STATES CAN OCCUR BY ABSORTION OR EMISTION OF RADIATION $\Delta E = h\nu = E_{n_2} - E_{n_1}$

III ANGULAR MOMENTUM IS QUANTIZED

$$l_n = n \frac{h}{2\pi} \equiv n\hbar \qquad n = \text{INTEGER}$$

$$= m v_n r$$



IN A CIRCULAR ORBIT

CENTRIPETAL FORCE f_c = ELECTROSTATIC FORCE

$= F_e$

$$f_c = \frac{mv^2}{r} = F_e = \frac{|q||e|}{4\pi\epsilon_0 r^2}$$

$$\frac{m}{r}\left(\frac{n\hbar}{mr}\right)^2 = \frac{|q||e|}{4\pi\epsilon_0 r^2}$$

$$r_n = \frac{4\pi\epsilon_0 \hbar^2}{|q||e|m} n^2$$

IF $|q| = |e|$, WE GET $r_1 = 5.29\,nm$.

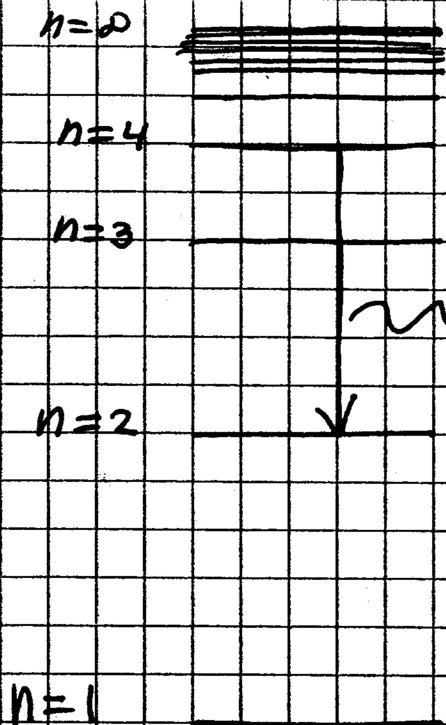
<u>TOTAL ENERGY</u> = KE + V_{POT}

$$E_T = \frac{1}{2} m v_n^2 - \frac{|q||e|}{4\pi\epsilon_0}\frac{1}{r_n}$$

$$\boxed{E_T = -\frac{m|e|^2|q|^2}{8\epsilon_0^2 h^2}\frac{1}{n^2}}$$

ENERGY IS QUANTIZED

DISCRETE ENERGY LEVELS



$$h\nu = |E_2 - E_4| = \Delta E_{4\to 2}$$

IN GENERAL CONSIDER $n_2 > n_1$

FOR HYDROGEN ATOM

$$\Delta E_{n_2\to n_1} = \frac{me^4}{8\epsilon_0^2 h^2}\left[\frac{1}{n_1^2} - \frac{1}{n_2^2}\right] = h\nu$$

$$\bar{\nu} = \frac{me^4}{8\epsilon_0^2 h^3 c}\left[\frac{1}{n_1^2} - \frac{1}{n_2^2}\right] = R_H\left[\frac{1}{n_1^2} - \frac{1}{n_2^2}\right]$$

$$R_H = 109{,}736\ \text{cm}^{-1}$$

$$R_H^{EXP} = 109{,}677.57\ \text{cm}^{-1}$$