אפקט קומפטון

Representation of a Photon

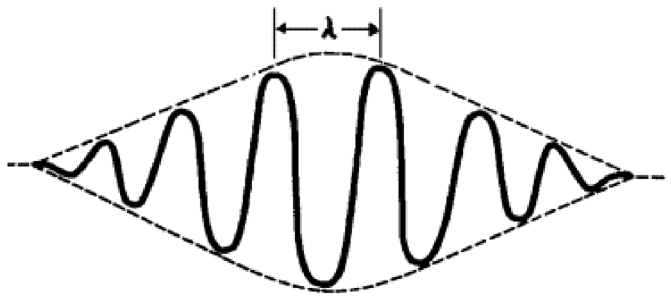
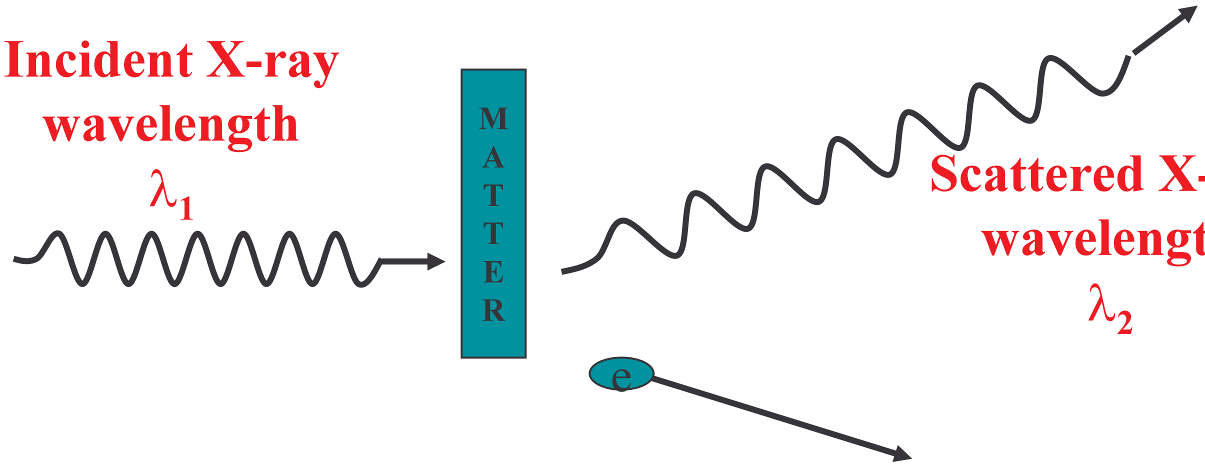


Figure 2

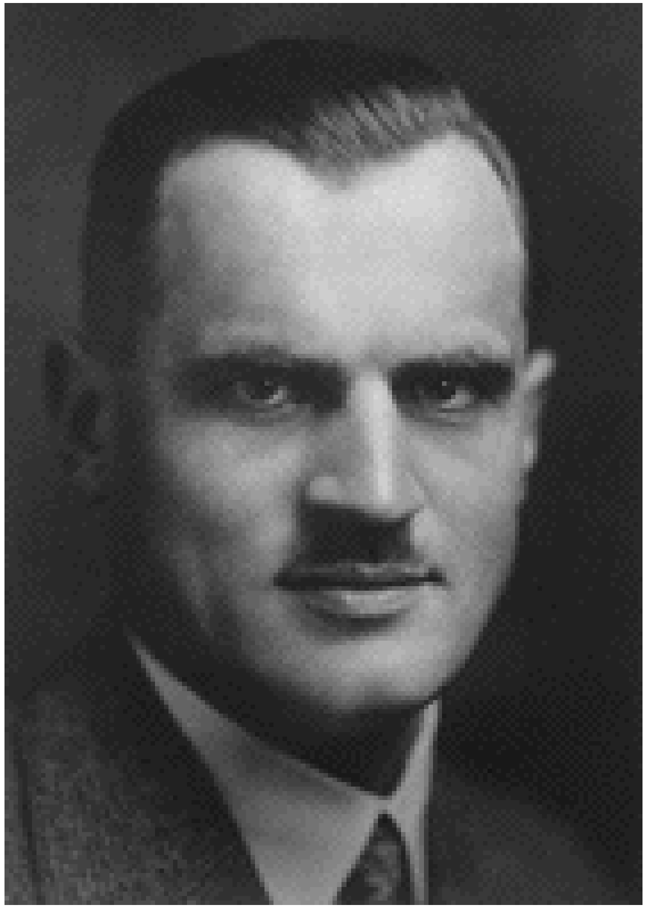


$\lambda_2 > \lambda_1$

Electron comes flying out

$$\lambda_{compton} = \frac{h}{mc}$$

$$\lambda_{compton}(e) = 0.024\ \overset{o}{A}$$

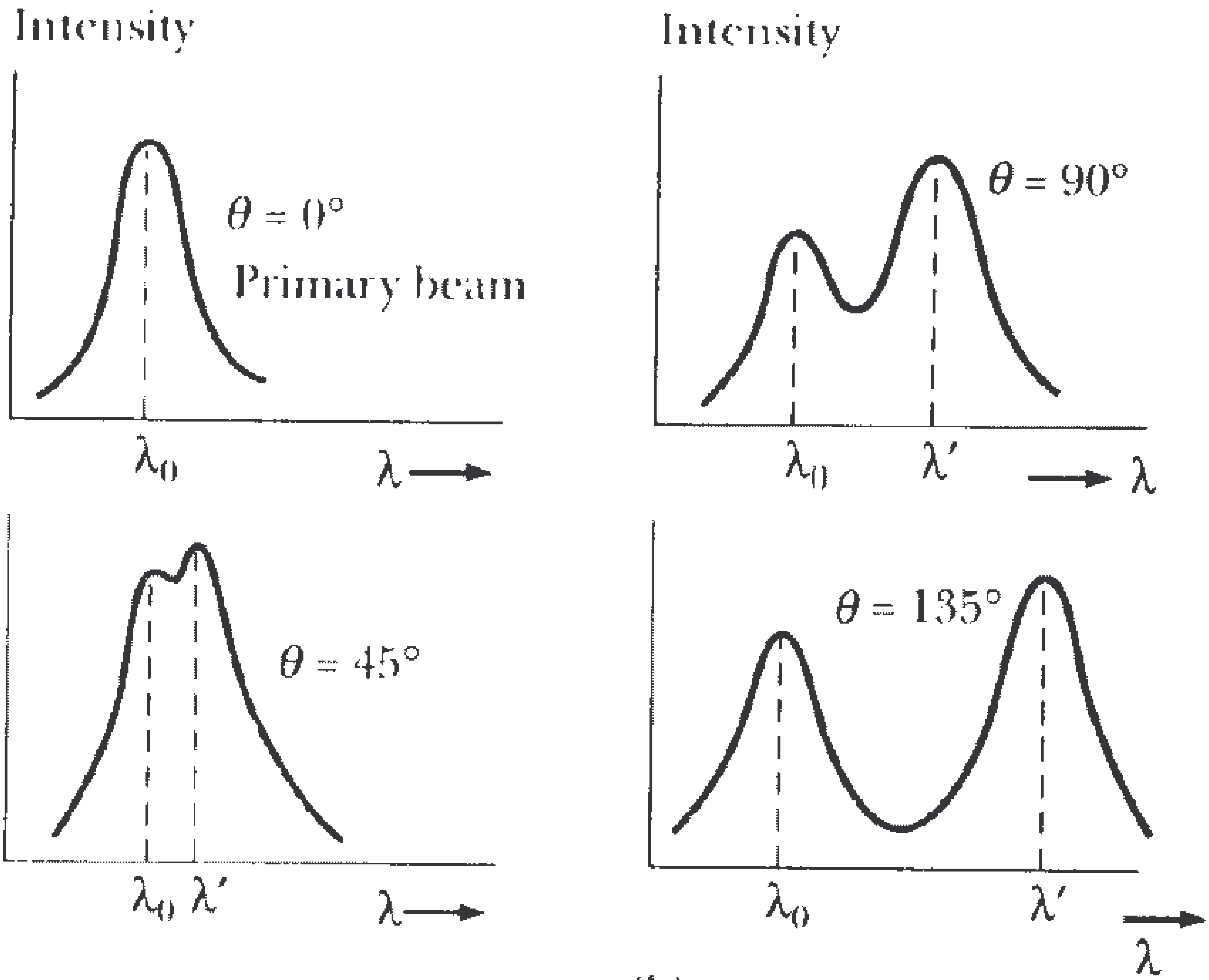


קומפטון (1892-1962)

Nobel prize, 1927,

for his discovery of the effect named after him

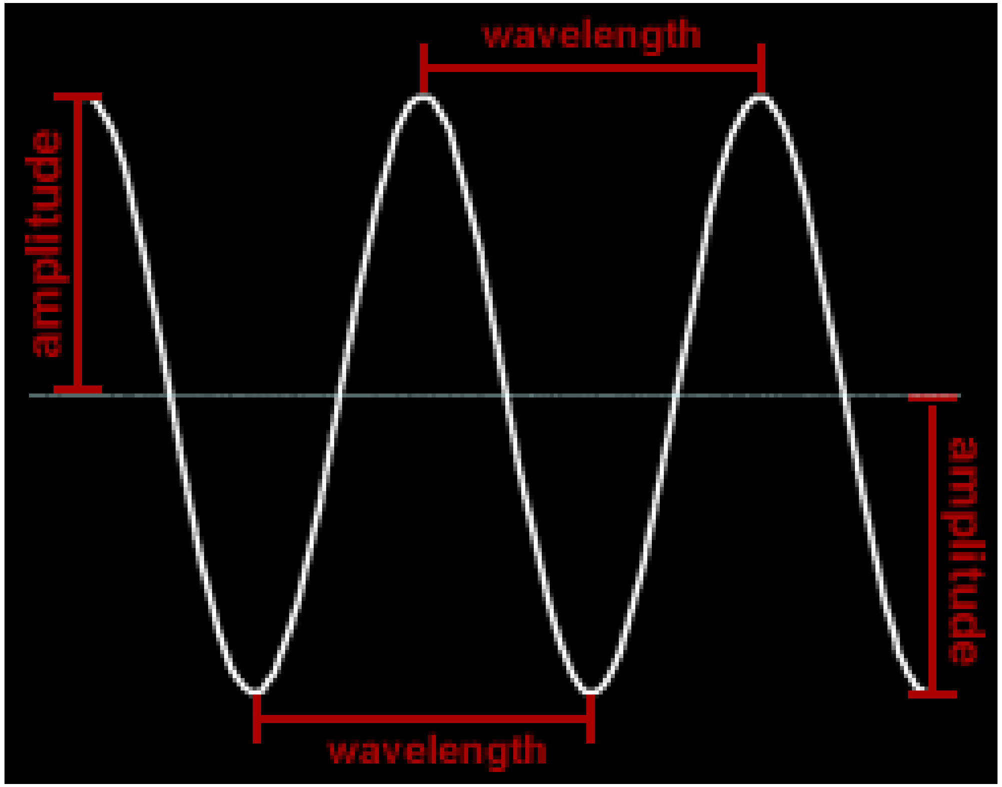
(performed in 1922)


Intensity
θ = 0°
Primary beam
λ0
λ
Intensity
θ = 90°
λ0
λ′
λ
θ = 45°
λ0 λ′
λ
θ = 135°
λ0
λ′
λ

(b)

Light Waves

Until about 1900, the classical wave theory of light described most observed phenomenon.



Light waves:

<u>Characterized by:</u>

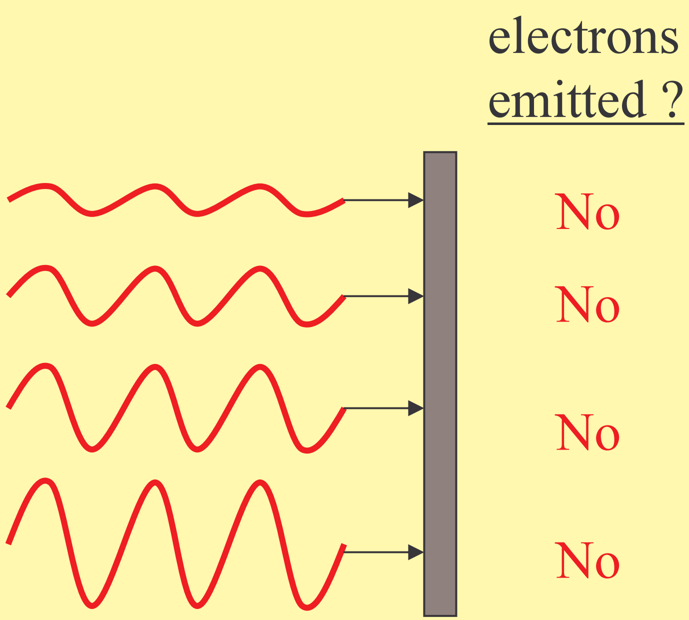
- Amplitude (A)
- Frequency (ν)
- Wavelength (λ)

Energy α A^2

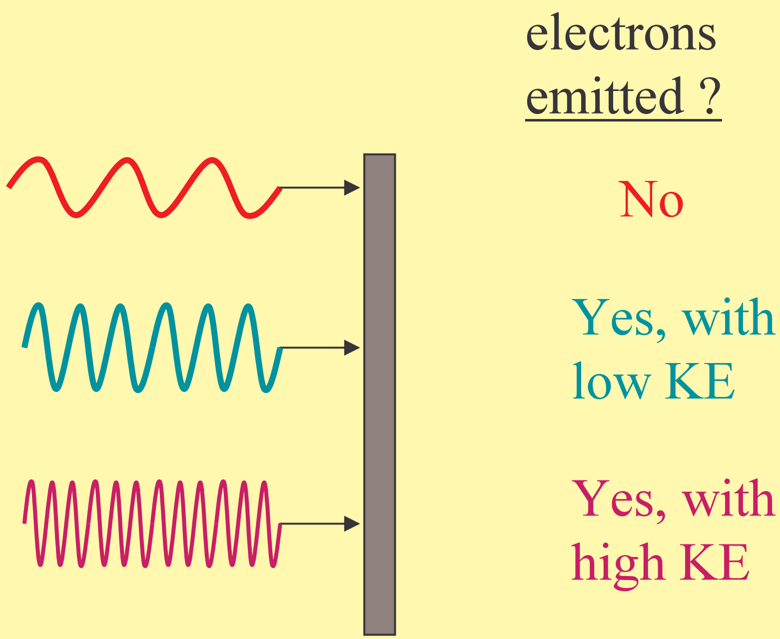
האפקט הפוטואלקטרי

השיטה הקלסית

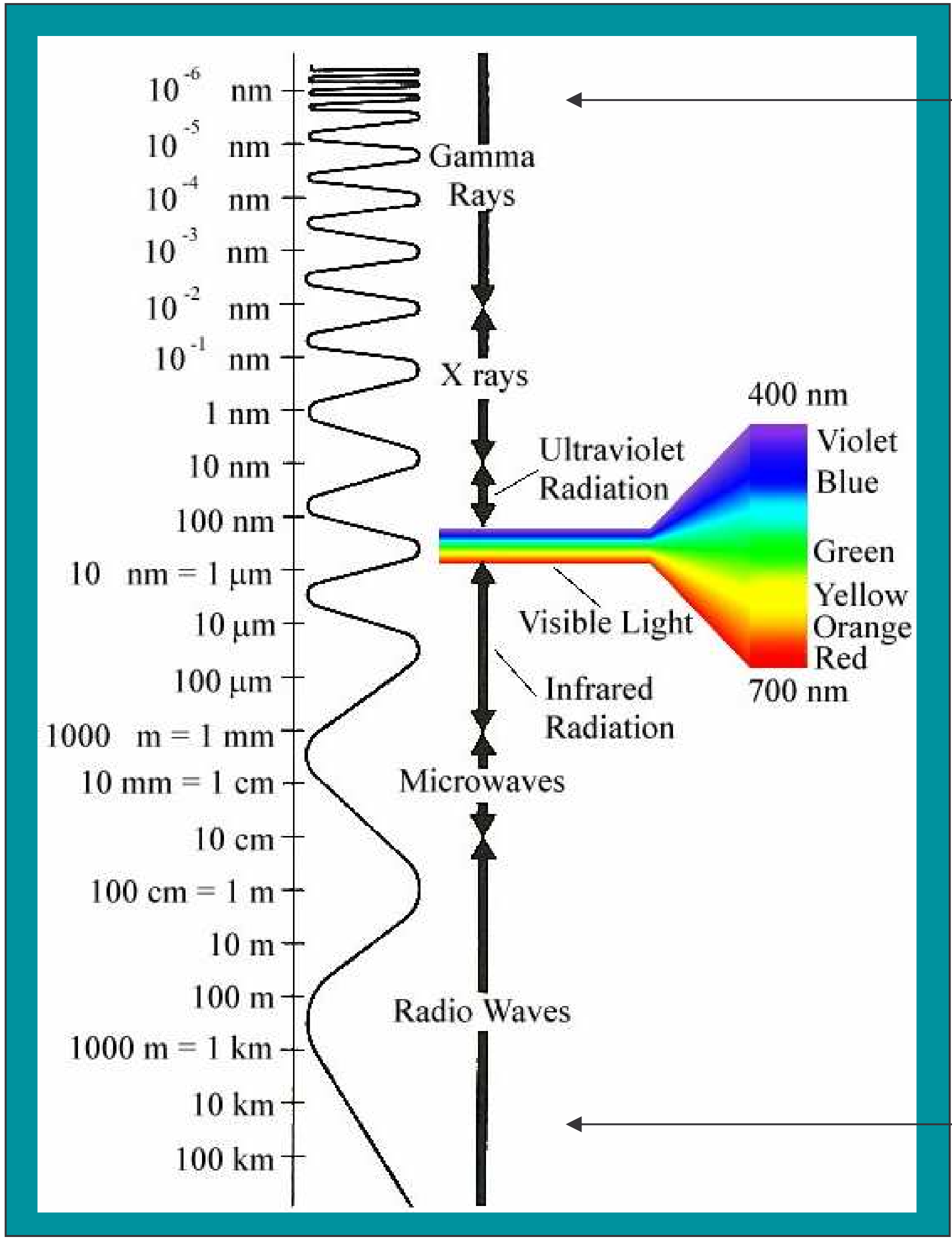
הגדלת האנרגיה על ידי עצמת הגל



שנוי באורך הגל



The Electromagnetic Spectrum



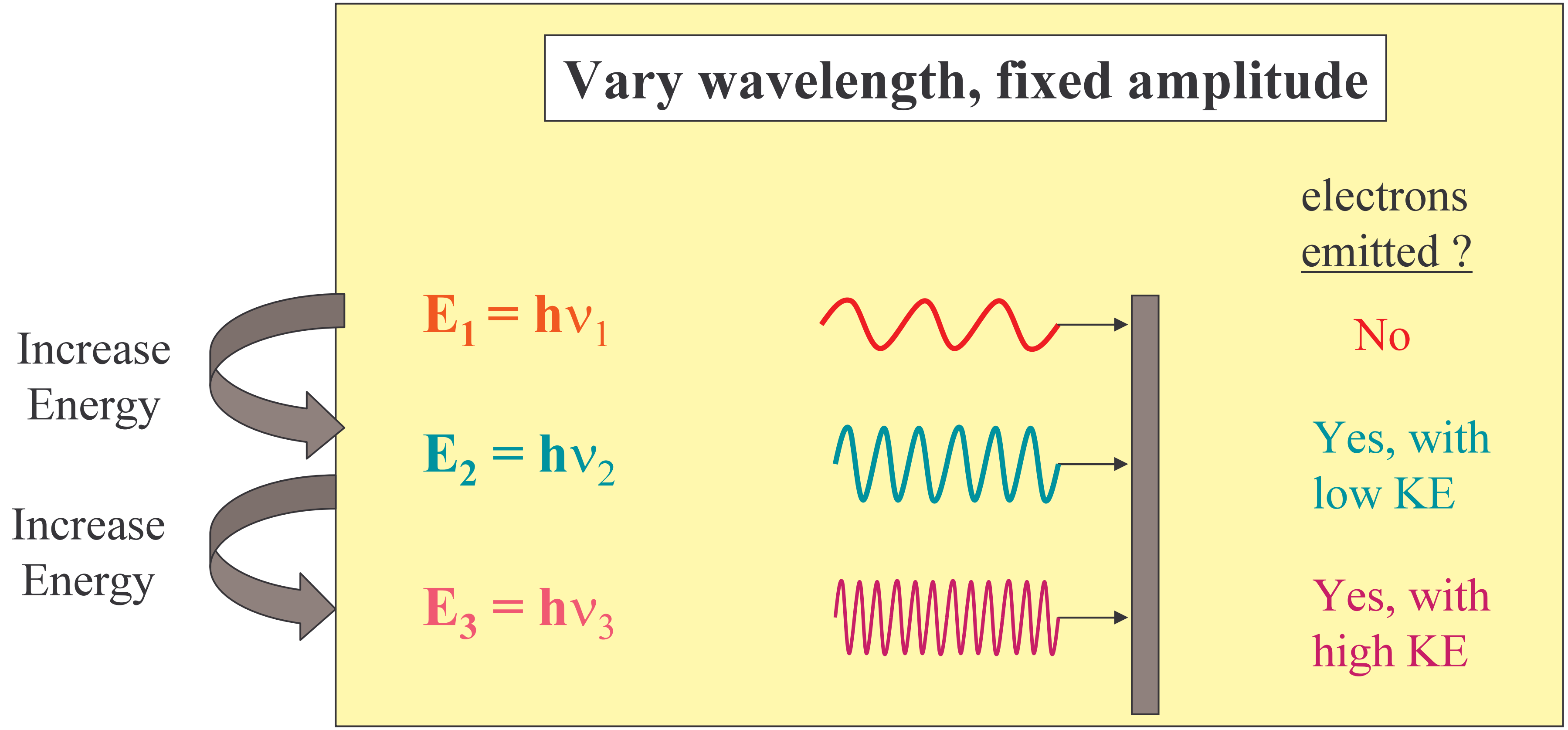
Shortest wavelengths
(Most energetic photons)

$$E = h\nu = hc/\lambda$$

$h = 6.6 \times 10^{-27}$ [erg*sec]
(Planck's constant)

Longest wavelengths
(Least energetic photons)

Interpretation of Photoelectric Effect



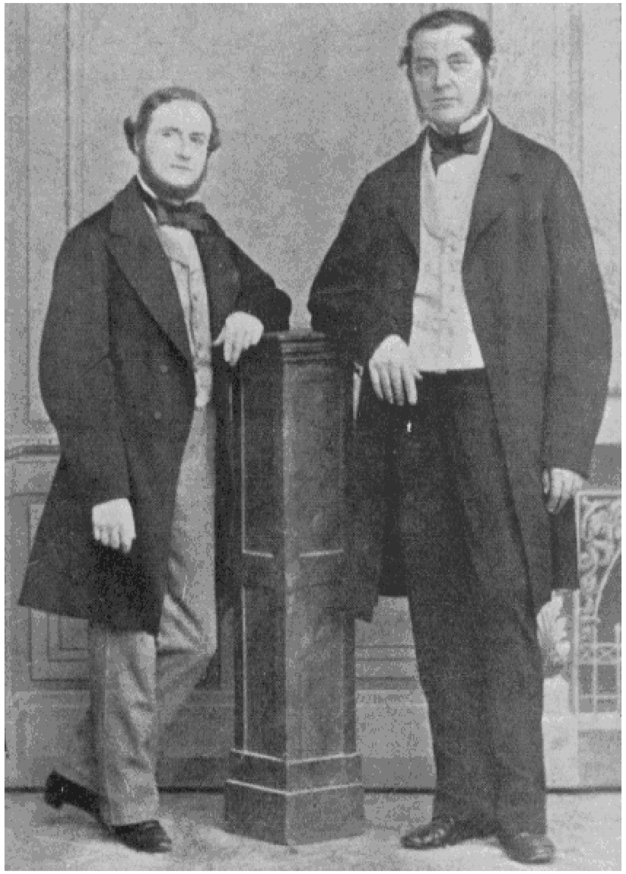
$E_3 > E_2 > E_1$

Photoelectric Effect Applet

רוברט מיליקן(1868-1953)

Nobel Prize, 1923,

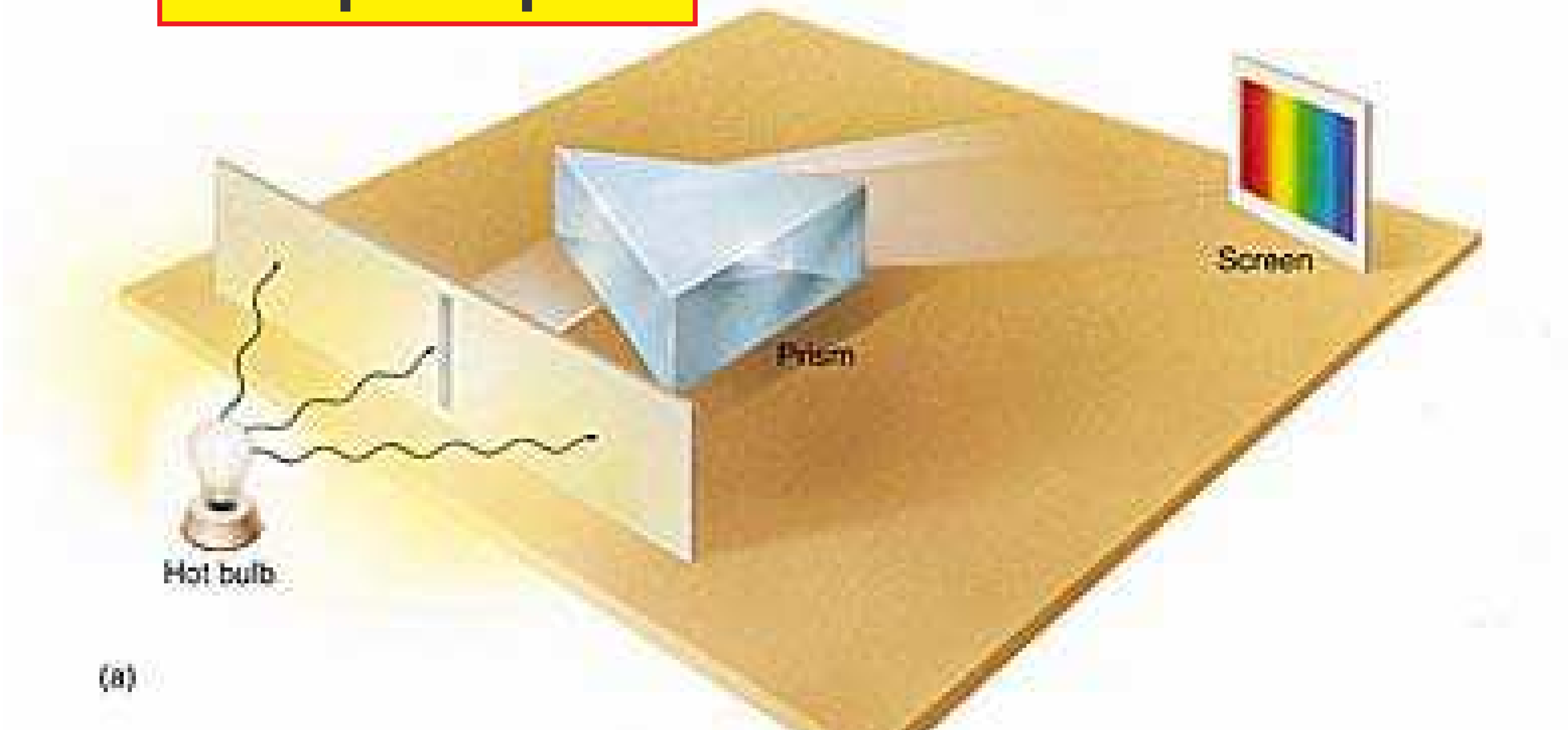
for his work on the elementary charge of electricity and on the photoelectric effect.

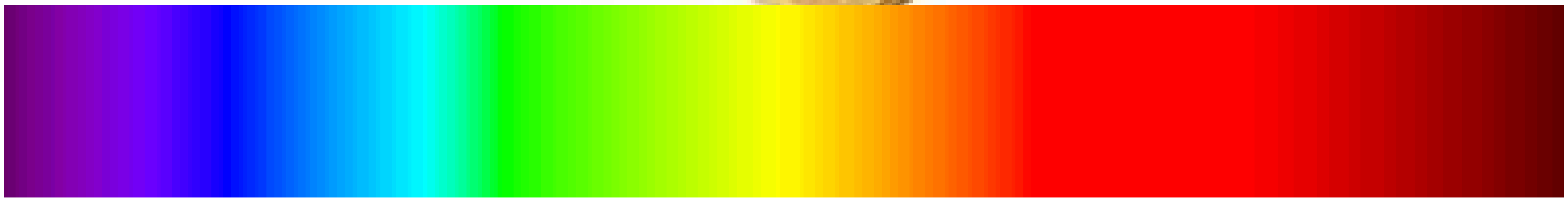


(1824-1887)קירכהוף

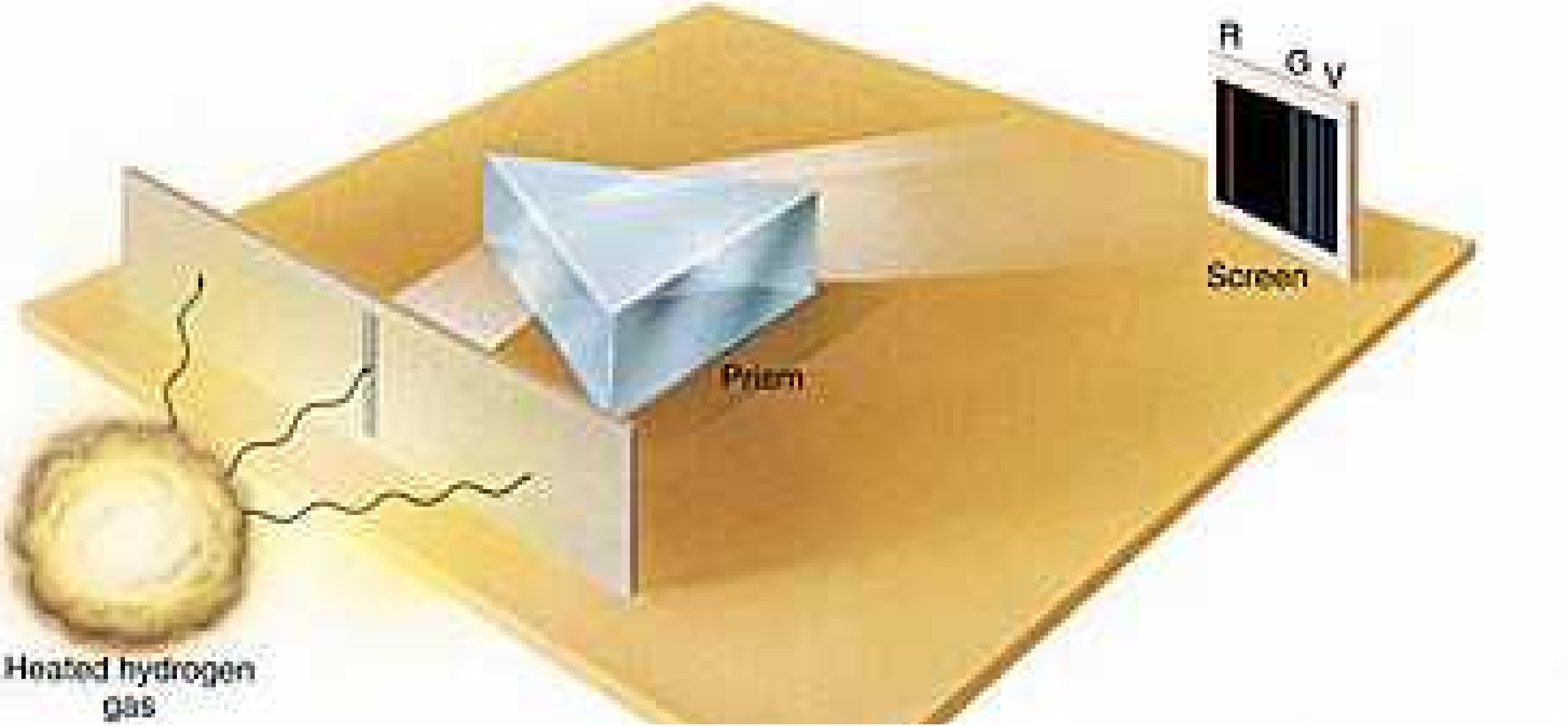
רוברט בונזן (1811-1899)

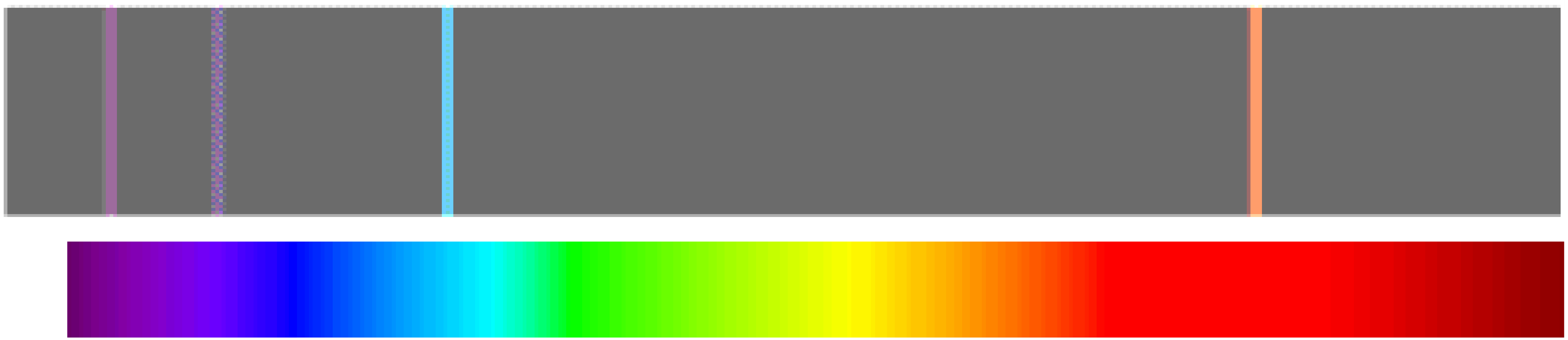
ספקטרוסקופיה

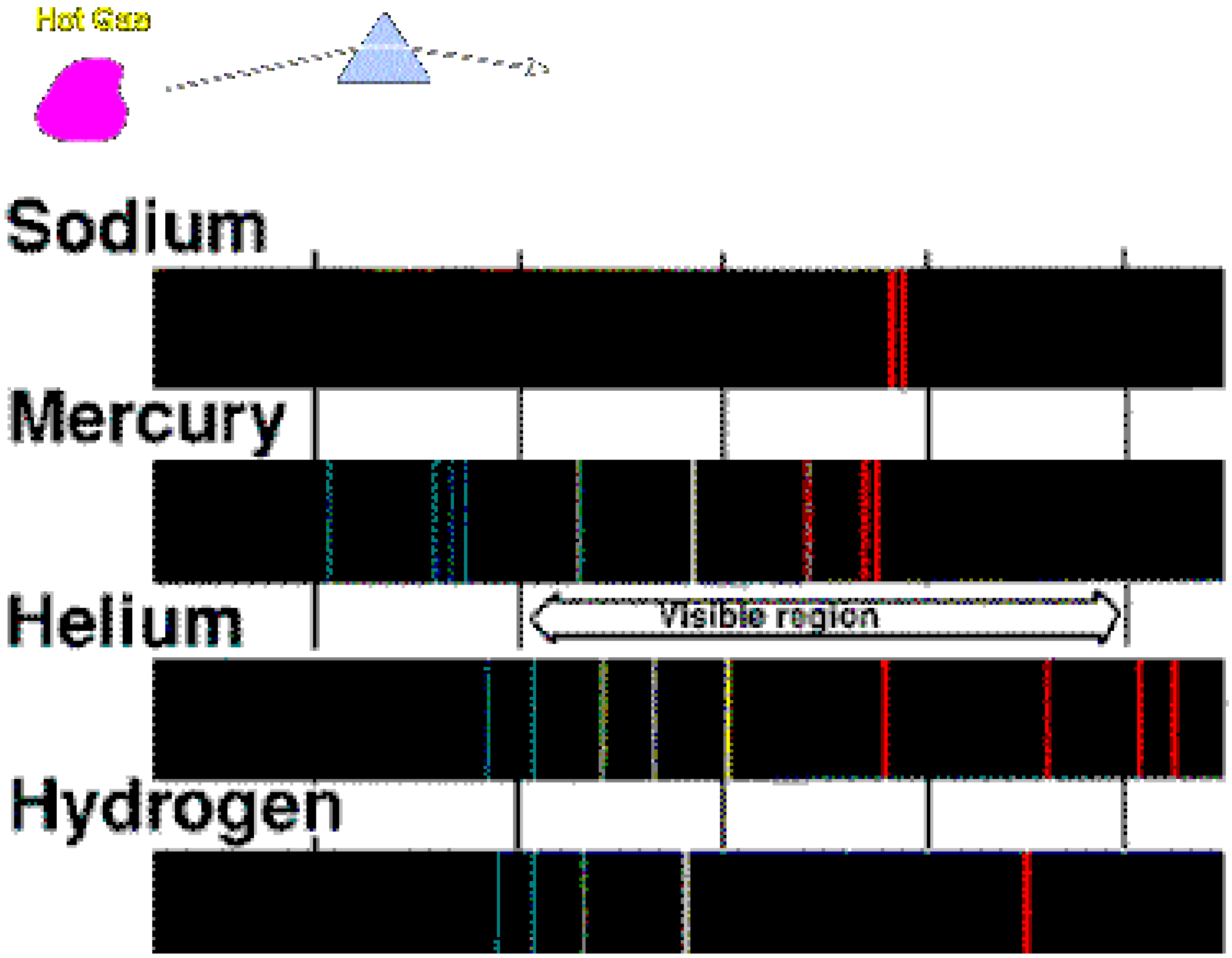




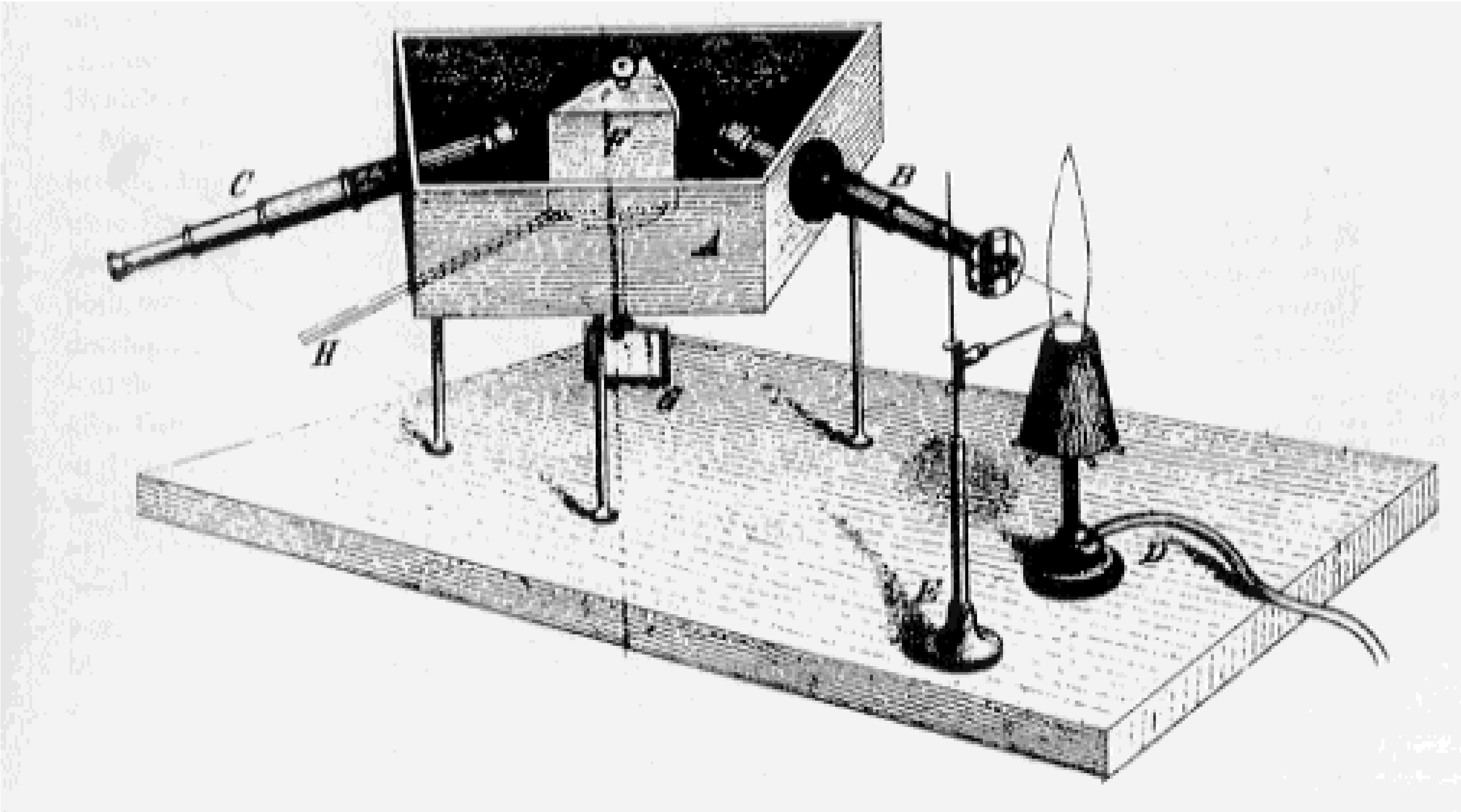
ספקטרוסקופיה



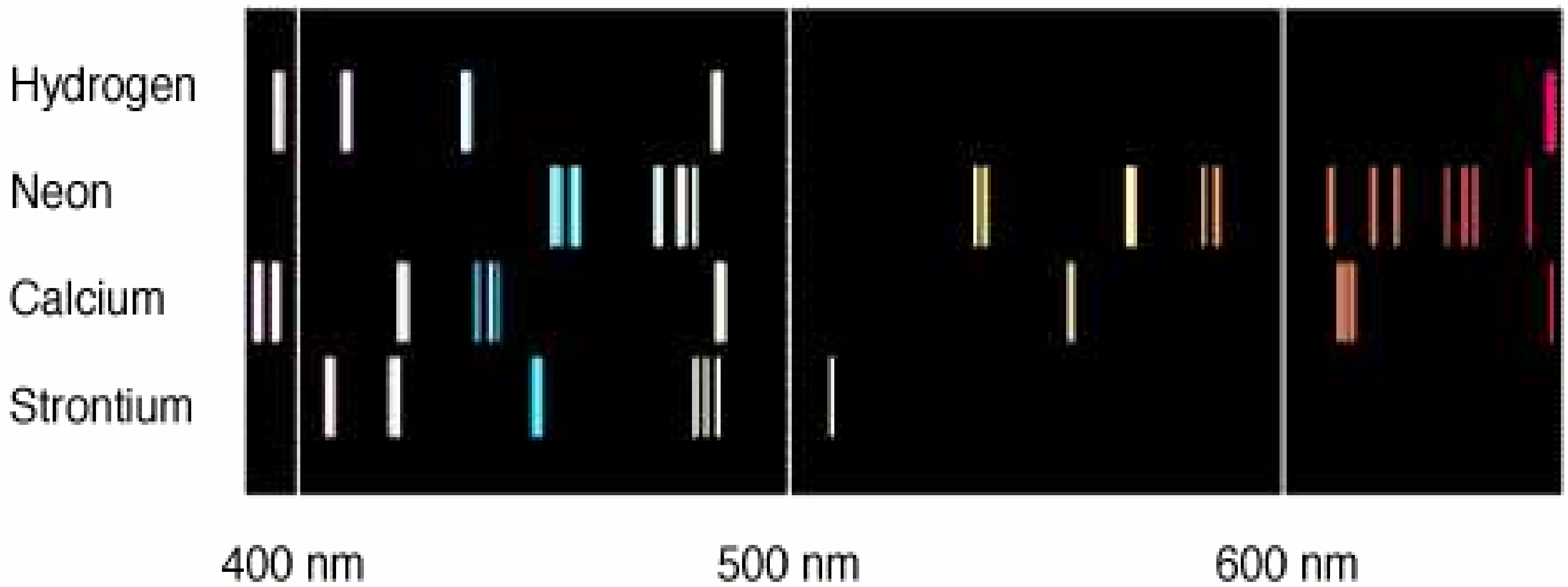




Hot Gas
Sodium
Mercury
Helium
Visible region
Hydrogen


C
B
H
D
E

ספקטרה של פליטה

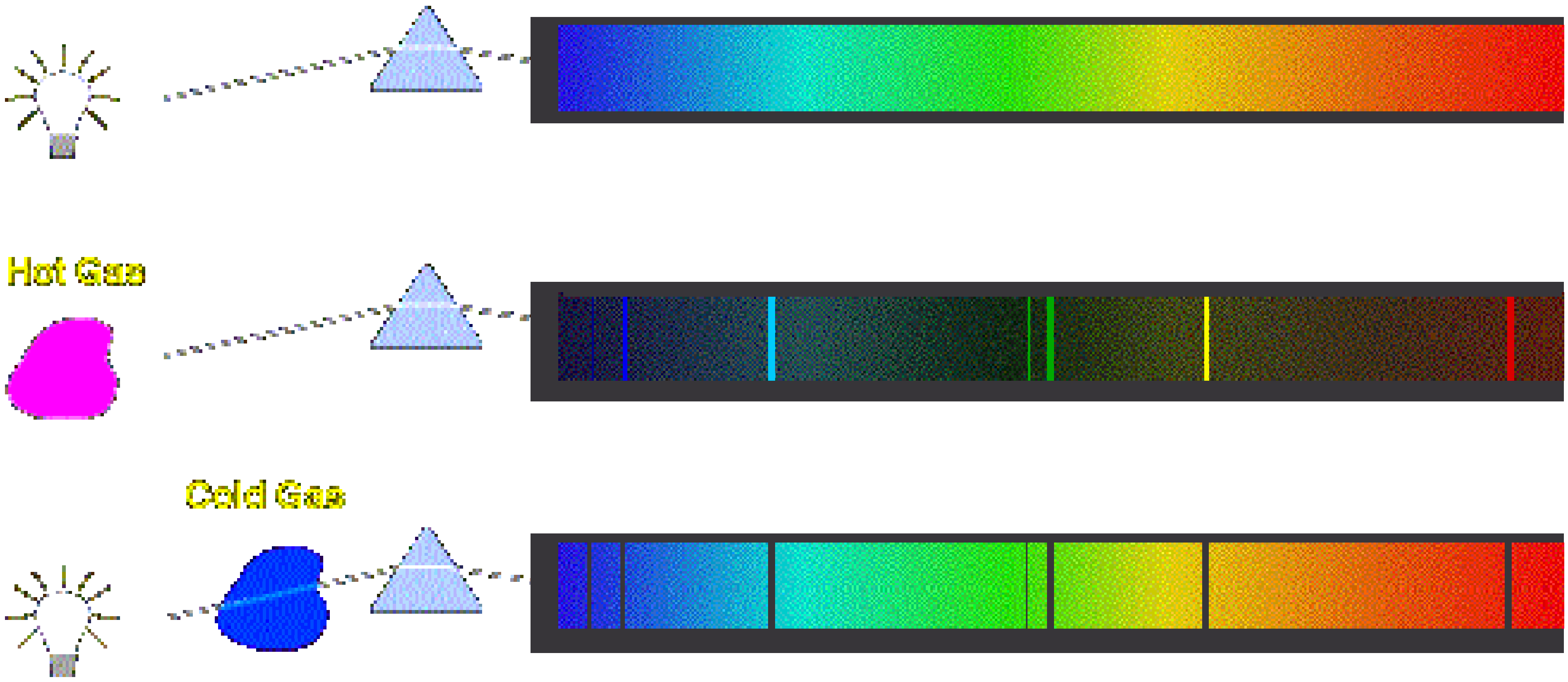


Periodic Table of the Elements

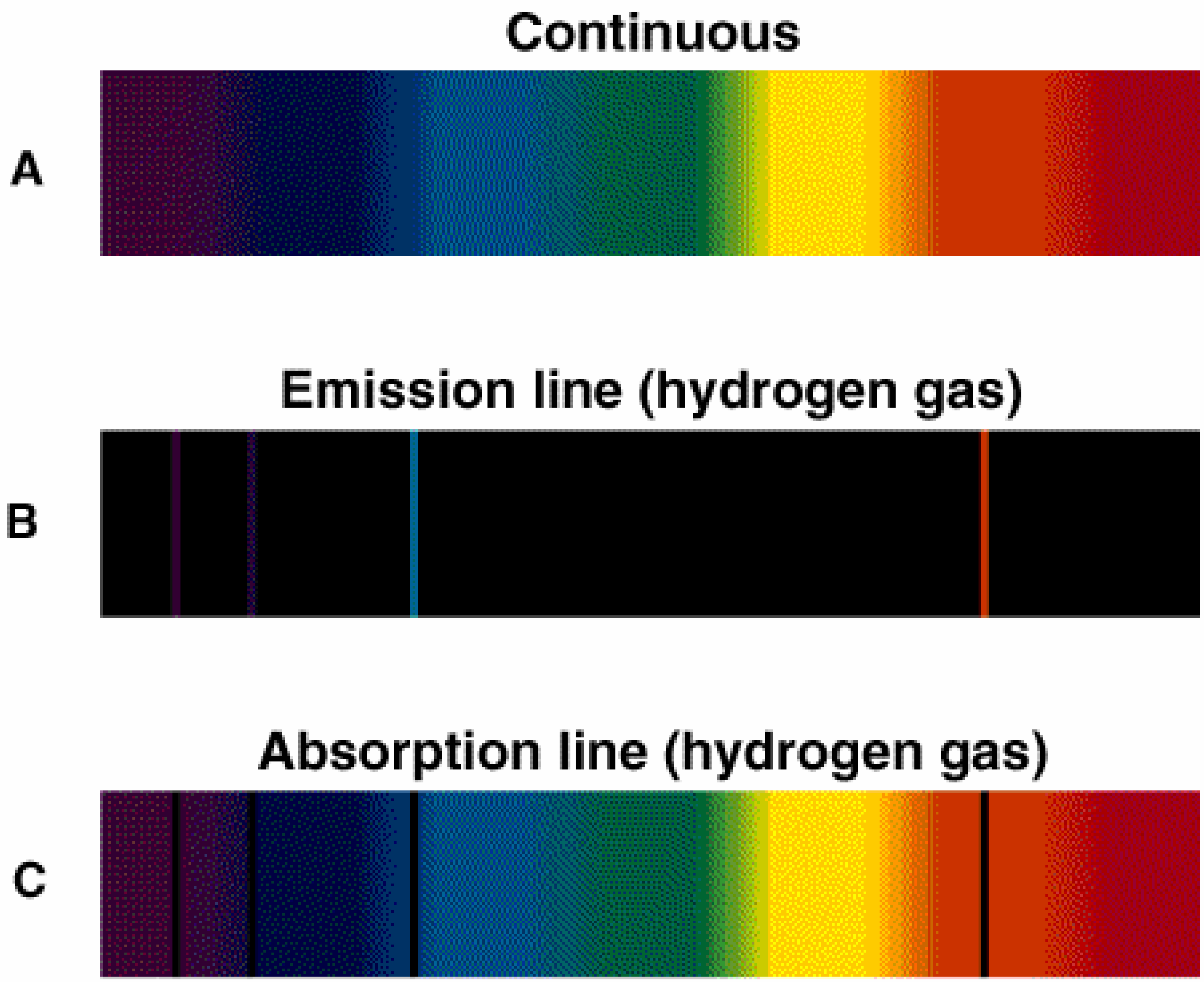
	IA	IIA	IIIB	IVB	VB	VIB	VIIB	VII	VII	VII	IB	IB	IIIA	IVA	VA	VIA	VIIA	0
1	1 H																	2 He
2	3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
3	11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
4	19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
5	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
6	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
7	87 Fr	88 Ra	89 +Ac	104 Rf	105 Ha	106 Sg	107 Ns	108 Hs	109 Mt	110 110	111 111	112 112	113 113					

* Lanthanide Series	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
+ Actinide Series	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

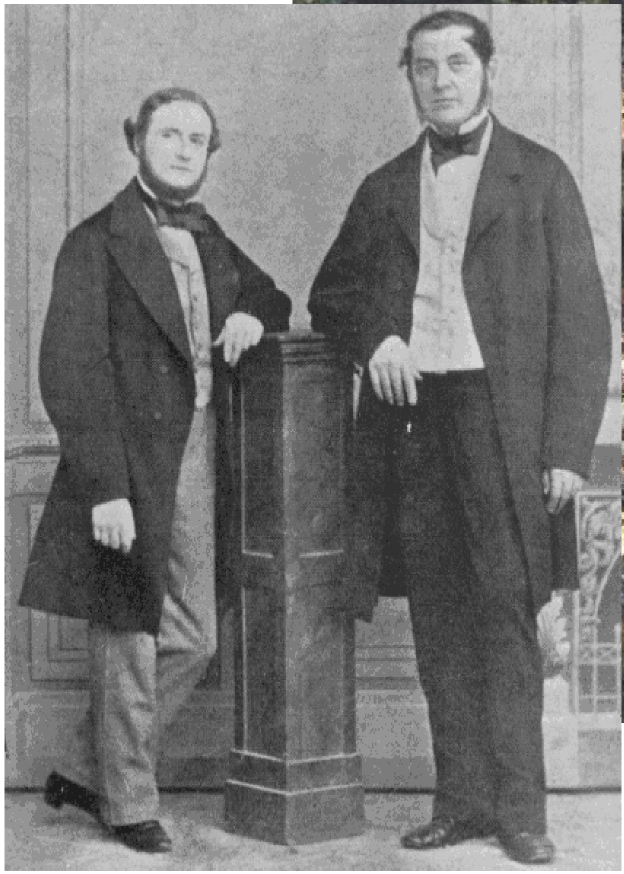
ספקטרוסקופיה



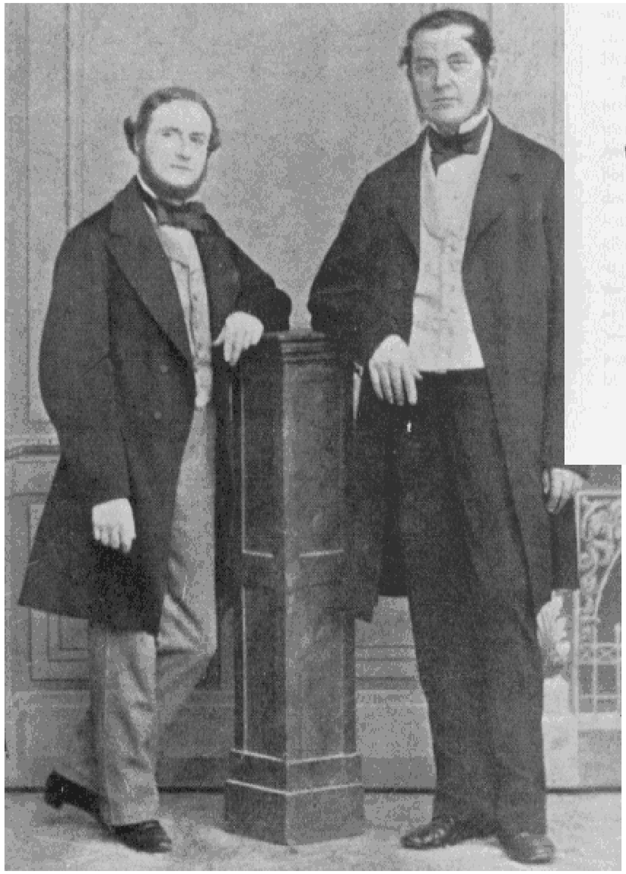
שלשת סוגי הספקטרה

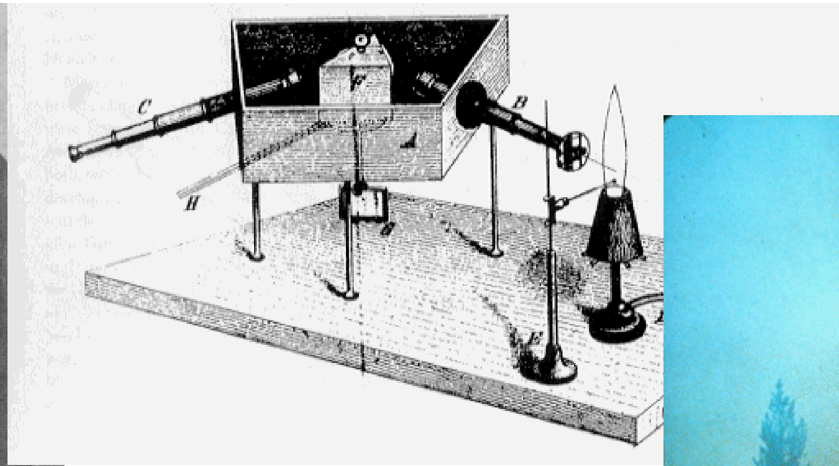


היידלברג



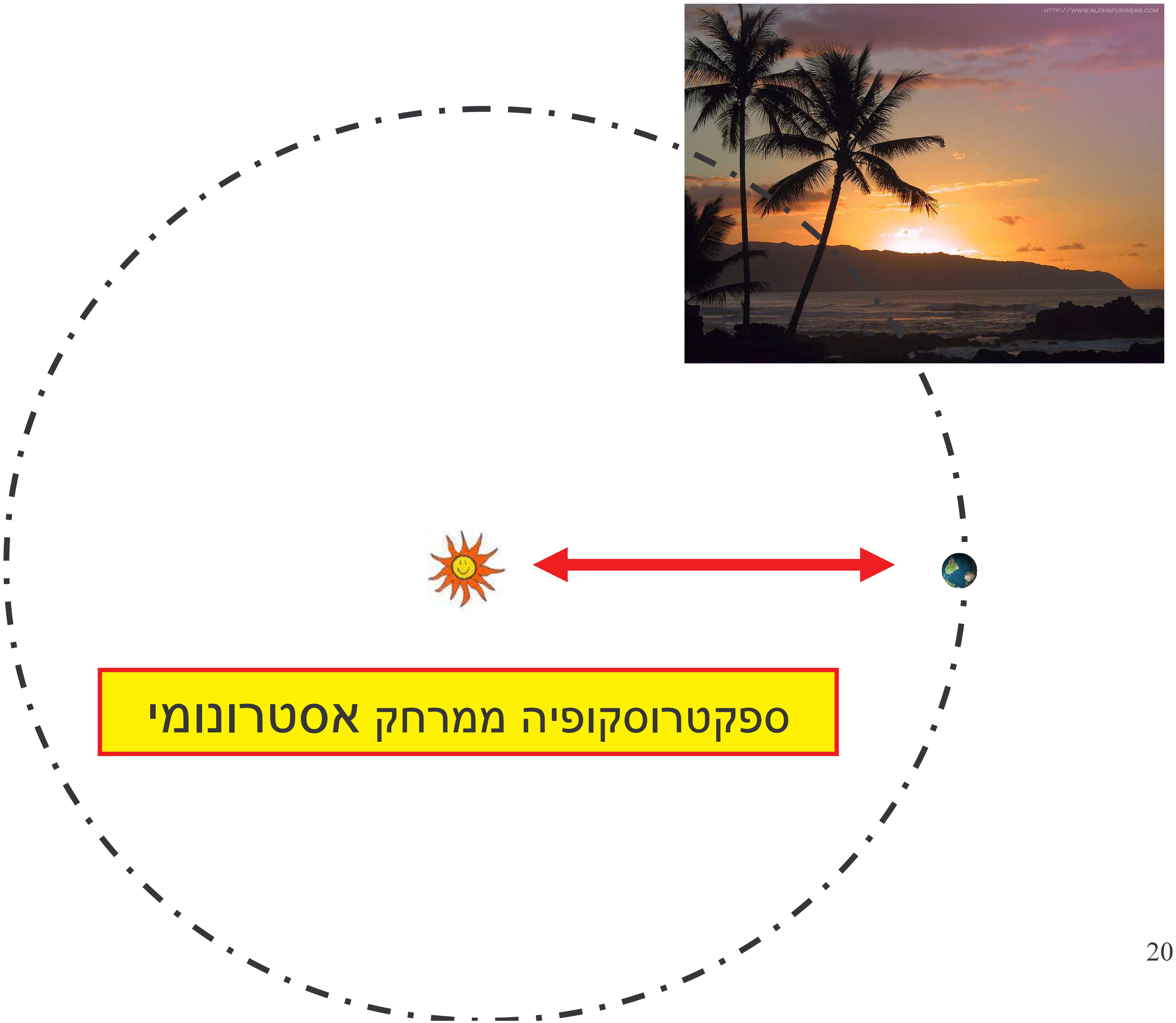
בונזן וקירכהוף

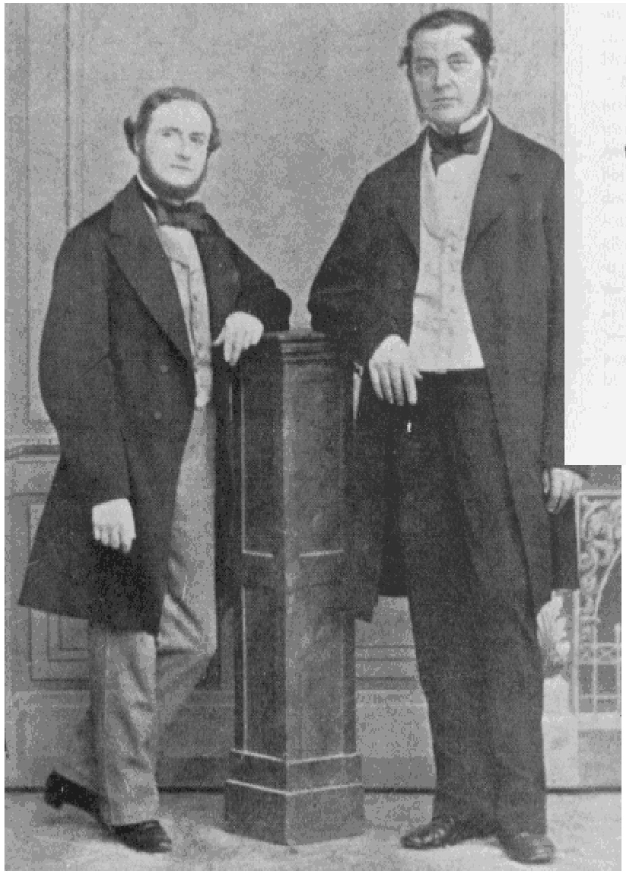




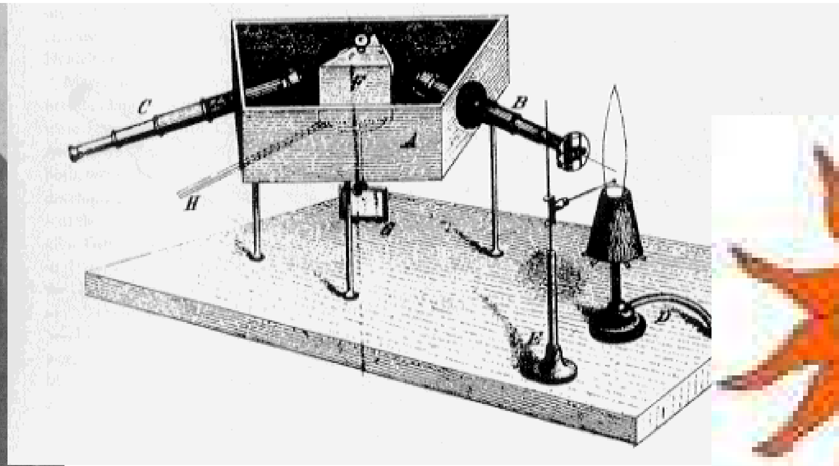
בונזן וקירכהוף

ספקטרוסקופיה ממרחק


ספקטרוסקופיה ממרחק אסטרונומי



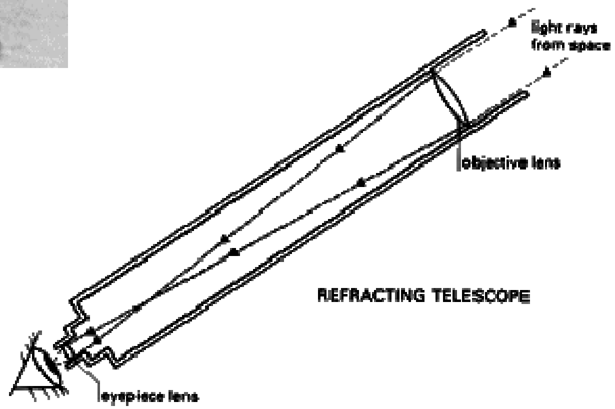
בונזן וקירכהוף



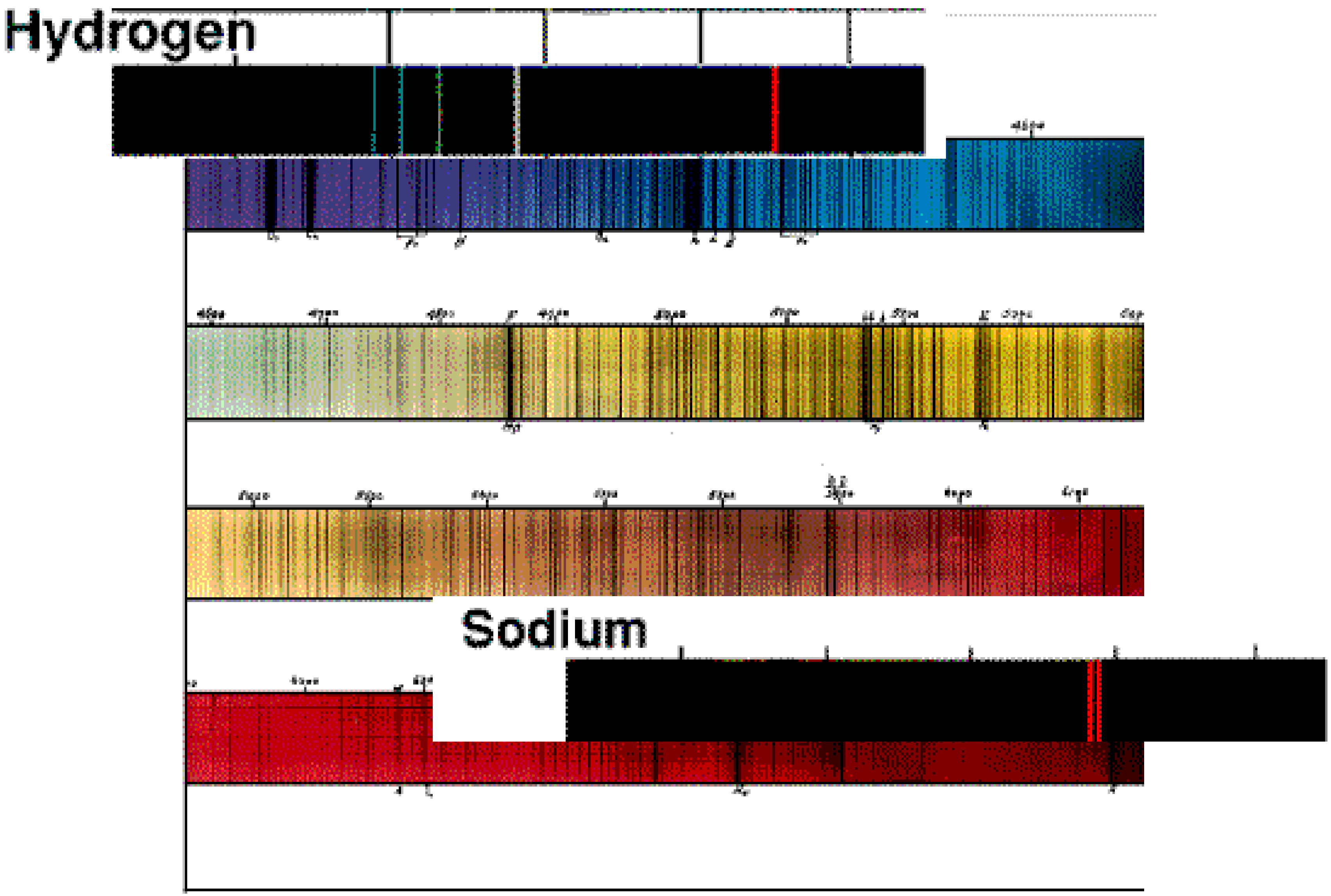
ספקטרוסקופיה אסטרונומית

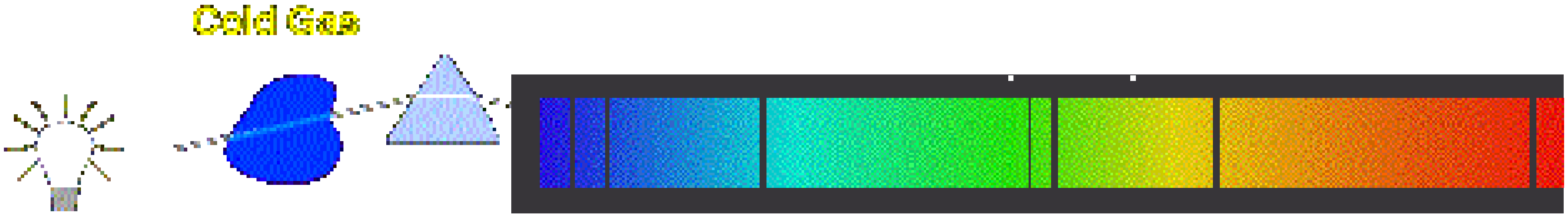
נפתחו השמיים

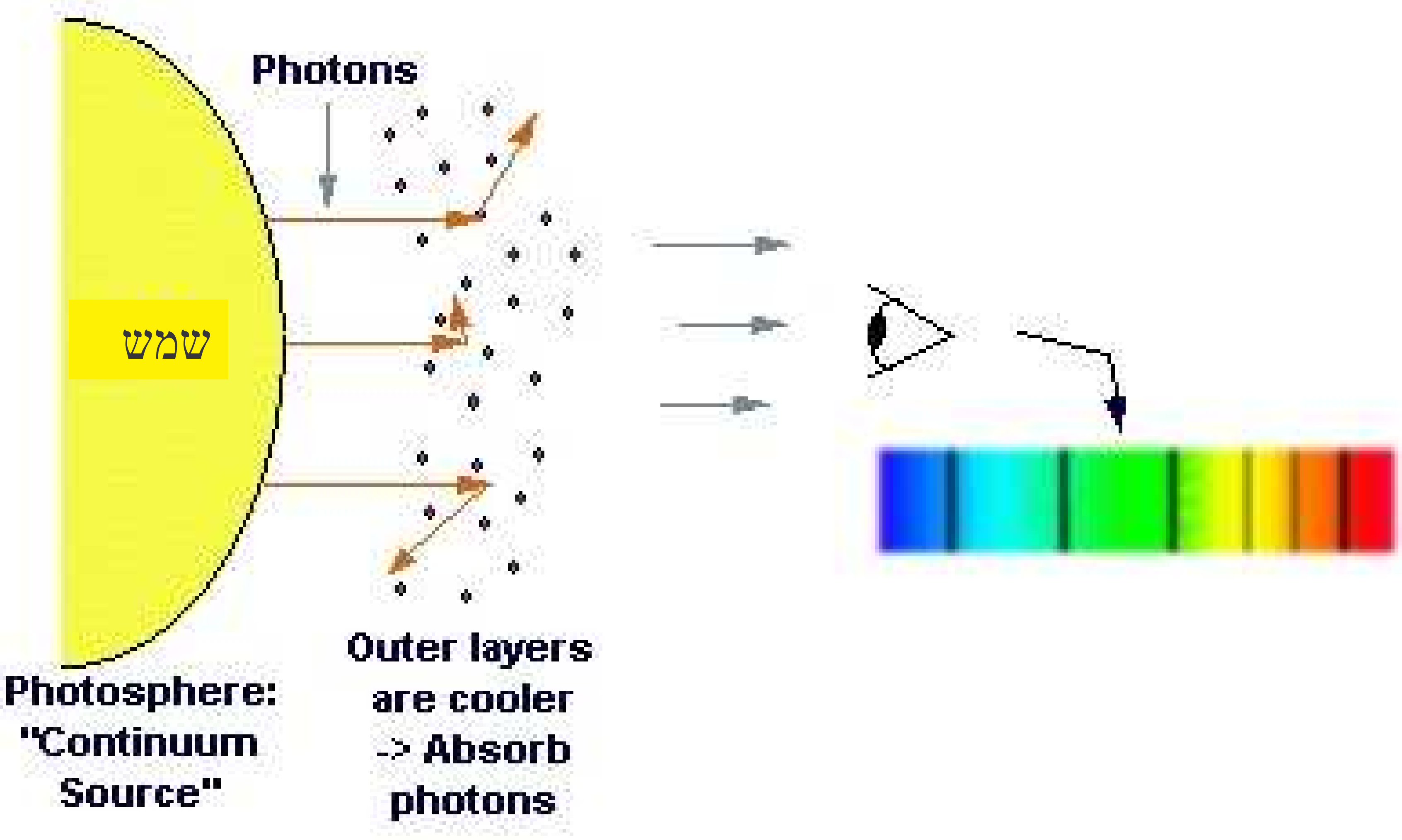
וארא מראות אלהים

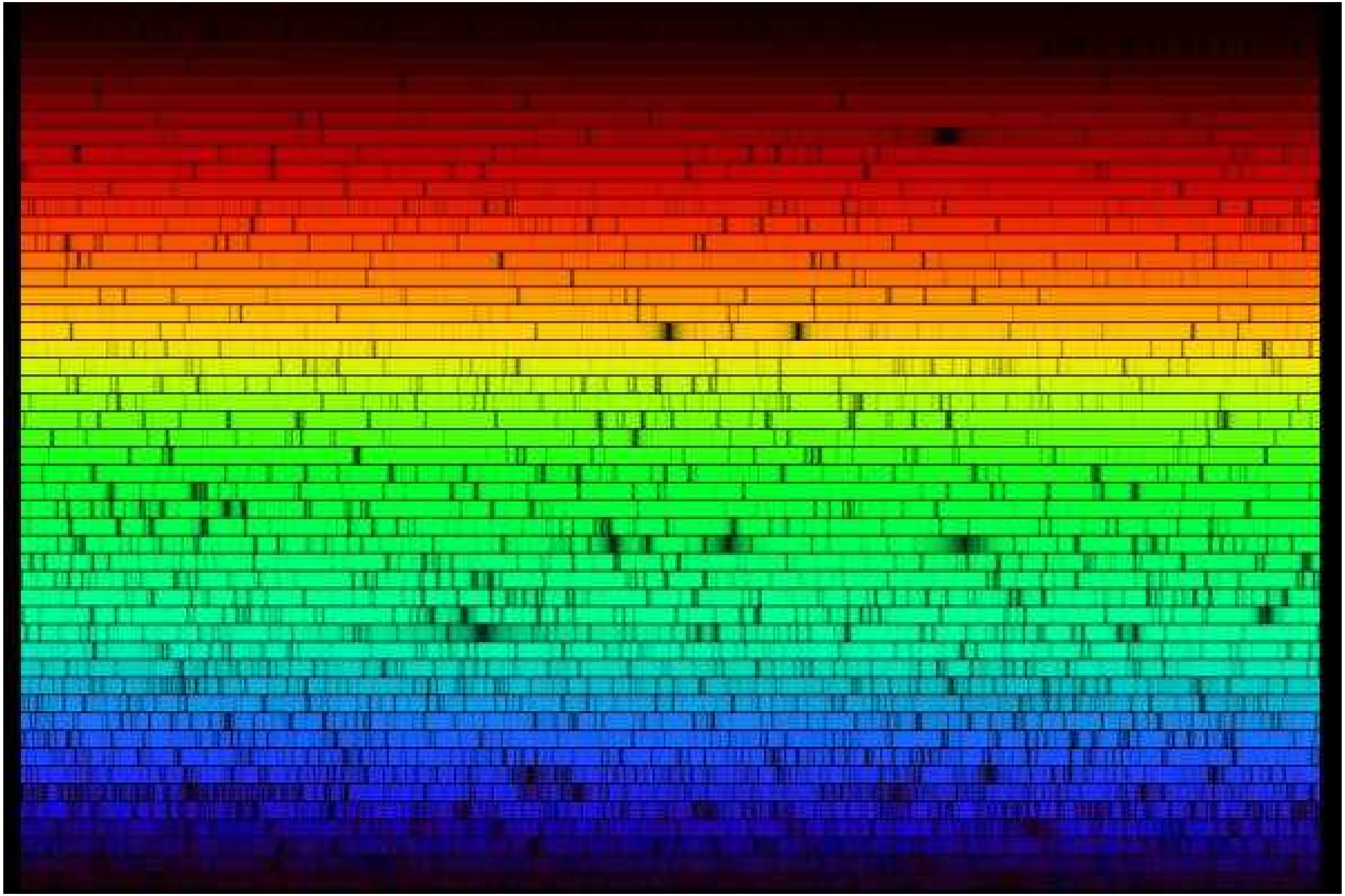


קווי פראונאופר של השמש




Cold Gas

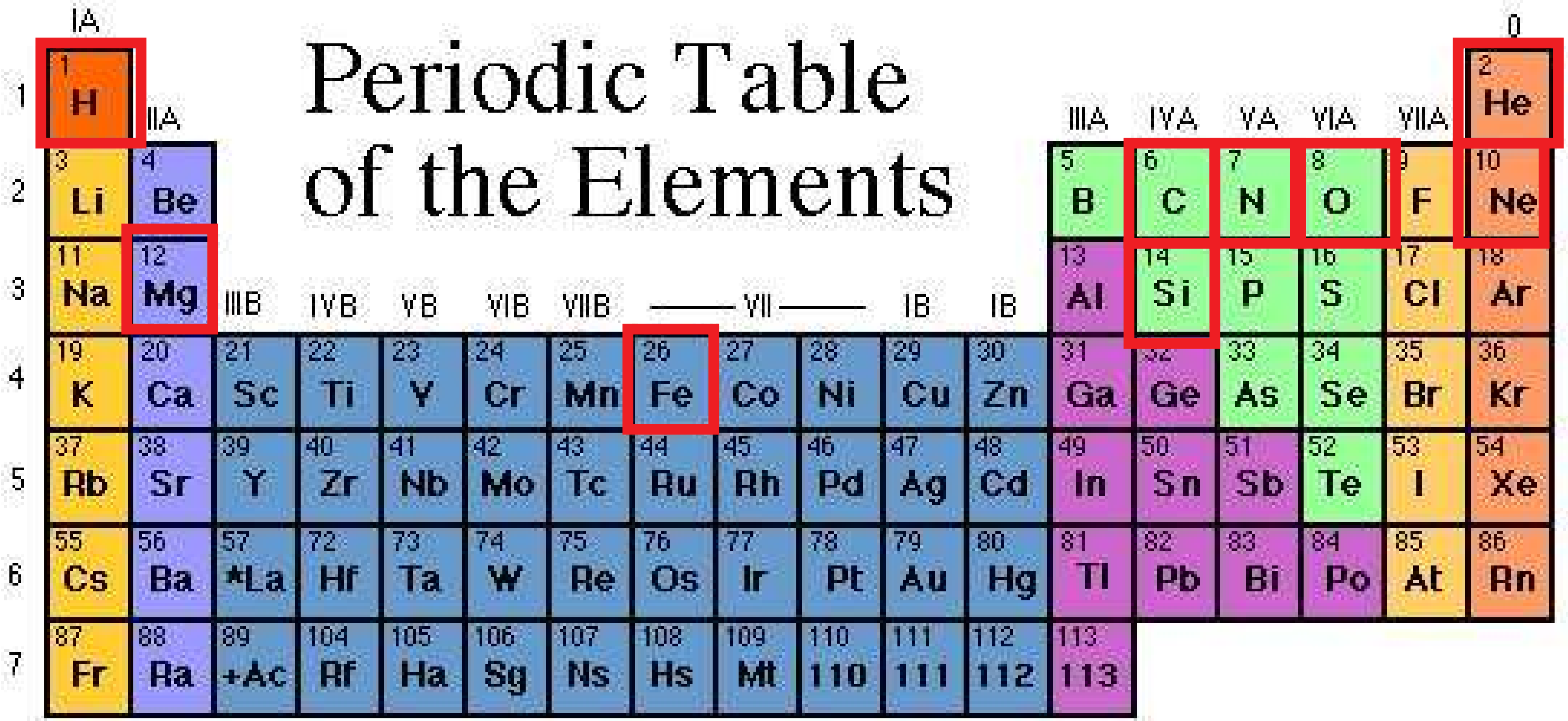

Photons
שמש
Photosphere: "Continuum Source"
Outer layers are cooler -> Absorb photons



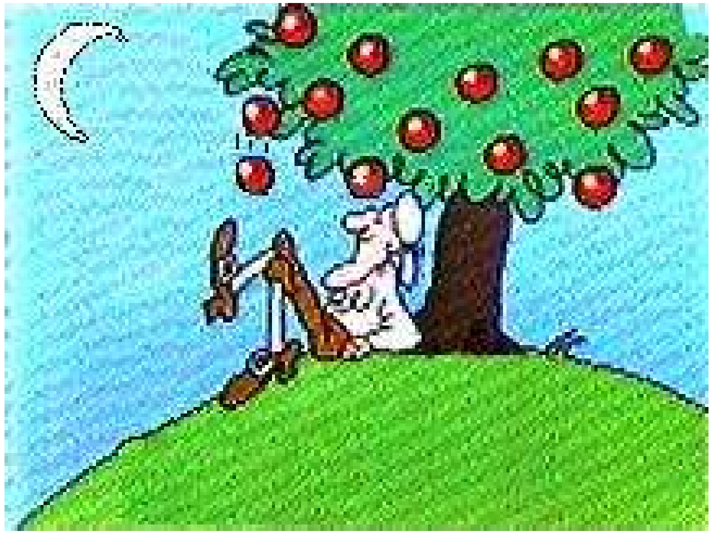
טמפרטורת השפה – 6000 מעלות

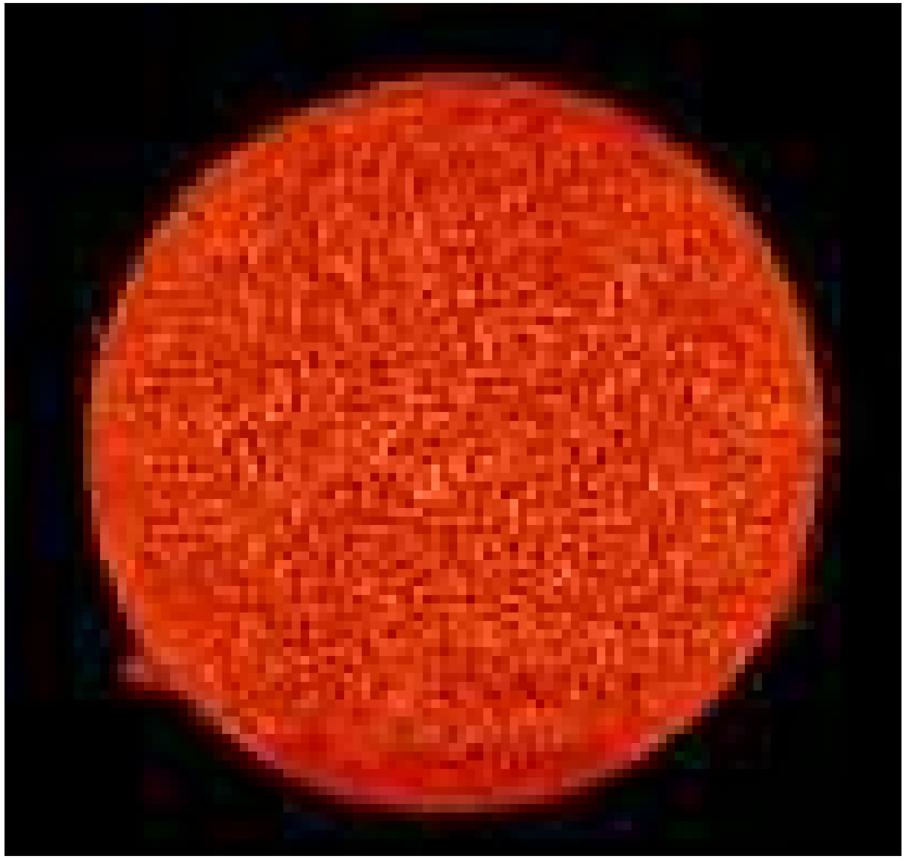
השמש עשויה:

מימן	91.2%
הליום	8.7%
שאר היסודות	0.1%



כדור ענק לוהט של גז מימן והליום





רדיוס השמש = 100 רדיוסי ארץ

מסת השמש = 300,000 מסות ארץ

הקווים הספקטרליים של אטום המימן

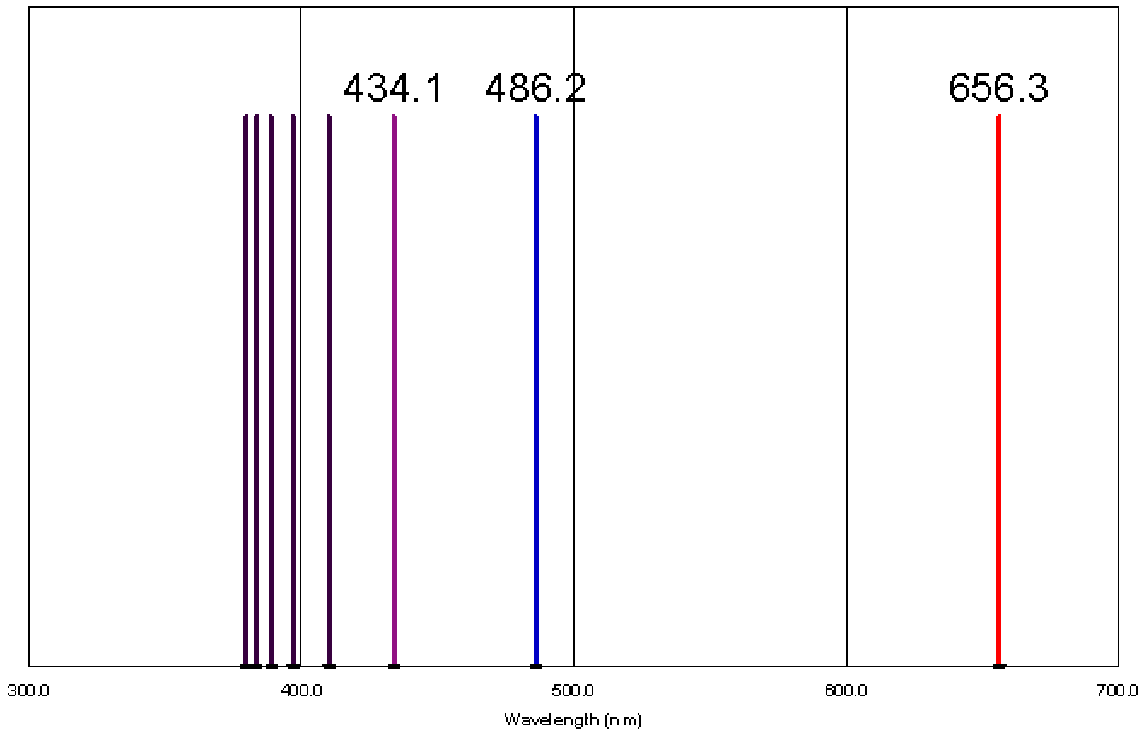
סדרת בלמר

$$H_\alpha = 6563\ \overset{o}{A}$$

$$H_\beta = 4861\ \overset{o}{A}$$

$$H_\gamma = 4340\ \overset{o}{A}$$

$$H_\delta = 4101\ \overset{o}{A}$$



$$H_\infty = 3646\ \overset{o}{A}$$

הקווים הספקטרלים של אטום המימן

סדרת ליימן

$$L_\alpha = 1215\ \overset{o}{A}$$

$$L_\beta = 1025\ \overset{o}{A}$$

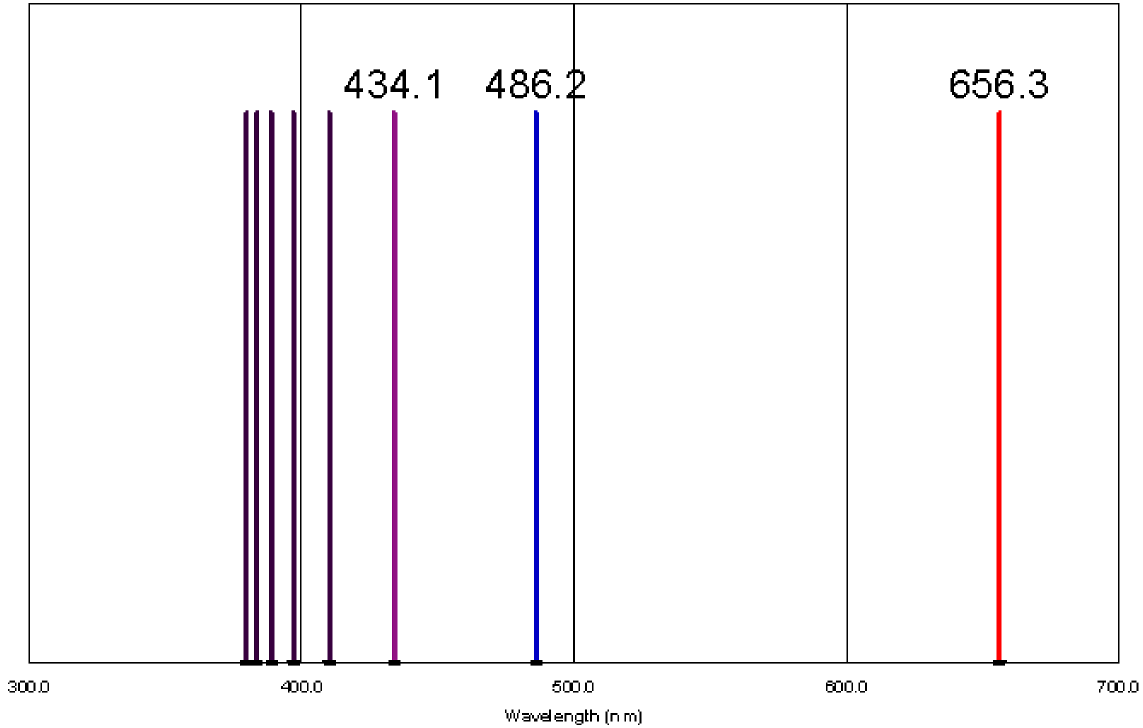
$$L_\gamma = 972\ \overset{o}{A}$$

$$\boxed{L_\infty = 911.5\ \overset{o}{A}}$$

הקווים הספקטרליים של אטום המימן

סדרת בלמר

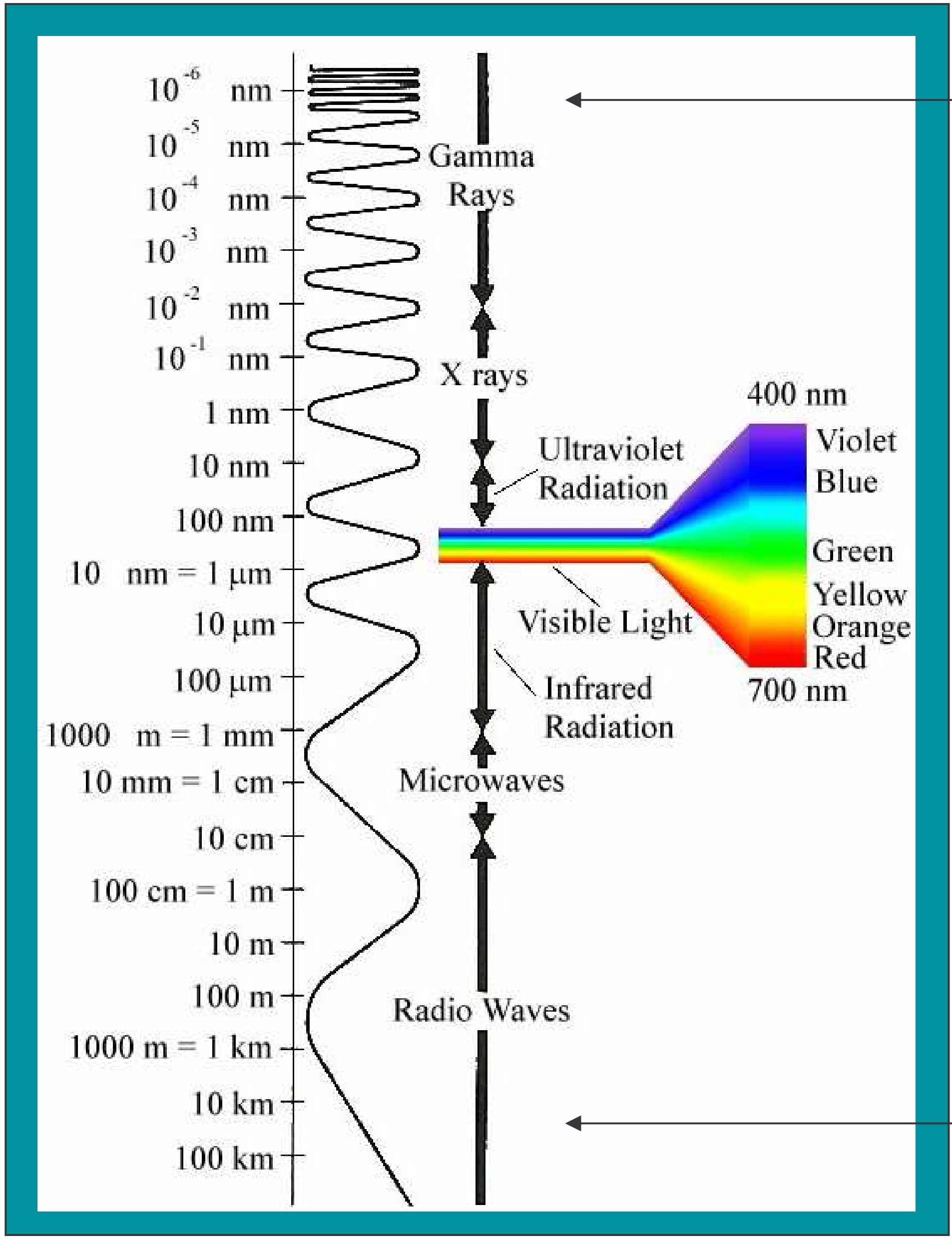
$$\frac{1}{\lambda_n} = A - \frac{B}{n^2}$$



$$\frac{1}{\lambda} = R\left(\frac{1}{2^2} - \frac{1}{n^2}\right)$$

$$R \approx 1.097 \times 10^5\,\mathrm{cm}^{-1}$$

The Electromagnetic Spectrum



Shortest wavelengths
(Most energetic photons)

$$E = h\nu = hc/\lambda$$

h = 6.6x10^{-27} [erg*sec]
(Planck's constant)

Longest wavelengths
(Least energetic photons)

הקווים הספקטרליים של אטום המימן

$$\frac{1}{\lambda_n} = R\left(\frac{1}{1^2} - \frac{1}{n^2}\right) \text{ Lyman}$$

$$\frac{1}{\lambda_n} = R\left(\frac{1}{2^2} - \frac{1}{n^2}\right) \text{ Balmer}$$

$$\frac{1}{\lambda_n} = R\left(\frac{1}{3^2} - \frac{1}{n^2}\right) \text{ Paschen}$$

$$\frac{1}{\lambda_n} = R\left(\frac{1}{4^2} - \frac{1}{n^2}\right) \text{ Brackett}$$

הקווים הספקטרליים של אטום המימן

$$\frac{1}{\lambda_{m,n}} = R\left(\frac{1}{m^2} - \frac{1}{n^2}\right)$$

$$E_{m,n} = \frac{hc}{\lambda_{m,n}} = hcR\left(\frac{1}{m^2} - \frac{1}{n^2}\right) = 13.6\left(\frac{1}{m^2} - \frac{1}{n^2}\right) ev$$

$$E_{m,n} = 13.6\left(\frac{1}{m^2} - \frac{1}{n^2}\right) ev$$

$n > m$

רמות האנרגיה של אטום המימן

$$E_k = -13.6 \frac{1}{k^2} ev$$

$$E_{m,n} = E_n - E_m$$

$$E_{m,n} = 13.6 \left(\frac{1}{m^2} - \frac{1}{n^2} \right) ev$$

n > m

$$\Delta E_{\text{electron}} = \frac{hc}{\lambda} = hcR\left(\frac{1}{n^2} - \frac{1}{m^2}\right)$$

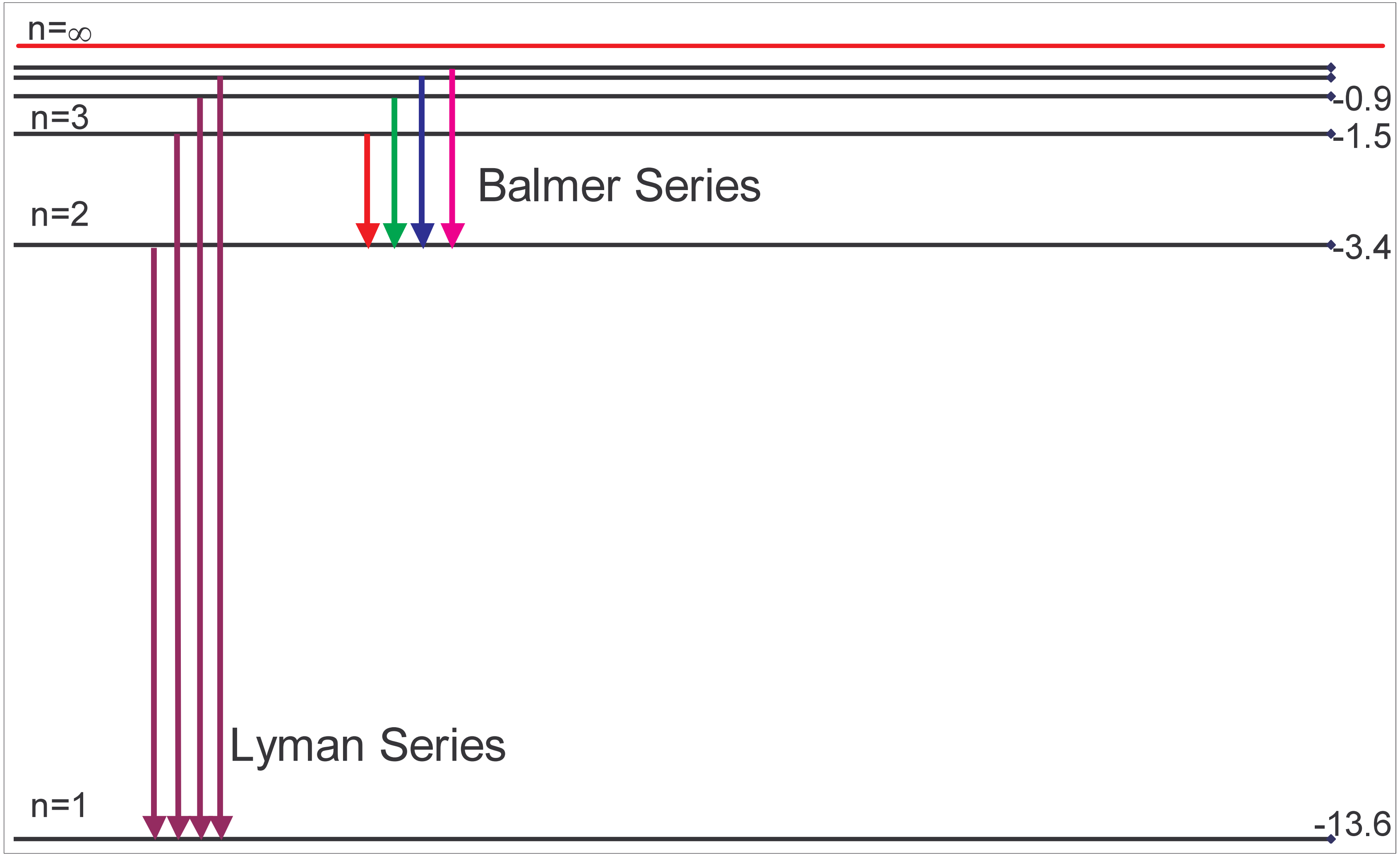
$$hcR = 13.6\ \text{eV}$$

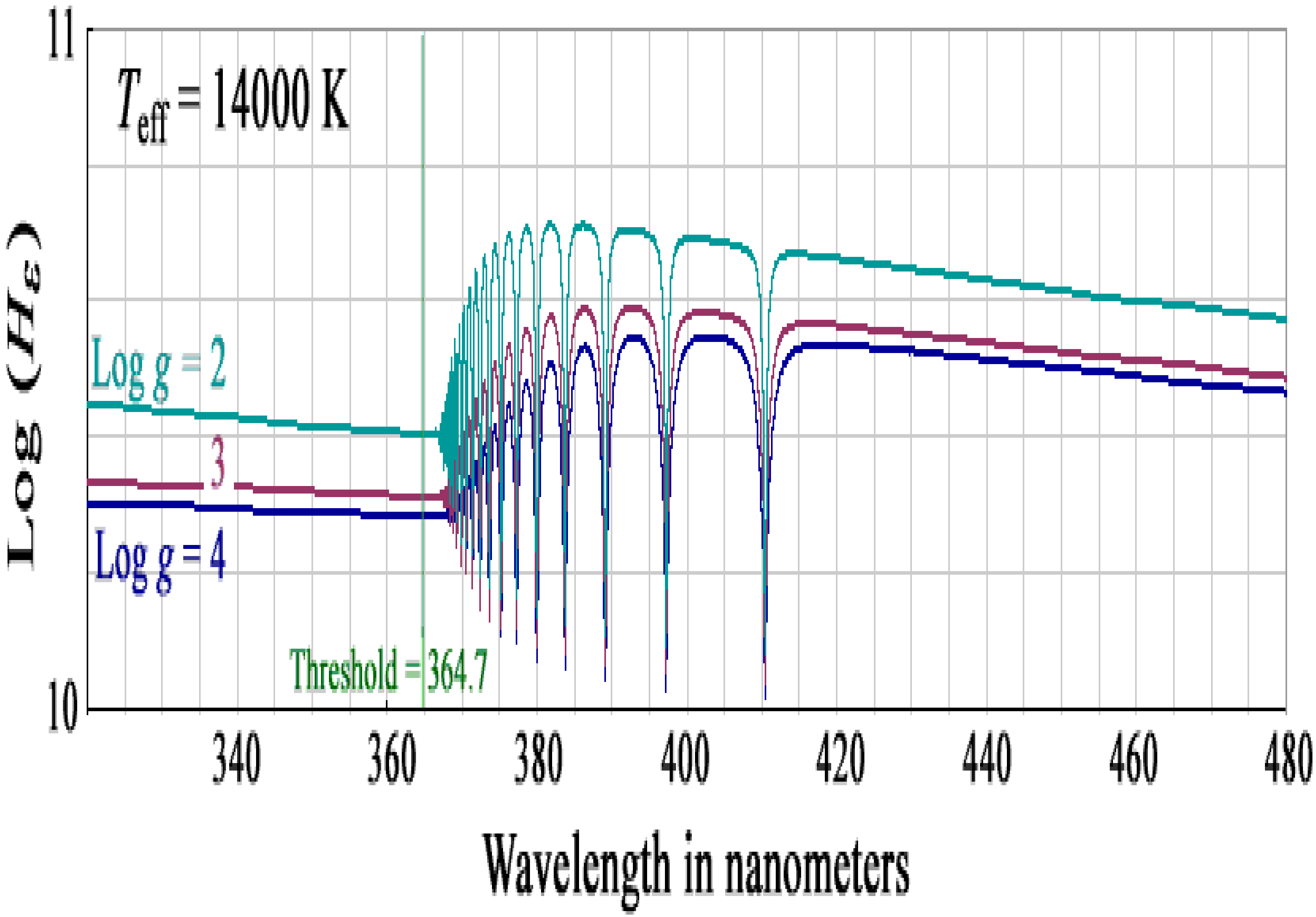
קוונטיזציה של רמות האנרגיה של אטום המימן

פליטה ספונטנית

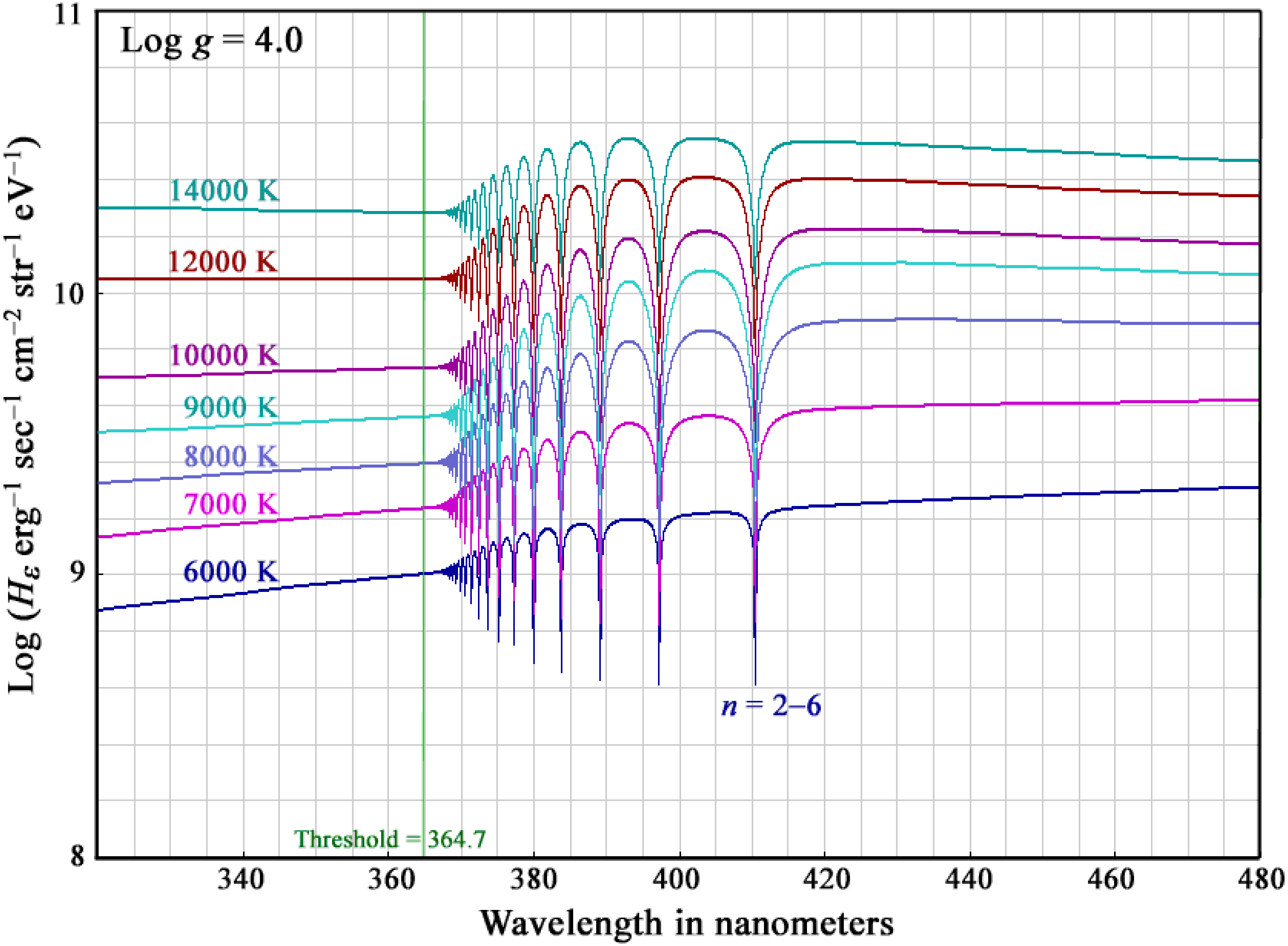
בליעה פוטונים רק עם אנרגיה של מעבר בין רמות

רמות האנרגיה של אטום המימן





T_{eff} = 14000 K
Log g = 2
3
Log g = 4
Threshold = 364.7
Log (H_ε)
Wavelength in nanometers
11
10
340
360
380
400
420
440
460
480


Log g = 4.0
14000 K
12000 K
10000 K
9000 K
8000 K
7000 K
6000 K
n = 2–6
Threshold = 364.7
11
10
9
8
340
360
380
400
420
440
460
480
Log (H_ε erg^-1 sec^-1 cm^-2 str^-1 eV^-1)
Wavelength in nanometers

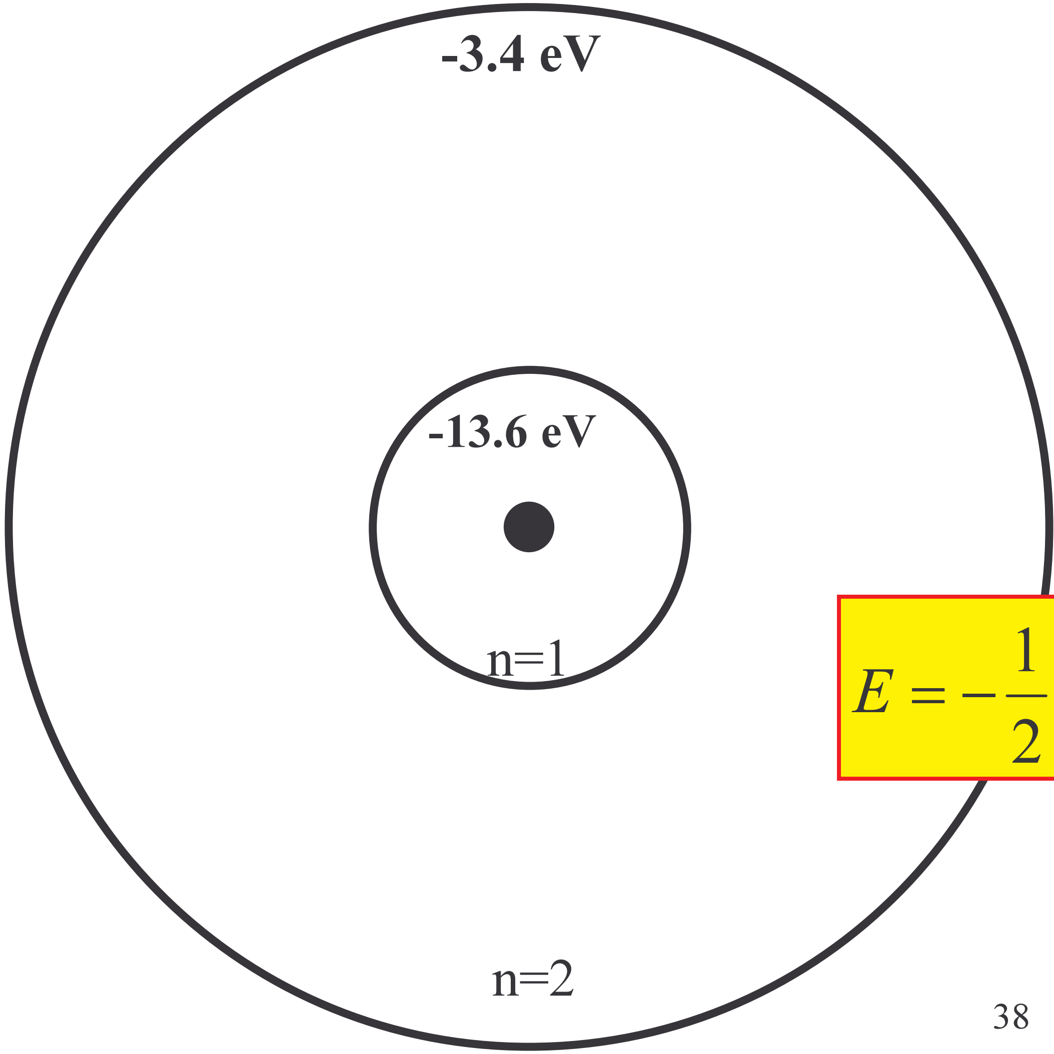
רמות האנרגיה של אטום המימן

$$E_n = -13.6\ \mathrm{eV}\,\frac{1}{\mathrm{n}^2}$$

$$m\frac{v^2}{r} = \frac{e^2}{r^2}$$

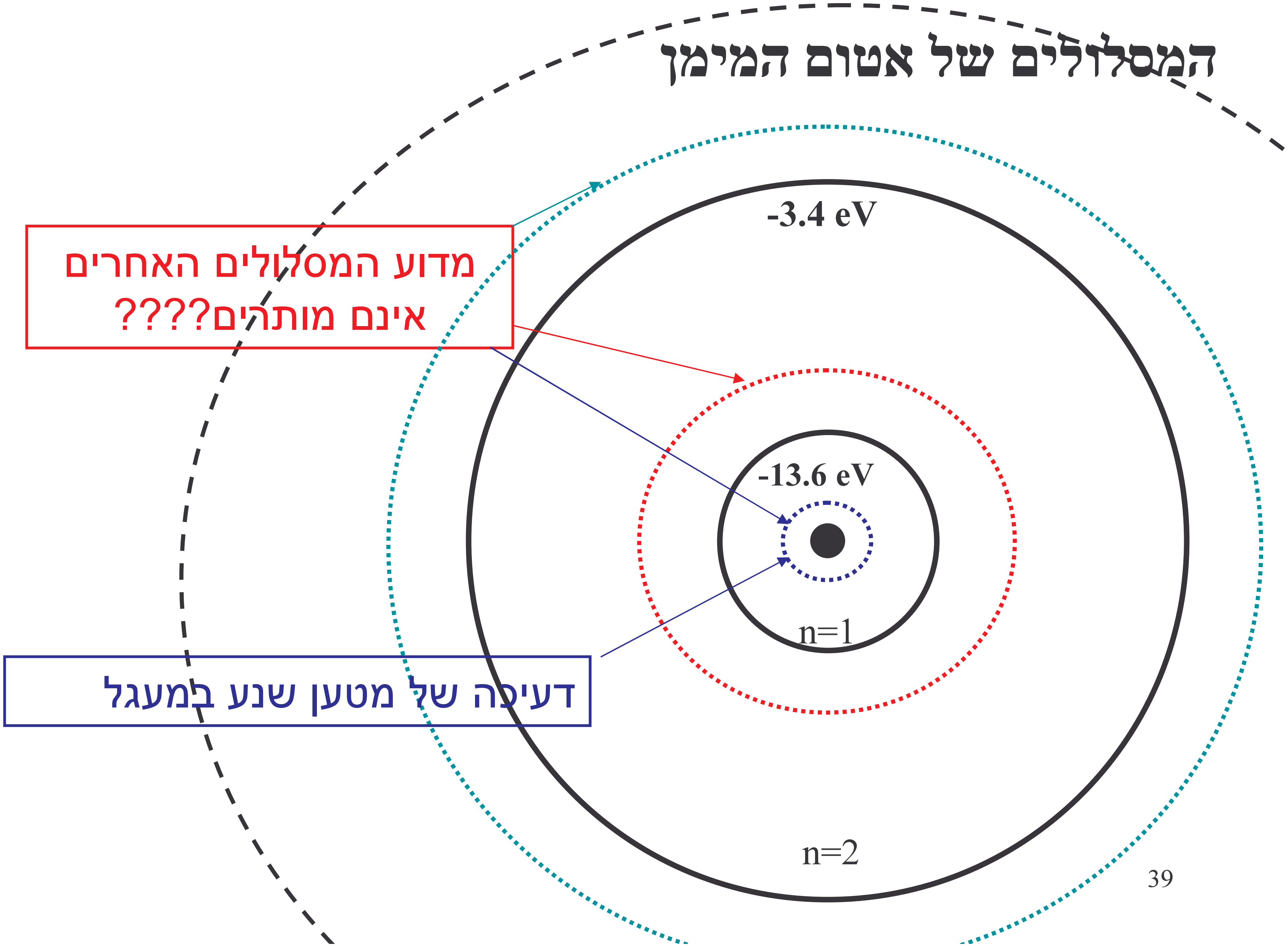
$$mv^2 = \frac{e^2}{r}$$

$$E_{kin} = \frac{1}{2}|U|$$



$$E = -\frac{1}{2}\frac{e^2}{r}$$

המסלולים של אטום המימן



Matter Waves ?

Maurice de Broglie: French experimental physicist, supports Compton's view of particle nature of radiation

Louis de Broglie: Maurice's brother, switches from graduate study in "History of physics", writes a revolutionary thesis

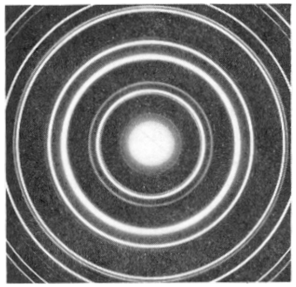
1924: He proposes that the wave-particle duality applies not only to radiation, but also to matter.

That is, just as a photon has light wave associated with it, an electron has an associated matter wave that governs its motion.

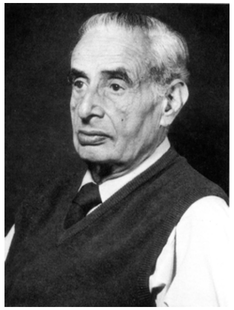
He further proposes that for matter and for radiation alike

$E = h\nu$ and $p = h/\lambda$ ($\lambda = h/p \Leftarrow$ de Broglie relation gives *de Broglie wavelength*

1921-1923: Davisson and Kunsman at Bell labs working on thermionic emission (actually studying electron emission from metal surfaces under electron bombardment) observe electron diffraction, but do not recognize it as such. (Davisson thinks pattern due to crystal structure of the metal).



(recall de Broglie paper wasn't until 1924)



1925: Walter Elsasser (who has read de Broglie's papers) explains Davisson-Kunsman results as electron diffraction – suggests it might be tested in same way as *x*-rays (scattering on a crystal)

1926: Davisson finally hears of de Broglie's ideas and devises (with Germer) definitive experiment to test de Broglie hypothesis:

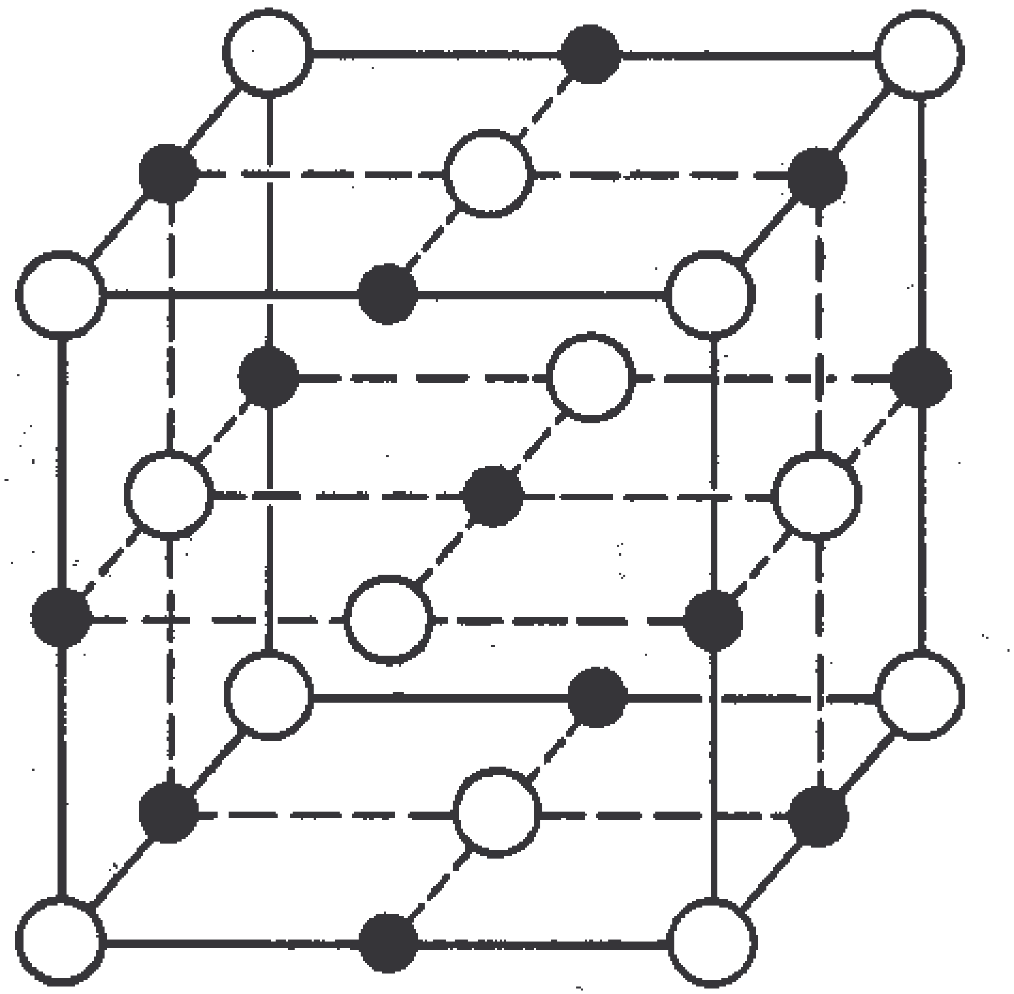
<u>more on Elsasser:</u>

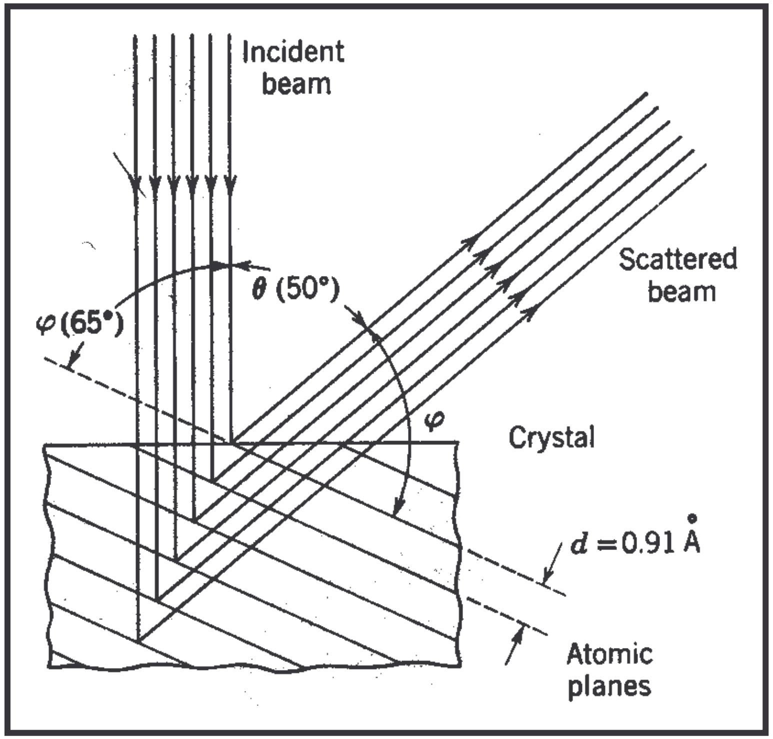
First to recognize the shell structure of atomic nuclei.

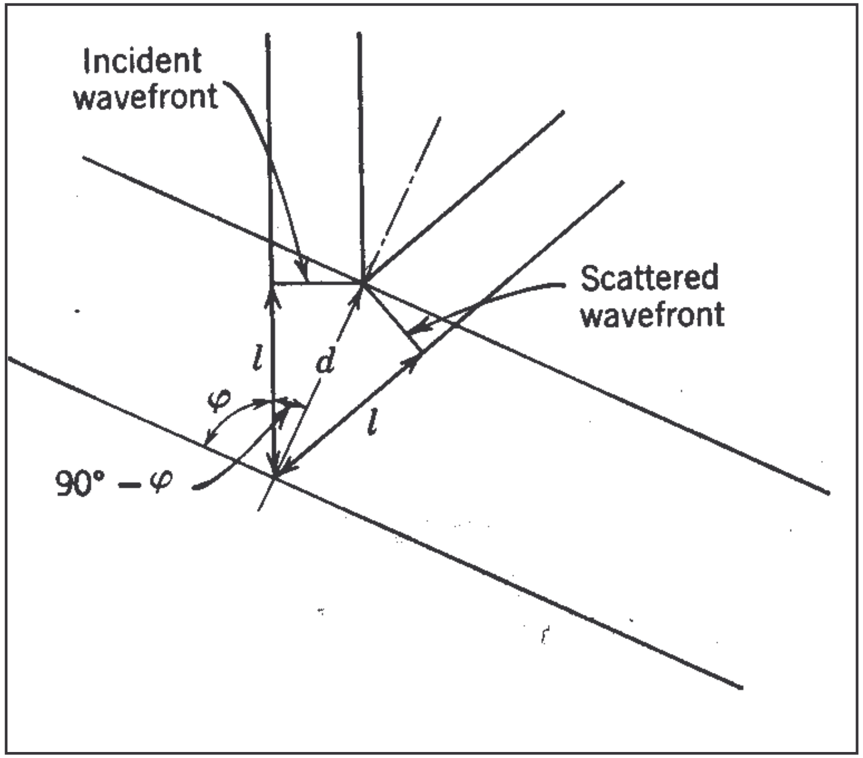
geophysics: provided important insights about the radiative transfer of heat in the atmosphere; fathered the generally accepted dynamo theory of the earth's magnetism.

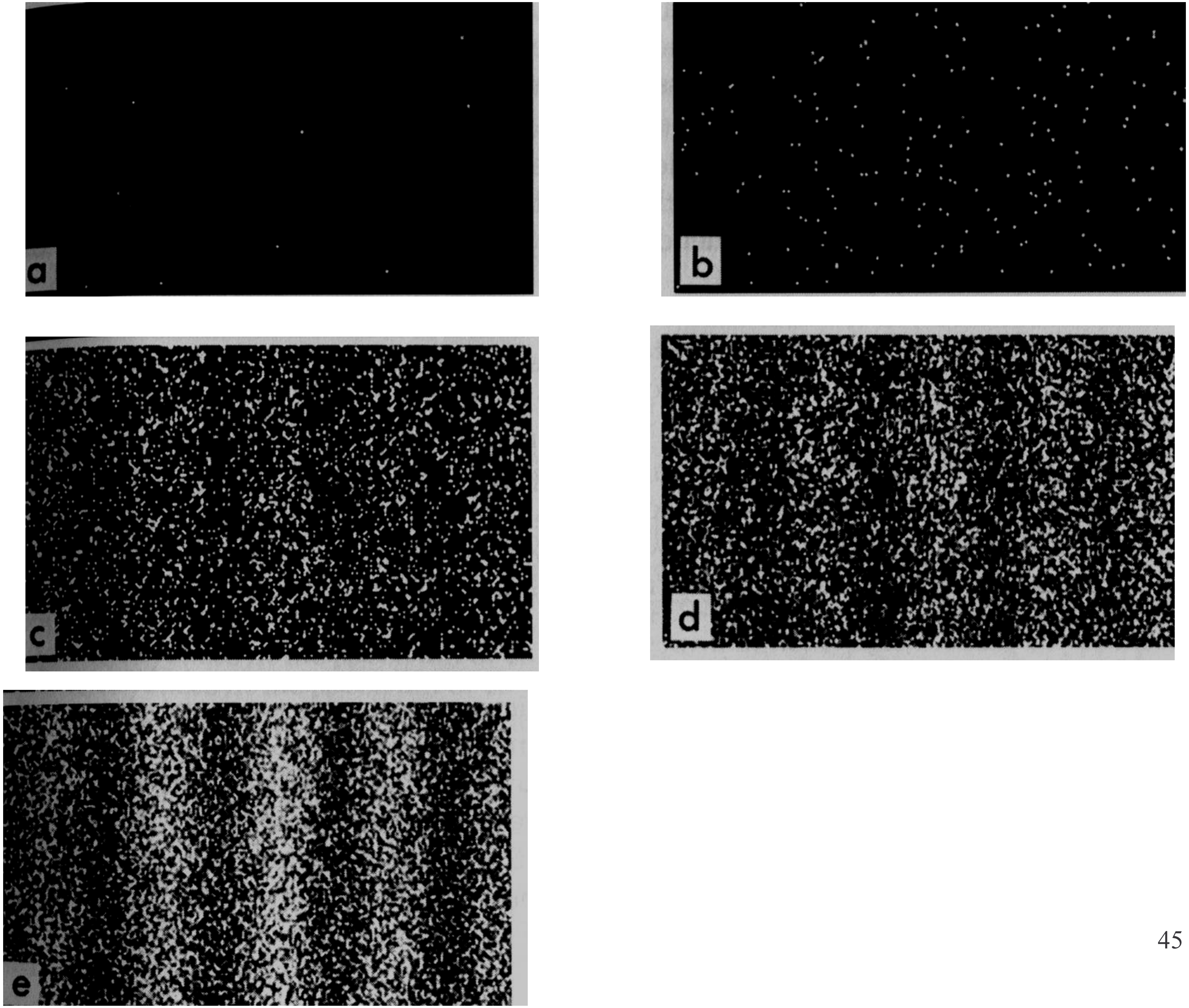
biophysics: last fifty years of his life spent developing a theory of organisms

Davisson-Germer apparatus:

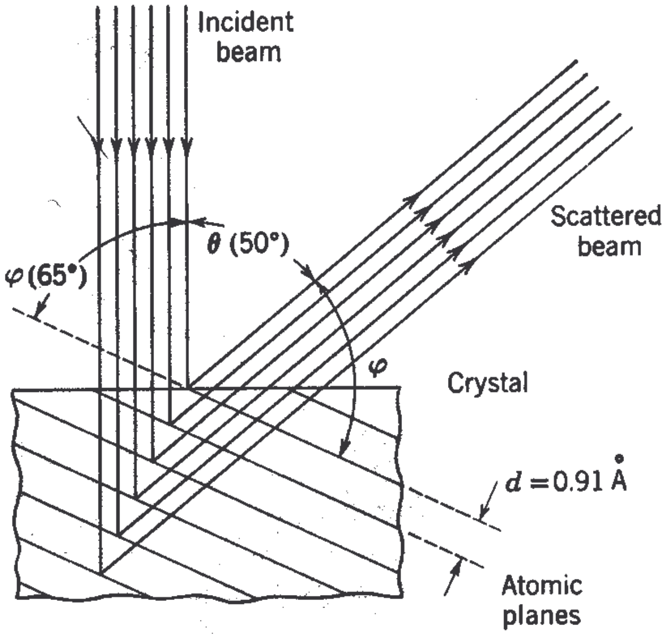


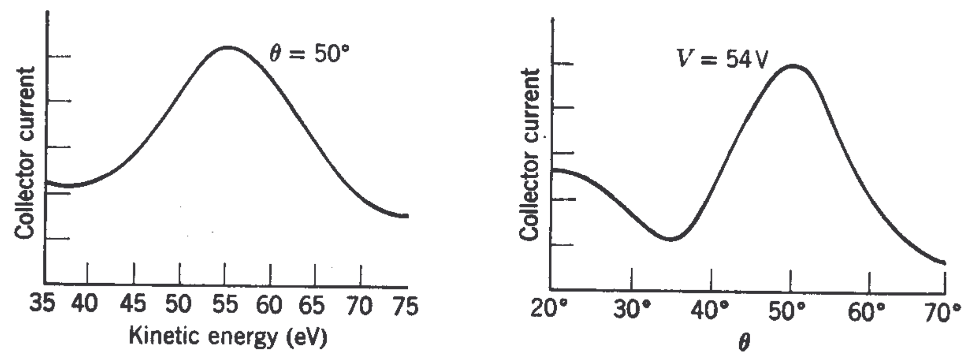

Incident
beam
Scattered
beam
θ (50°)
φ (65°)
φ
Crystal
d = 0.91 Å
Atomic
planes


Incident
wavefront
Scattered
wavefront
l
d
φ
l
90° − φ


a
b
c
d
e

This figure is for 54 eV electrons at 50° for which we have a peak:





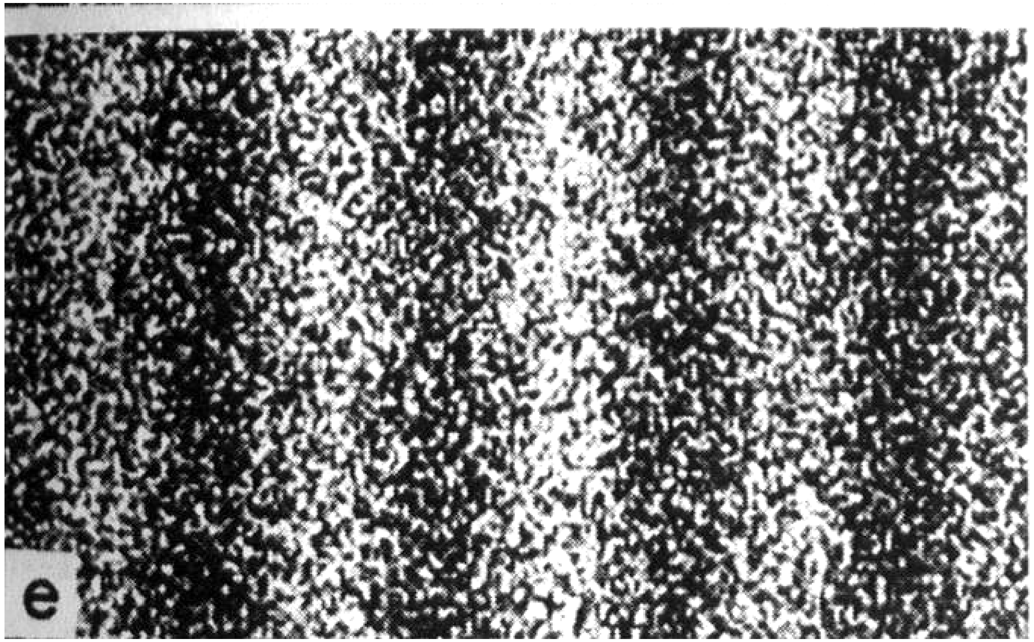
What wavelength do we measure ?
(recall $n\lambda = 2d\sin\phi$) $\lambda = 1.65$ Å

What de Broglie wavelength do we expect for 54 eV electrons ?

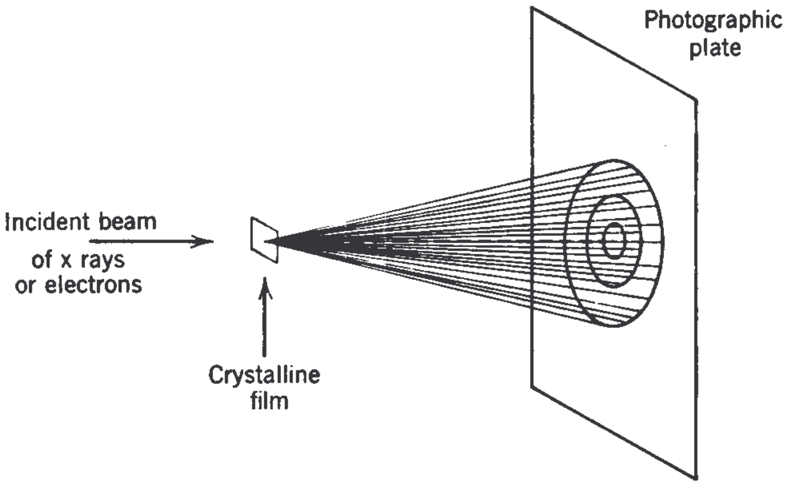
$\lambda = h/p = 1.65$ Å (using p value from Example 3-1)

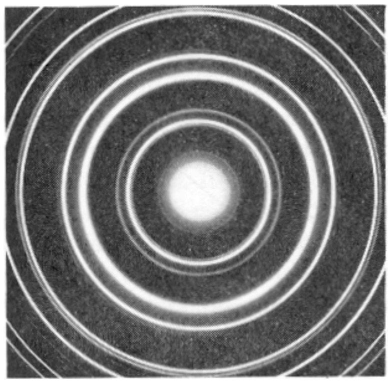
Let's look more closely at the dependence on electron energy (eV_0).

Start by asking: What is the relationship between λ and V_0 ?


e

1927: G. P. Thompson (son of JJ) sends a beam of higher energy electrons through a thin crystalline film





Where are all these lines coming from ?

And why is there such a variation in intensity ?

Key point: Interference is <u>NOT</u> between waves associated with one electron and waves associated with another. Interference is between different parts of the wave associated with a <u>SINGLE</u> electron that have been scattered from various regions of the crystal.

How would you verify this experimentally ?

Reduce electron beam intensity until it is so low that electrons are going through one at at time.

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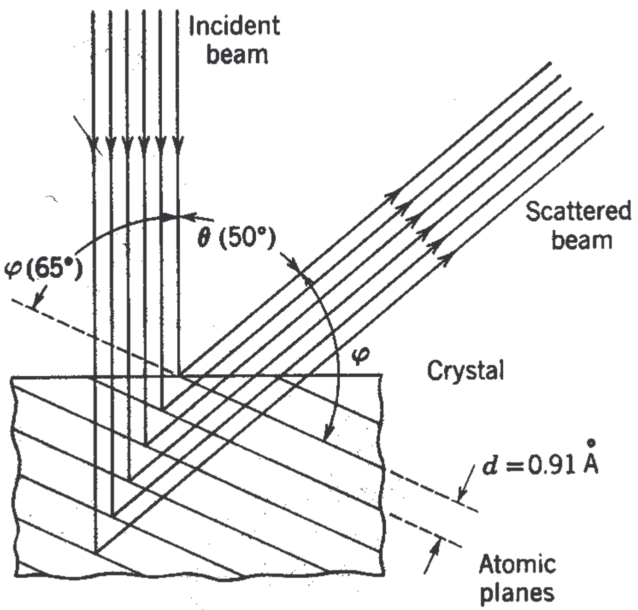
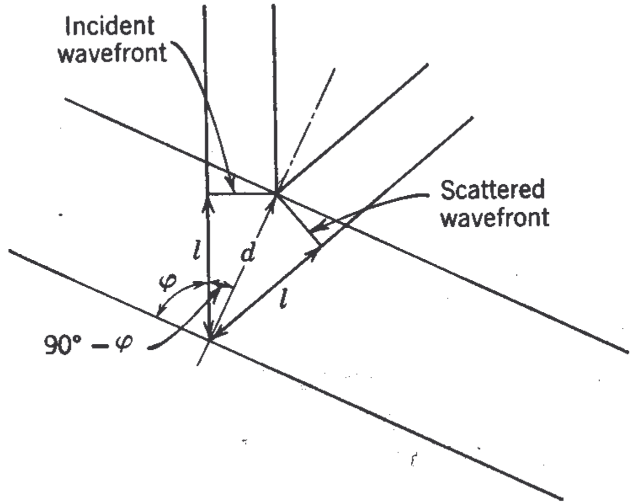
process is analogous to Bragg scattering of *x*-rays



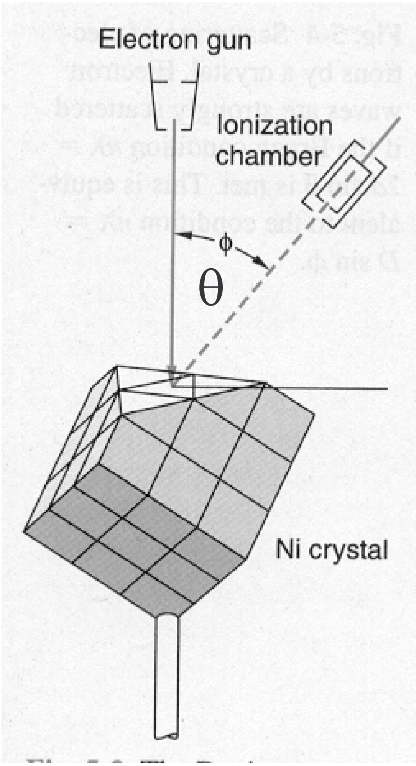


constructive interference if

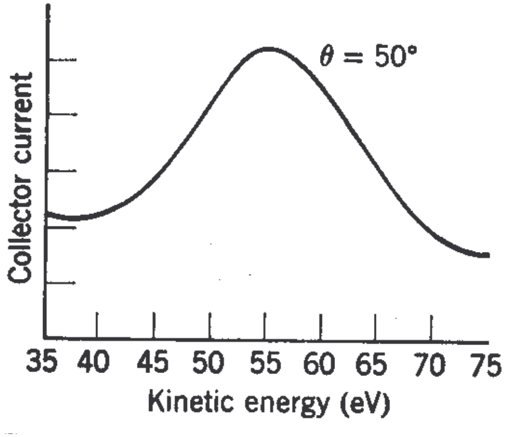
$n\lambda = 2d\sin\phi$

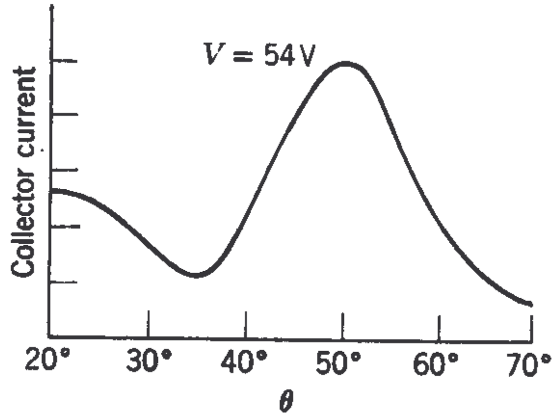
(Bragg relation)

Davisson-Germer apparatus:



Look at intensity as a function of electron kinetic energy (eV) and θ





How do we explain these peaks ?

Constructive interference of waves scattered by the periodic arrangement of atoms into planes of the crystal

Demonstration of de Broglie's hypothesis!

Send matter particles through small aperture and look for diffraction ($\lambda/a \sim 1$)

What kind of matter particles would be best ?

A particle with the largest possible wavelength, baseball is no good, maybe electron

Clearly, the smaller the aperture, the better – back in the 1920s, the smallest aperture available to experimenters was ~ 1 Å.
Any idea how they achieve such small apertures ?

Spacing between adjacent planes of atoms in a solid