Welcome to 3.091

Lecture 3

September 14, 2009

Atomic Models: Rutherford & Bohr

Periodic Table Quiz

1																	2
3	4											5	6	7	8	9	10
11	12											13	14	15	16	17	18
19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54
55	56	57	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86
87	88	89															

Name ____________ Grade ______ /10

La	Lazy
Ce	college
Pr	professors
Nd	never
Pm	produce
Sm	sufficiently
Eu	educated
Gd	graduates
Tb	to
Dy	dramatically
Ho	help
Er	executives
Tm	trim
Yb	yearly
Lu	losses.

La	Loony
Ce	chemistry
Pr	professor
Nd	needs
Pm	partner:
Sm	seeking
Eu	educated
Gd	graduate
Tb	to
Dy	develop
Ho	hazardous
Er	experiments
Tm	testing
Yb	young
Lu	lab assistants.

cannot be referring to 3.091!

must be the “other” chemistry professor

57

138.9055	57
920	
3455	3
6.146	La
1.10	
5.577	
[Xe]$5d^16s^2$	
Lanthanum	

CEase not I to slave, back breaking to tend;
PRideless and bootless stoking hearth and fire.
No Dream of mine own precious time to spend
Pour'ed More to sate your glutt'nous desire.
SMelting anew my ten-thousandth hour
EUtopia forever I eschew.
Growing Dimmer is my fleeing power
To Bid these curs'ed problem sets adieu.
DYing away whilst thy hosts are fought
HOpeless I come should in lecture I doze.
ERgo, like a sad slave, stay and rest nought.
Then Must I tool and toil while fatigue grows.
Yet, Bloody though I must be, and quite ill
Light the Universal abyss I will.

The Structure of the Atom

status report *ca.* end of the 19th century

* atom is electrically neutral

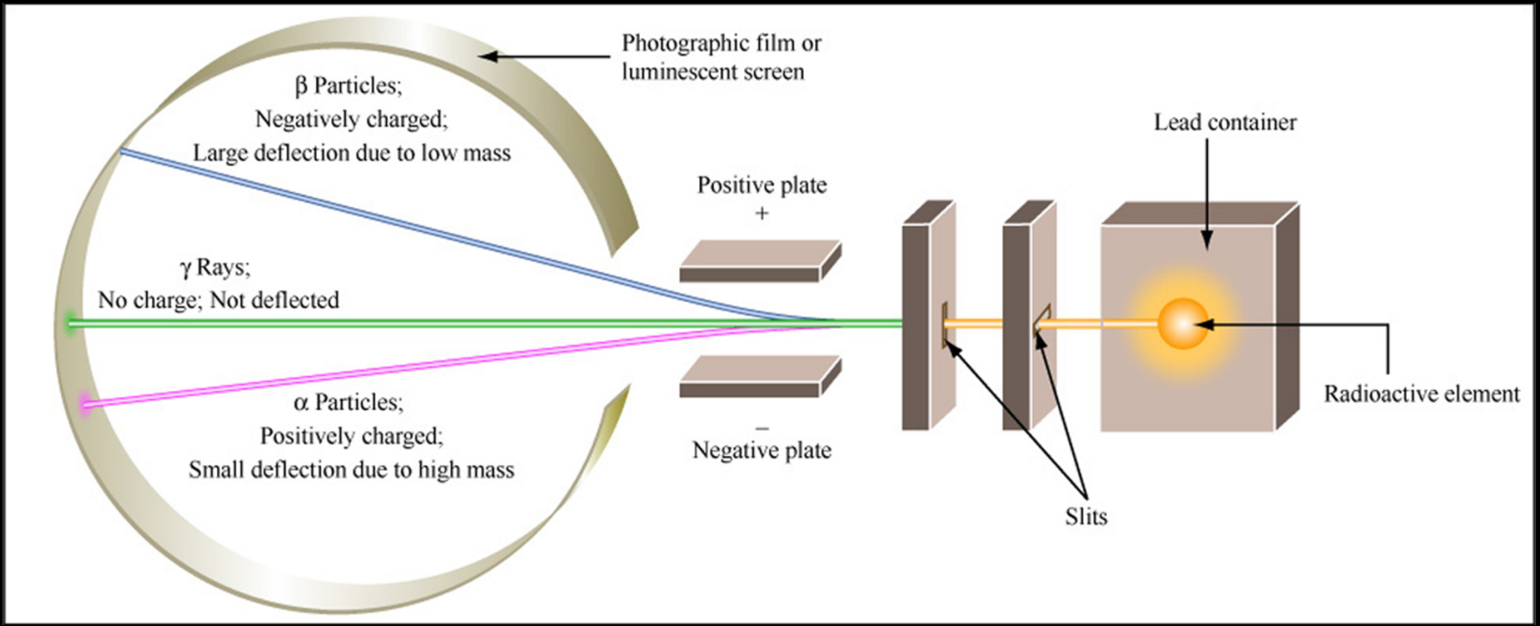
* -ve charge carried by electrons

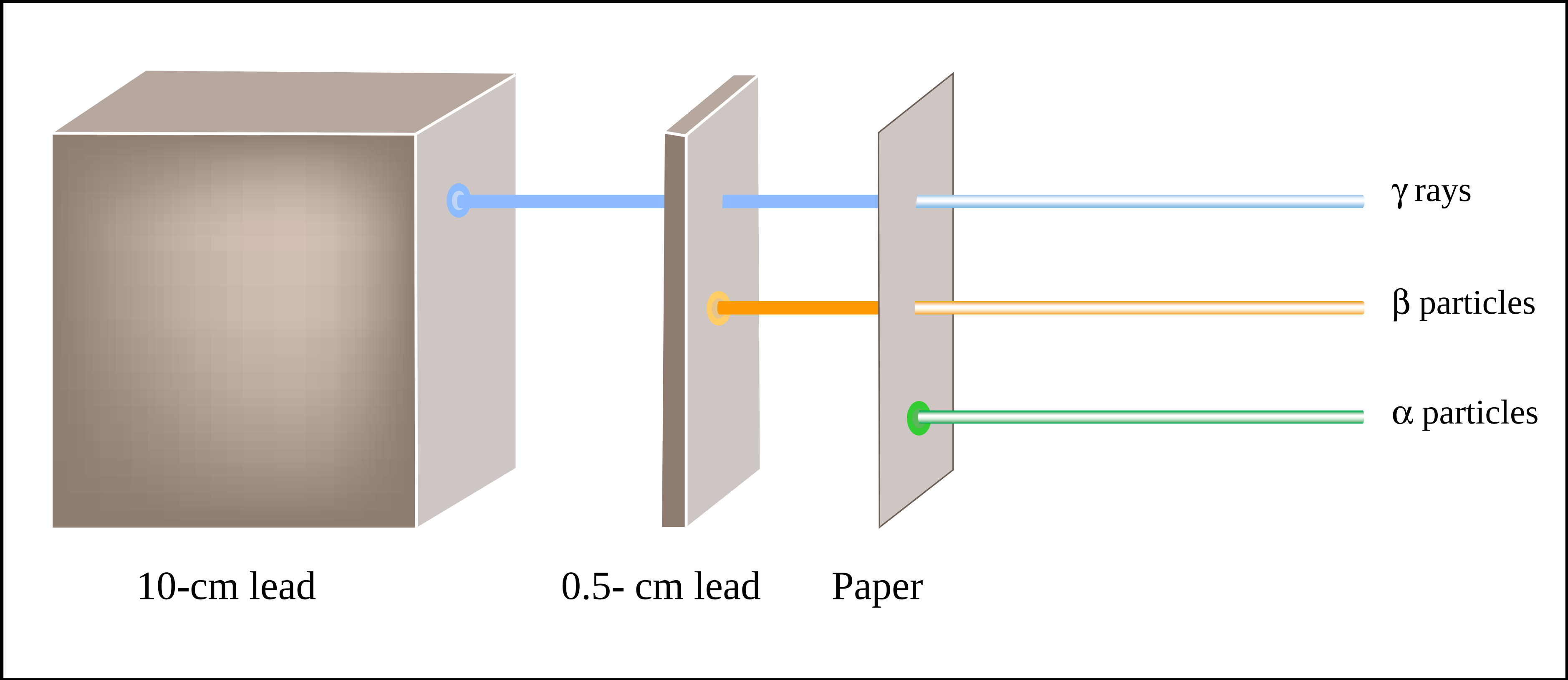
* e^- has very small mass

➪ bulk of the atom is +ve,

➪ most mass resides in +ve charge

Question:
what is the spatial distribution of charge inside an atom?


Photographic film or
luminescent screen
β Particles;
Negatively charged;
Large deflection due to low mass
Lead container
Positive plate
+
γ Rays;
No charge; Not deflected
Radioactive element
α Particles;
Positively charged;
Small deflection due to high mass
–
Negative plate
Slits


γ rays
β particles
α particles
10-cm lead
0.5- cm lead
Paper

Rutherford-Geiger-Marsden experiment

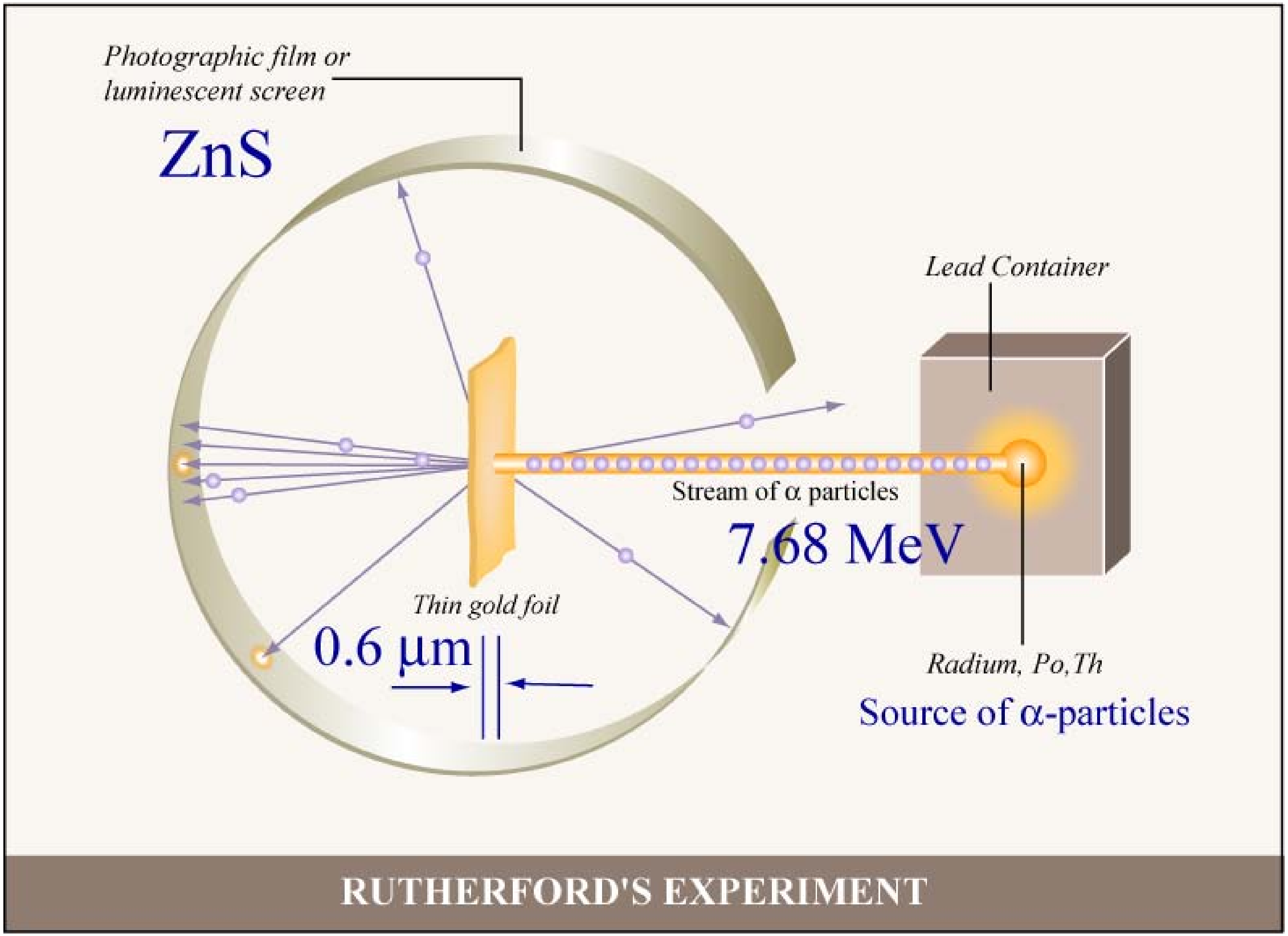
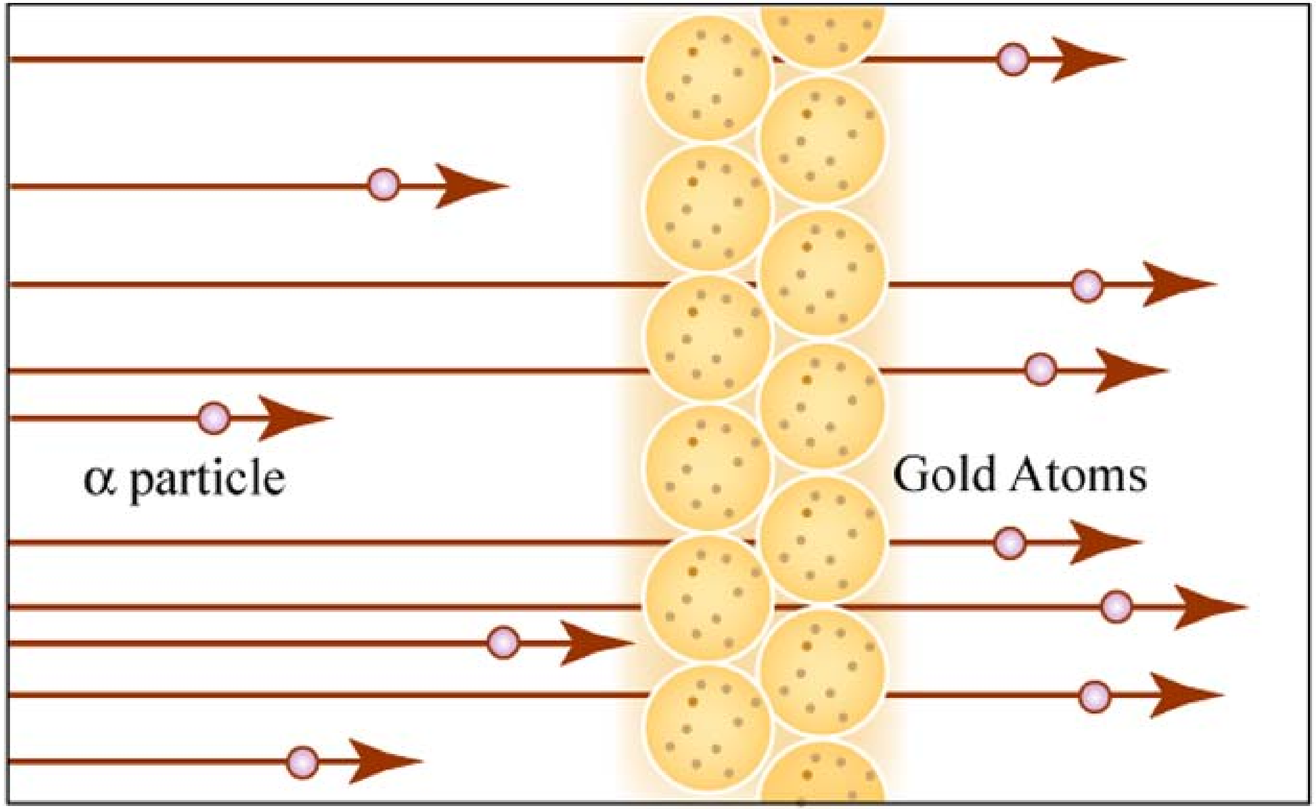
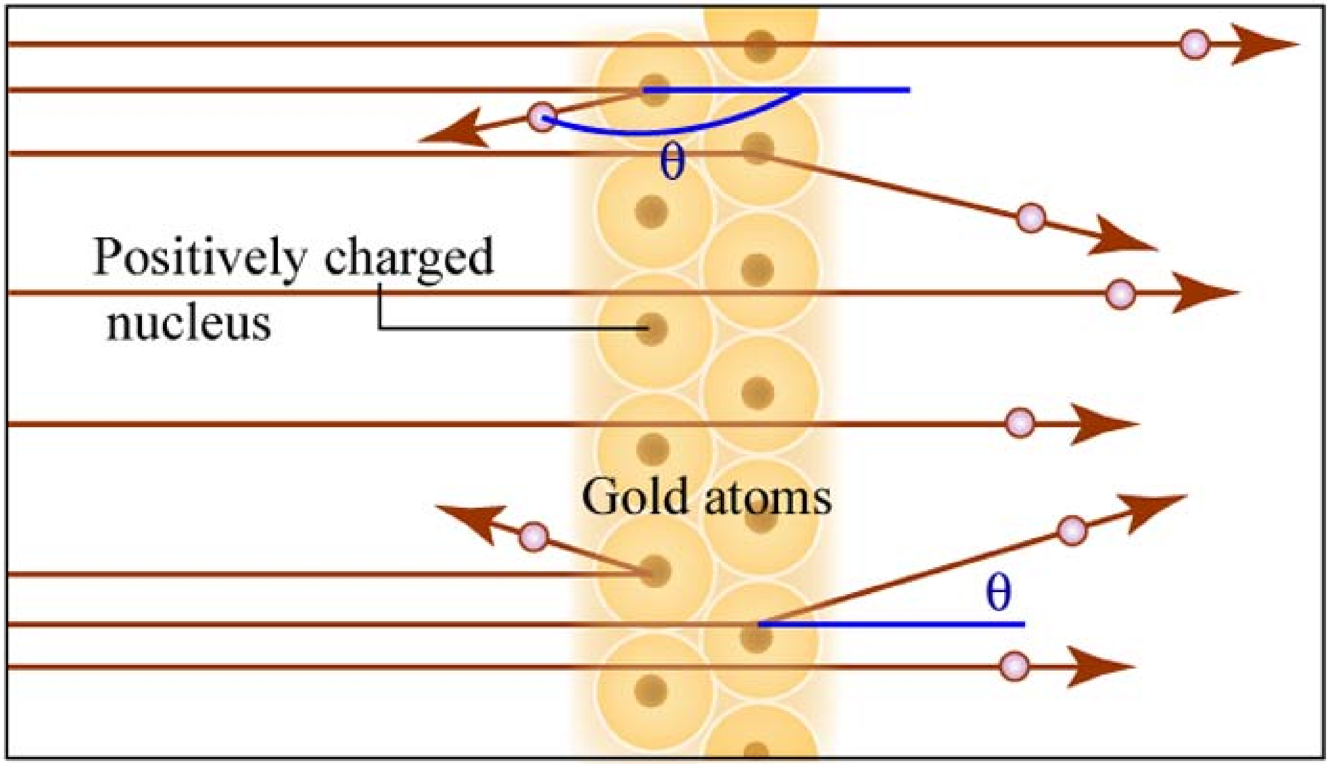


Image by MIT OpenCourseWare.

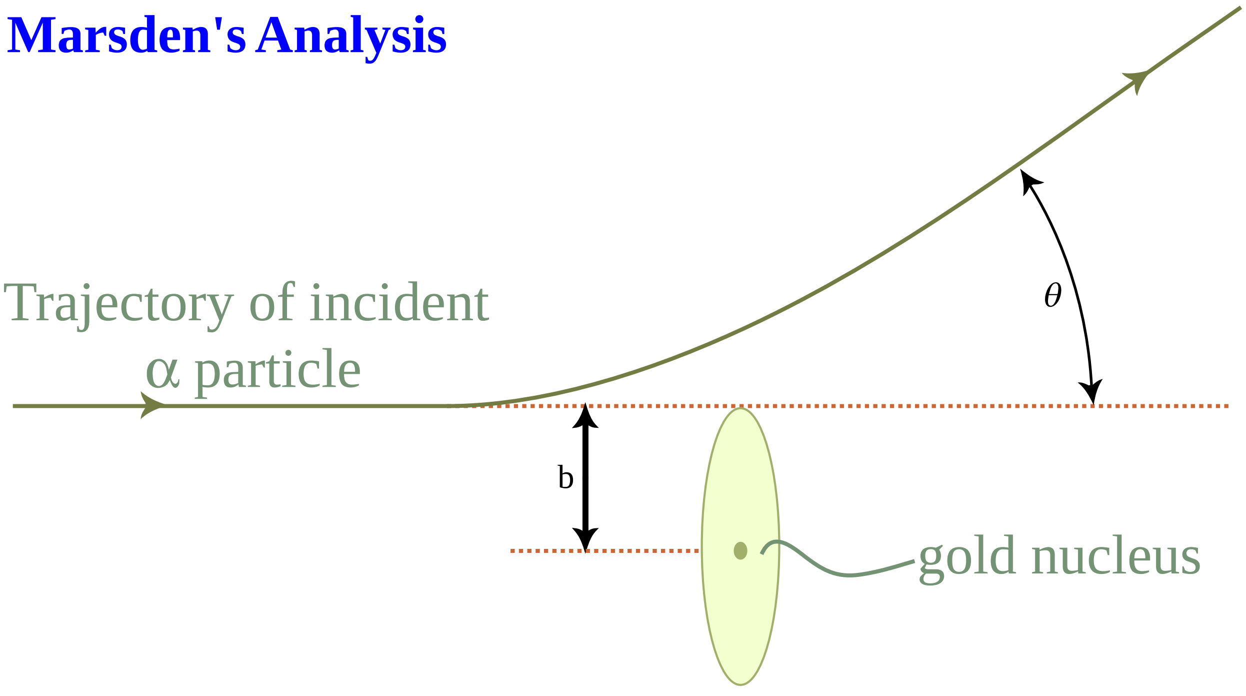


(B) What Rutherford expected if Thomoson's model were correct



(C) What Rutherford actually observed.

Marsden's Analysis



Scattering of an α-particle which approaches a heavy nucleus with an impact parameter b.

Image by MIT OpenCourseWare.

principles of modern chemistry:

* recognize patterns

* develop a quantitative model that
  - explains our observations
  - makes predictions that can be tested by experiment

THE

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PHILOSOPHICAL MAGAZINE

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[SIXTH SERIES.]

JULY 1913.

I. *On the Constitution of Atoms and Molecules.*

By N. Bohr, *Dr. phil. Copenhagen*.*

Introduction.

In order to explain the results of experiments on scattering of α rays by matter Prof. Rutherford† has given a theory of the structure of atoms. According to this theory, the atoms consist of a positively charged nucleus surrounded by a system of electrons kept together by attractive forces from the nucleus; the total negative charge of the electrons is equal to the positive charge of the nucleus. Further, the nucleus is assumed to be the seat of the essential part of the mass of the atom, and to have linear dimensions exceedingly small compared with the linear dimensions of the whole atom. The number of electrons in an atom is deduced to be approximately equal to half the atomic weight. Great interest is to be attributed to this atom-model; for, as Rutherford has shown, the assumption of the existence of nuclei, as those in question, seems to be necessary in order to account for the results of the experiments on large angle scattering of the α rays‡.

In an attempt to explain some of the properties of matter on the basis of this atom-model we meet, however, with difficulties of a serious nature arising from the apparent

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† E. Rutherford, Phil. Mag. xxi. p. 669 (1911).
‡ See also Geiger and Marsden, Phil. Mag. April 1913.

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instability of the system of electrons: difficulties purposely avoided in atom-models previously considered, for instance, in the one proposed by Sir J. J. Thomson*. According to the theory of the latter the atom consists of a sphere of uniform positive electrification, inside which the electrons move in circular orbits.

The principal difference between the atom-models proposed by Thomson and Rutherford consists in the circumstance that the forces acting on the electrons in the atom-model of Thomson allow of certain configurations and motions of the electrons for which the system is in a stable equilibrium; such configurations, however, apparently do not exist for the second atom-model. The nature of the difference in question will perhaps be most clearly seen by noticing that among the quantities characterizing the first atom a quantity appears—the radius of the positive sphere—of dimensions of a length and of the same order of magnitude as the linear extension of the atom, while such a length does not appear among the quantities characterizing the second atom, viz. the charges and masses of the electrons and the positive nucleus; nor can it be determined solely by help of the latter quantities.

The way of considering a problem of this kind has, however, undergone essential alterations in recent years owing to the development of the theory of the energy radiation, and the direct affirmation of the new assumptions introduced in this theory, found by experiments on very different phenomena such as specific heats, photoelectric effect, Röntgen-rays, &c. The result of the discussion of these questions seems to be a general acknowledgment of the inadequacy of the classical electrodynamics in describing the behaviour of systems of atomic size†. Whatever the alteration in the

Bohr Postulates for the Hydrogen Atom

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1. Rutherford atom is correct
2. Classical EM theory not applicable to orbiting e^-
3. Newtonian mechanics applicable to orbiting e^-
4. $E_{\text{electron}} = \text{E}_{\text{kinetic}} + E_{\text{potential}}$
5. e^- energy quantized through its angular momentum:

   $L = mvr = nh/2\pi, \quad n = 1, 2, 3, \ldots$

6. Planck-Einstein relation applies to e^- transitions:

   $\Delta E = E_{\text{f}} - E_{\text{i}} = h\nu = hc/\lambda$

   $$c = \nu\lambda$$

	Quantity	Symbol	Value	Units (SI)
1	Speed of light in vacuum	c	299 792 458	$m\ s^{-1}$
2	Permeability of vacuum	μ_0	$4\pi \times 10^{-7}$	$N\ A^{-2}$
3	Permittivity of vacuum	$\varepsilon_0 = 1/\mu_0 c^2$	$8.854\ 187\ 817... \times 10^{-12}$	$F\ m^{-1}$
4	Newtonian constant of gravitation	G	$6.672\ 59(85) \times 10^{-11}$	$m^3\ kg^{-1}\ s^{-2}$
5	Planck constant	h	$6.626\ 075\ 5(40) \times 10^{-34}$	Js
6	h-bar	$\hbar = h/2\pi$	$1.054\ 572\ 66(63) \times 10^{-34}$	Js
7	Elementary charge	e	$1.602\ 177\ 33(49) \times 10^{-19}$	C
8	Electron mass	m_e	$9.109\ 389\ 7(54) \times 10^{-31}$	kg
9	Proton mass	m_p	$1.672\ 623\ 1(10) \times 10^{-27}$	kg
10	Neutron mass	m_n	$1.674\ 928\ 6(10) \times 10^{-27}$	kg
11	Avogadro constant	N_A, L	$6.022\ 136\ 7(36) \times 10^{23}$	mol^{-1}
12	Atomic mass constant	m_u	$1.660\ 540\ 2(10) \times 10^{-27}$	kg
13	Molar gas constant	R	8.314 510(70)	$J\ mol^{-1}\ K^{-1}$
14	Boltzmann constant	$k = R/N_A$	$1.380\ 658(12) \times 10^{-23}$	$J\ K^{-1}$
15	Molar volume (ideal gas), STP	V_m	0.022 414 10(19)	$m^3\ mol^{-1}$
16	Faraday constant	$F = N_A e$	96 485.309(29)	$C\ mol^{-1}$

Image by MIT OpenCourseWare.

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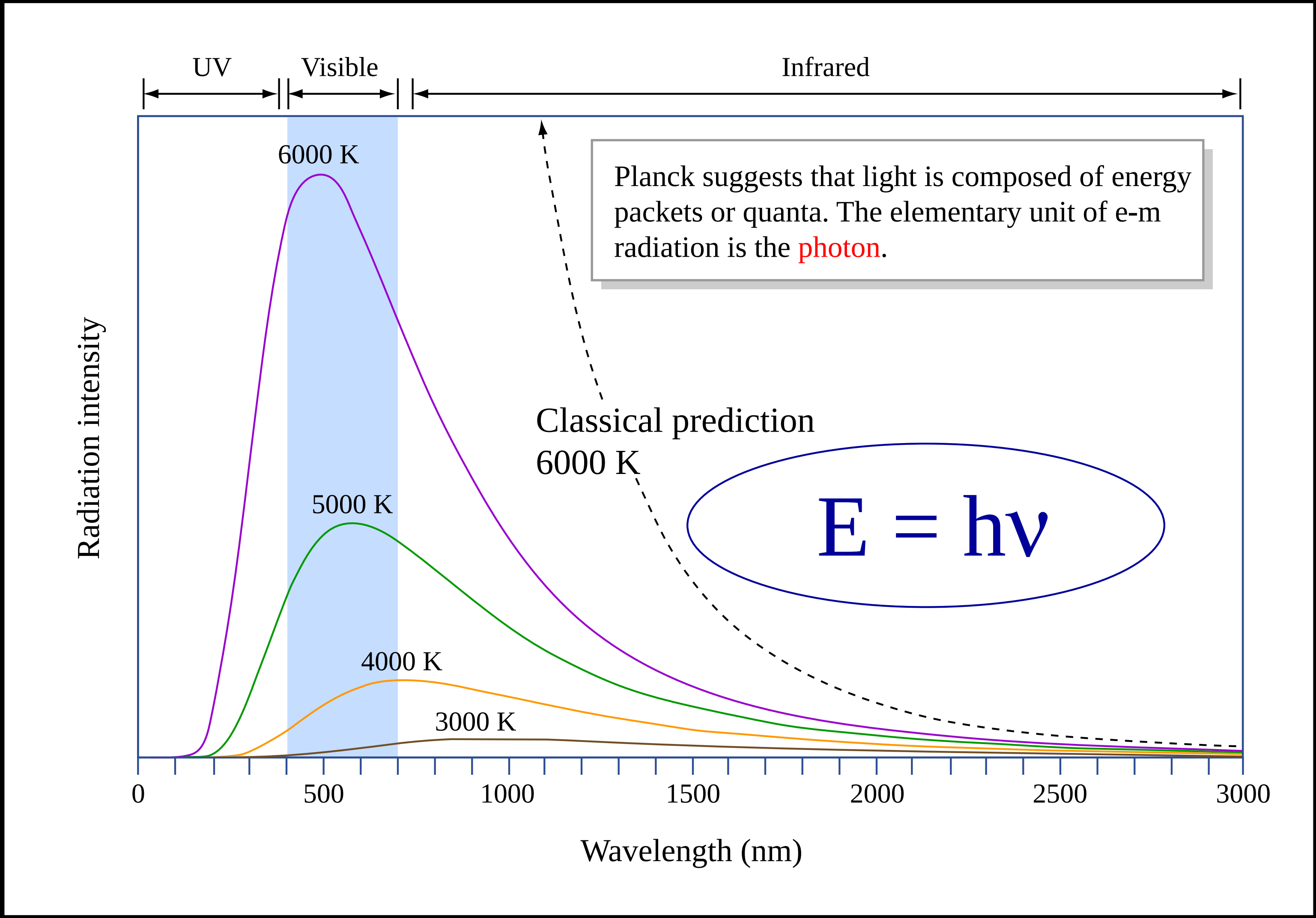
UV
Visible
Infrared
6000 K
5000 K
4000 K
3000 K
Planck suggests that light is composed of energy packets or quanta. The elementary unit of e-m radiation is the photon.
Classical prediction
6000 K
E = hν
Radiation intensity
0
500
1000
1500
2000
2500
3000
Wavelength (nm)

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179820K
A0972K
500
FEM HUNDREDE
KRONER
DANMARKS NATIONALBANK
NIELS BOHR
500
FEM HUNDREDE KRONER

Fig. 18.10. NIELS BOHR.
(Courtesy of the Edgar Fahs Smith Collection.)

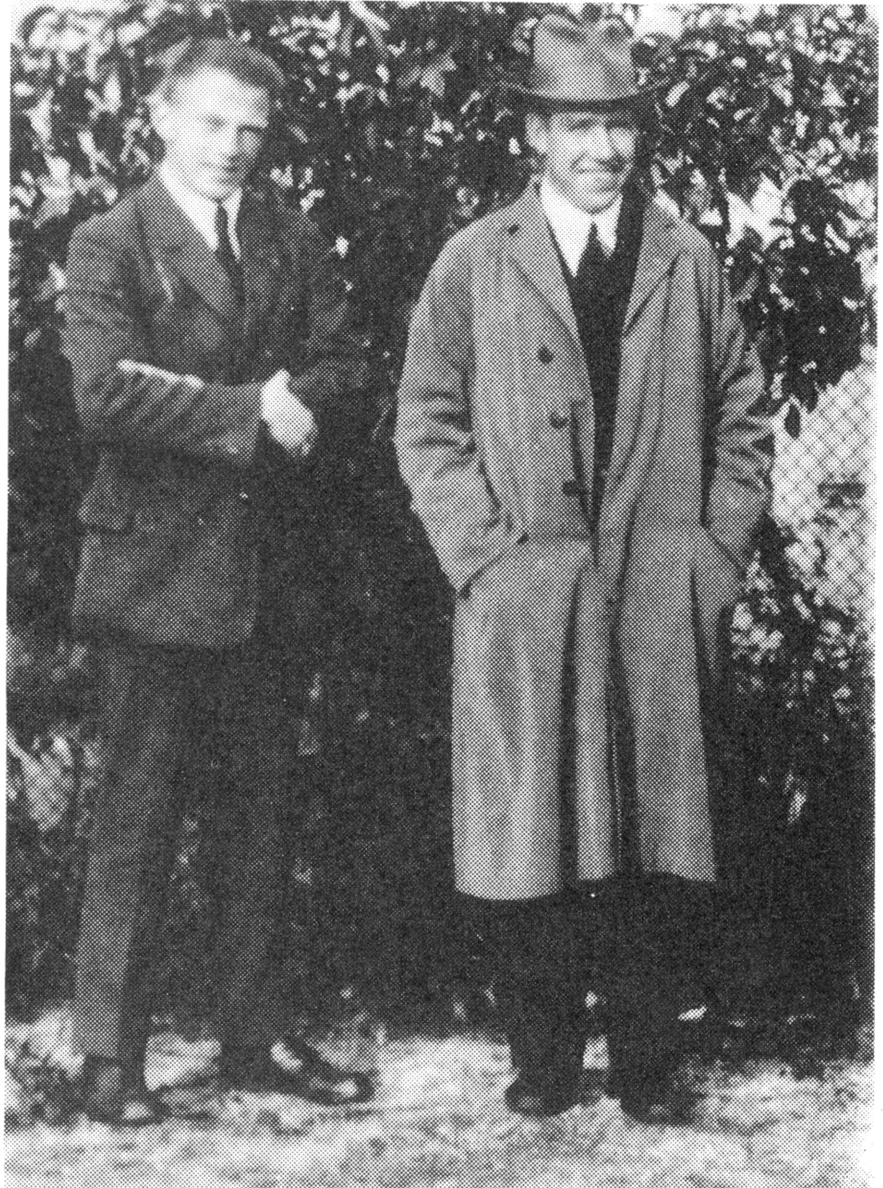


Plate 6 Niels Bohr and Werner Heisenberg, *ca.* 1925. (Niels Bohr Archive.)

Plate 7 Niels Bohr and Albert Einstein in Brussels, October 1930, during the Solvay Conference. (Niels Bohr Archive.)

Plate 31 Royal visit to Carlsberg on May 22, 1957. From left to right, Queen Elizabeth, the Duke of Edinburgh, Niels Bohr, Crown Princess (later Queen) Margrethe, Mrs Bohr, King Fredrik IX. (Niels Bohr Archive.)

Plate 30 Niels Bohr with Louis Armstrong, in Copenhagen. (Niels Bohr Archive.)

Isotopes of Hydrogen

$^{1}_{1}H$ **hydrogen**

1766 Henry Cavendish, London

$^{2}_{1}H$ **deuterium**

1931 Harold Urey, Columbia U.

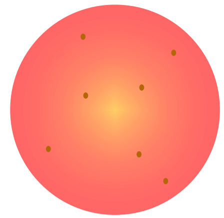
$^{3}_{1}H$ **tritium**

1934 Ernest Rutherford, Cambridge U.

1803

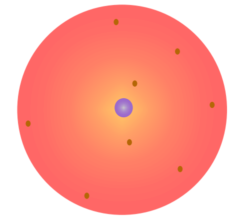
Dalton proposes the indivisible unit of an element is the atom.

1904



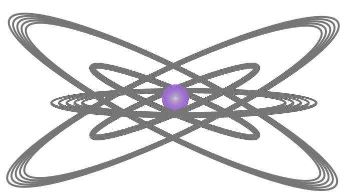
Thomson discovers electrons, believed to reside within a sphere of uniform positive charge (the "plum pudding" model).

1911



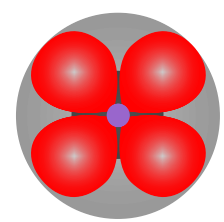
Rutherford demonstrates the existence of a positively charged nucleus that contains nearly all the mass of an atom.

1913

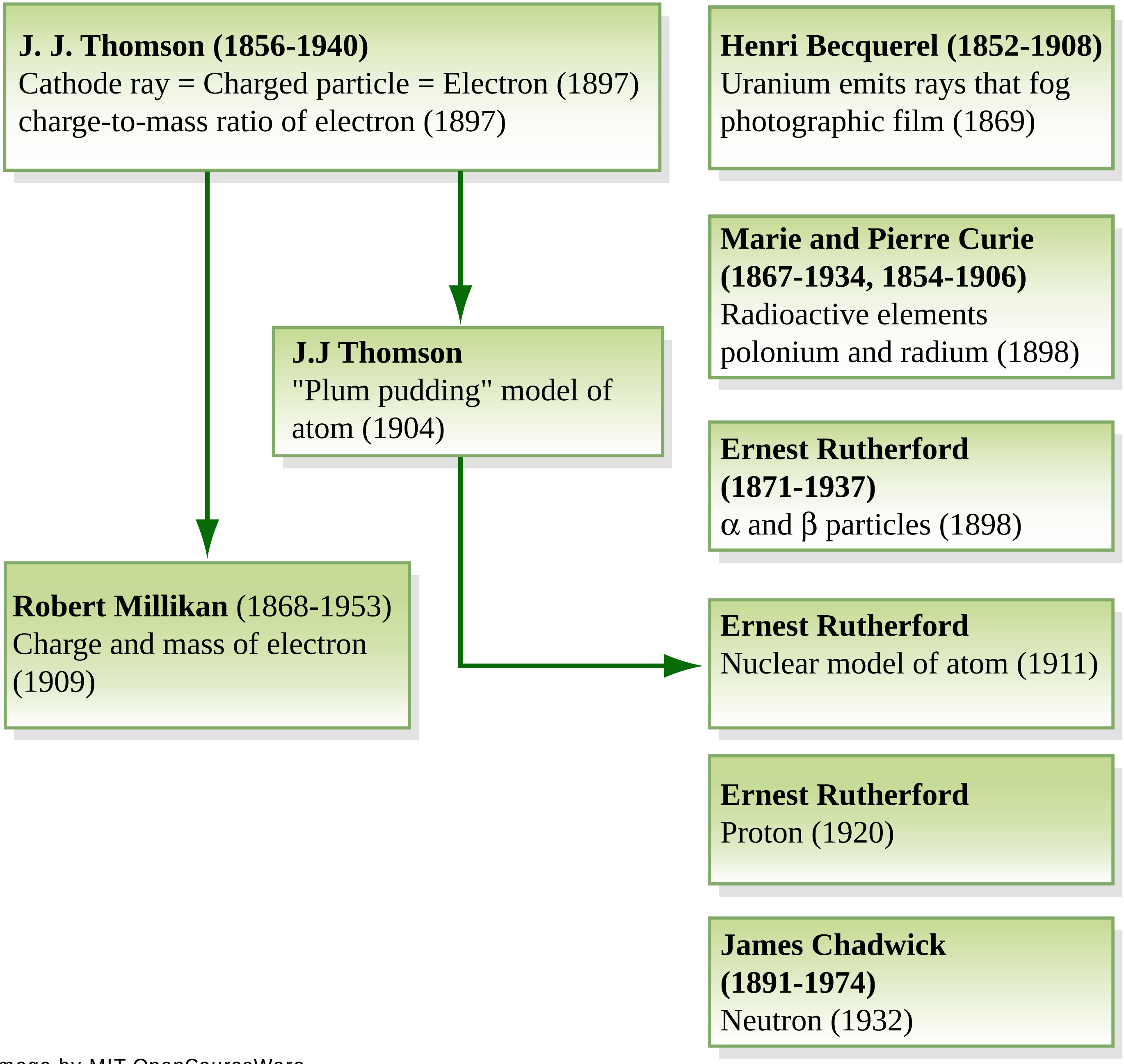


Bohr proposes fixed circular orbits around the nucleus for electrons.

1926



In the current model of the atom, electrons occupy regions of space (orbitals) around the nucleus determined by their energies.



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