TABLE OF INFORMATION

Rest mass of the electron	$m_e = 9.11 \times 10^{-31}$ kilogram $= 9.11 \times 10^{-28}$ gram
Magnitude of the electron charge	$e = 1.60 \times 10^{-19}$ coulomb $= 4.80 \times 10^{-10}$ statcoulomb (esu)
Avogadro's number	$N_A = 6.02 \times 10^{23}$ per mole
Universal gas constant	$R = 8.31$ joules/(mole • K)
Boltzmann's constant	$k = 1.38 \times 10^{-23}$ joule/K $= 1.38 \times 10^{-16}$ erg/K
Speed of light	$c = 3.00 \times 10^{8}$ m/s $= 3.00 \times 10^{10}$ cm/s
Planck's constant	$h = 6.63 \times 10^{-34}$ joule • second $= 4.14 \times 10^{-15}$ eV • second
	$\hbar = h/2\pi$
Vacuum permittivity	$\epsilon_0 = 8.85 \times 10^{-12}$ coulomb^2/(newton • meter^2)
Vacuum permeability	$\mu_0 = 4\pi \times 10^{-7}$ weber/(ampere • meter)

在科学家座谈会上的讲话

（2020年9月11日）

习近平

现在，我国经济社会发展和民生改善比过去任何时候都更加需要科学技术解决方案，都更加需要增强创新这个第一动力。同时，在激烈的国际竞争面前，在单边主义、保护主义上升的大背景下，我们必须走出适合国情的创新路子，特别是要把原始创新能力提升摆在更加突出的位置，努力实现更多“从0到1”的突破。希望广大科学家和科技工作者肩负起历史责任，坚持面向世界科技前沿、面向经济主战场、面向国家重大需求、面向人民生命健康，不断向科学技术广度和深度进军。

How people in science see each other

undergraduate | PhD student | postdoc | PI / Professor | technician

seen by undergraduate

seen by PhD student

seen by postdoc

seen by PI / Professor

seen by technician

Chuck Norris

created by
@biomatushiq
http://sotak.info/sci.jpg

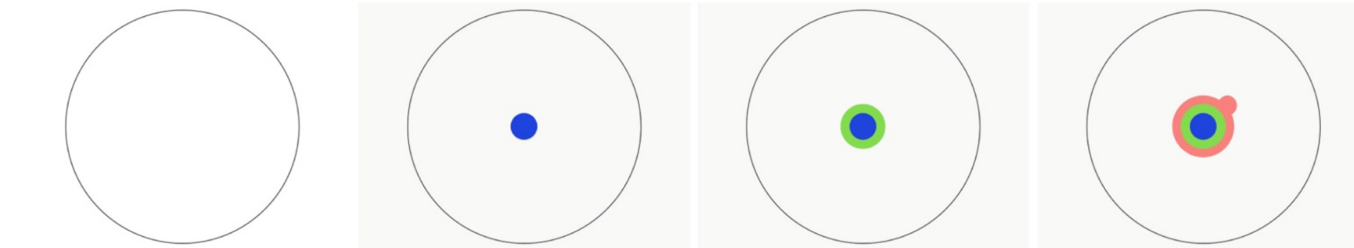
The Illustrated Guide to a Ph.D by Matt Might

Imagine a circle that contains all of human knowledge:

By the time you finish elementary school, you know a little:

By the time you finish high school, you know a bit more:

With a bachelor's degree, you gain a specialty:

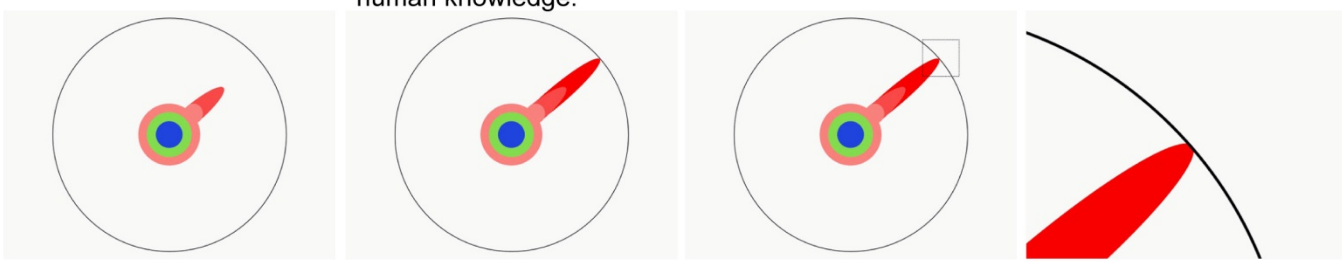


A master's degree deepens that specialty:

Reading research papers takes you to the edge of human knowledge:

Once you're at the boundary, you focus:

You push at the boundary for a few years:

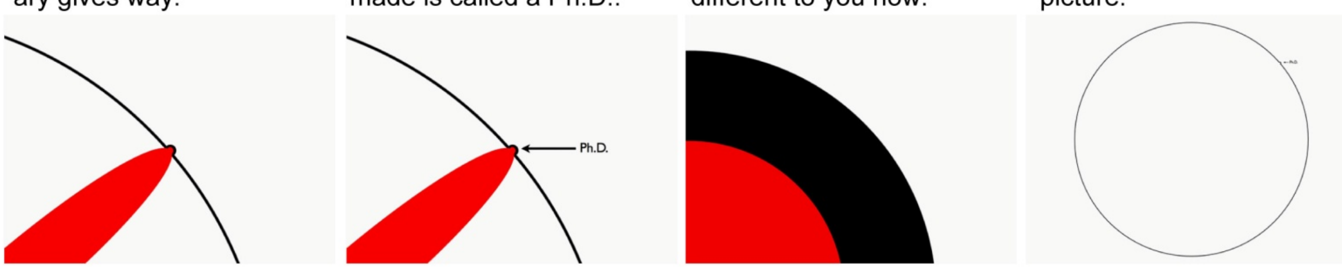


Until one day, the boundary gives way:

And, that dent you've made is called a Ph.D.:

Of course, the world looks different to you now:

So, don't forget the bigger picture:



Keep pushing.


5 EURO
5
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10 EURO
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50
50 EURO
50
100
100 EURO
100
200
200 EURO
200
500
500 EURO
500

吾生也有涯，而知也无涯。以有涯随无涯，殆已！ —庄子

学而不思则罔，思而不学则殆。 — Confucius

Reference books

Modern Atomic & Nuclear Physics, Fujia Yang and J. H. Hamilton, World Scientific Publishing Co., 2010

原子物理学（第四版），杨福家，高等教育出版社，2008

Introduction to Quantum Mechanics (2^{nd} Edition), David J. Griffiths, 机械工业出版社 (reprint Edition)

量子力学 卷I　曾谨言，科学出版社

量子物理（新概念物理教程），赵凯华 罗蔚茵 高等教育出版社

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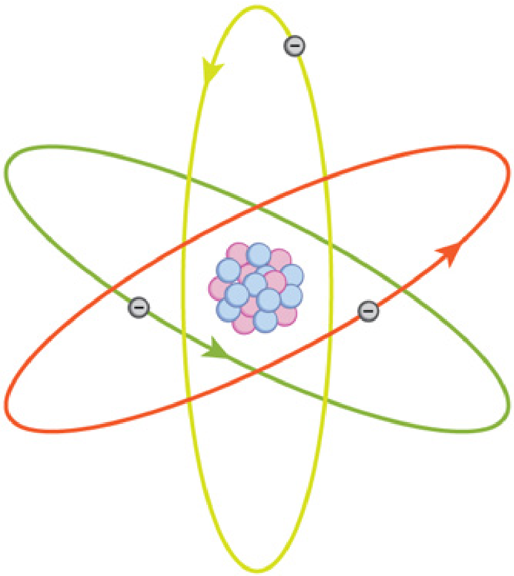
Chapter 1
The Configuration of the Atom: Rutherford Model



atomic planetary model
Rutherford, 1911

USA Atomic Energy Commission
1946-1975

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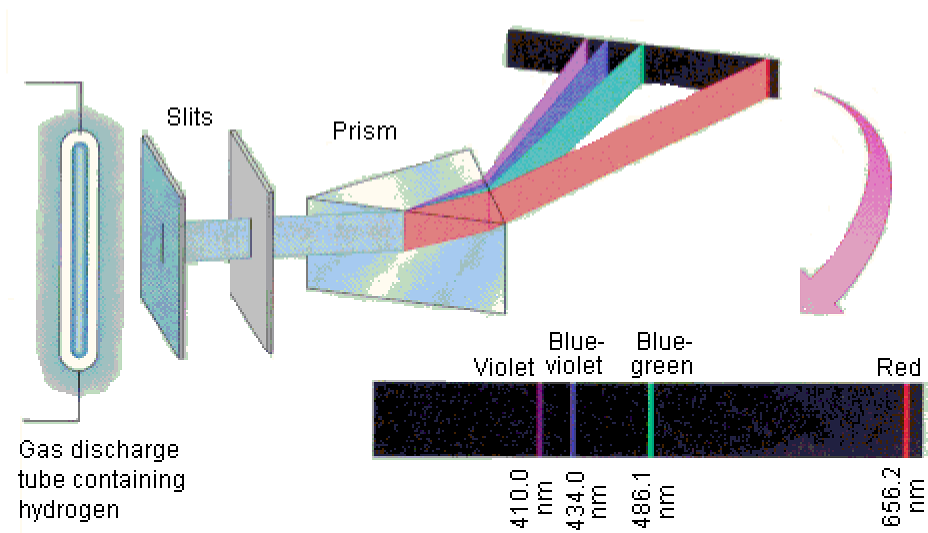
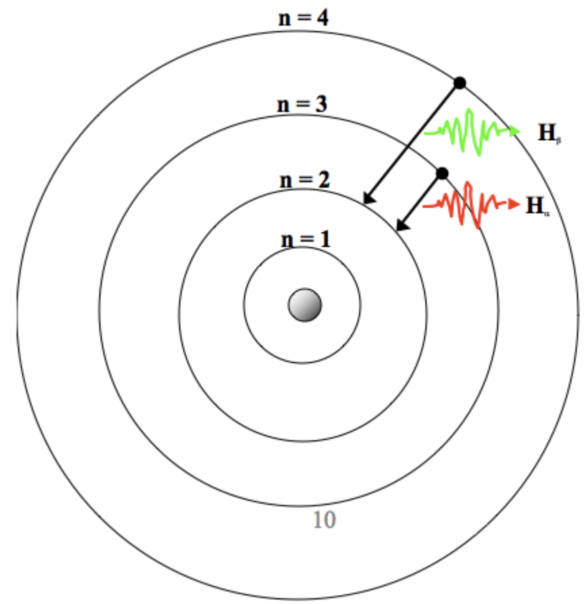
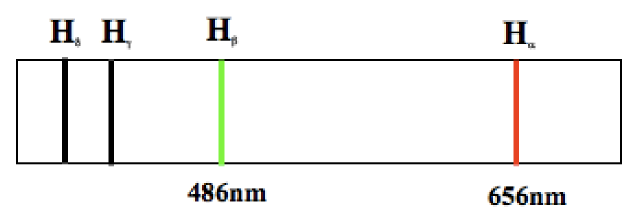
Chapter 2
Introduction of Quantum Concepts and the Bohr Model

Spectrum of Atomic Hydrogen





$E_{n'} - E_{n''} = h\nu$



Chapter 3
Introductory Quantum Mechanics: Concepts and the Schrödinger Equation

Schrödinger equation

$$i\hbar\frac{\partial}{\partial t}\Psi(\mathbf{r},t) = \hat{H}\Psi(\mathbf{r},t)$$

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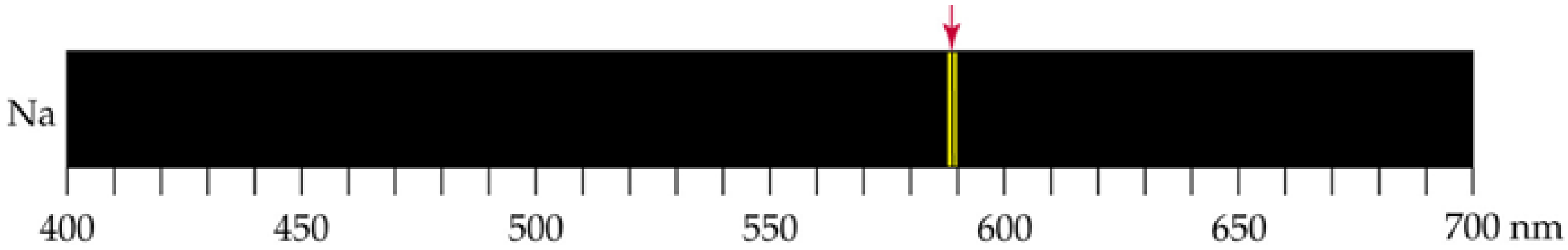
Chapter 4
Fine Structure in Atomic Spectra: Electron Spin



doublet lines of Alkali Metals

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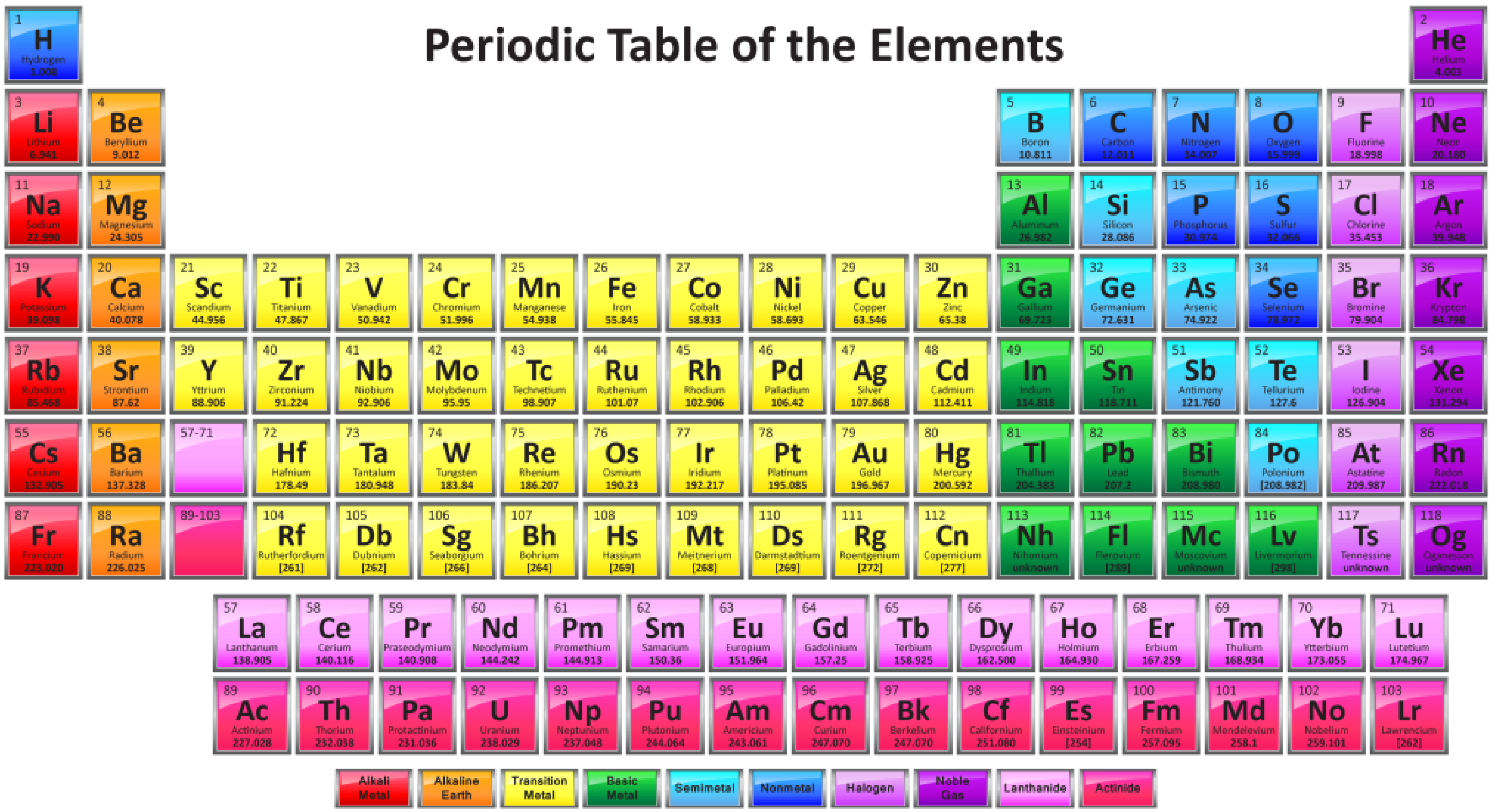
Chapter 5
Multi-Electron Atoms: The Pauli Exclusion Principle

Mendeleev (1869)



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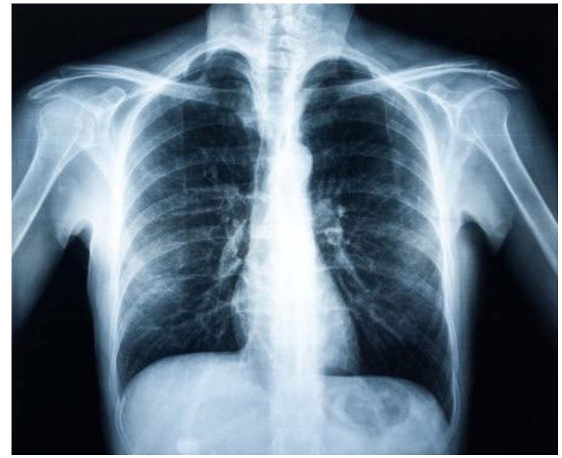
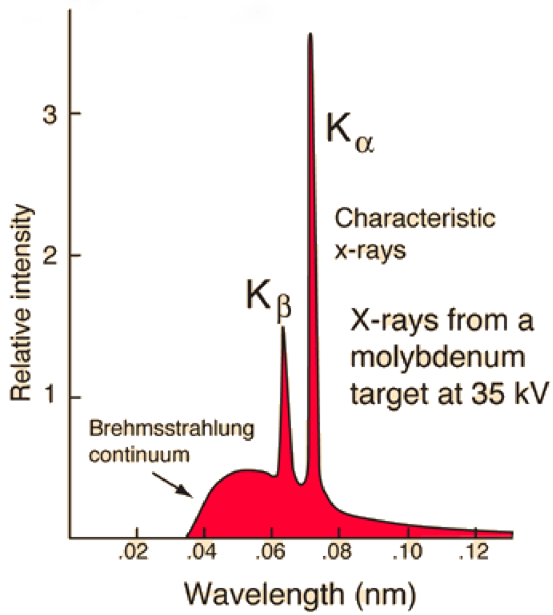
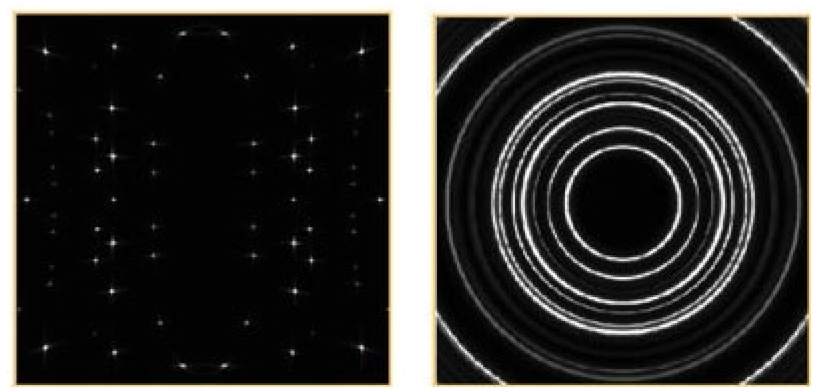
Chapter 6
X-rays





X-ray emission spectrum



X-ray Diffraction (XRD)

Grading Policy

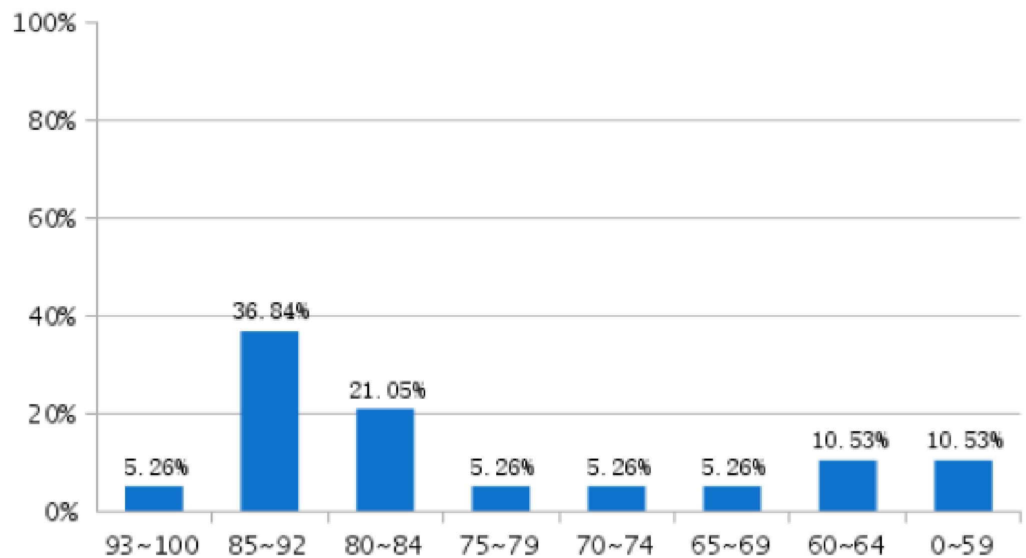
Homework (30%)
Attendance (10%)
Final Exam (60%)

深圳大学期末考试试卷分析表

2018-2019学年第一学期

课程编号	6400370002	课程名称	量子力学（1）
课序号	01	课程类别	专业选修课
课程学分	4	考核表样式	期末考试(有附加题)
考试方式	闭卷	主讲教师	李武
实考人数	19		

期末基本题得分情况	93～100:	1	人，	占总数:	5.26%
	85～92:	7	人，	占总数:	36.84%
	80～84:	4	人，	占总数:	21.05%
	75～79:	1	人，	占总数:	5.26%
	70～74:	1	人，	占总数:	5.26%
	65～69:	1	人，	占总数:	5.26%
	60～64:	2	人，	占总数:	10.53%
	0～59:	2	人，	占总数:	10.53%
	最高分:	93	最低分:		15
	平均分:	75.63	标准差:		18.28
附加题有效得分:		2	人，	占总数:	10.53%



A sample Exam Question

二. (10 points) When alpha particles are directed onto atoms in a thin foil, some make very close collisions with the nuclei of the atoms and are scattered at large angles. If an alpha particle with an initial kinetic energy of 5MeV happens to be scattered through an angle of 180 degree, what is its distance of the closest approach to the scattering nucleus?(Assume that the metal foil is made of silver, with Z=50. m_{Ag}=107.9u, m_{α}=4.0u)

群名称：IAS2020量子力学(I)
群　号：579464568

Office hours:
4-6pm, Wednesday, Office 341

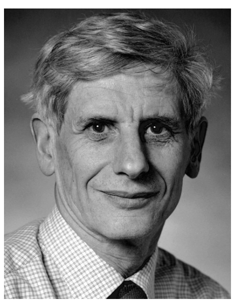
Academic Family Tree

Arnold Sommerfeld
(1868–1951)

Werner Heisenberg (1901-1976)
(**Nobel Prize 1932**)

Hans Bethe (1906-2005)
(**Nobel Prize 1967**)

Rudolf Peierls(1907–1995)



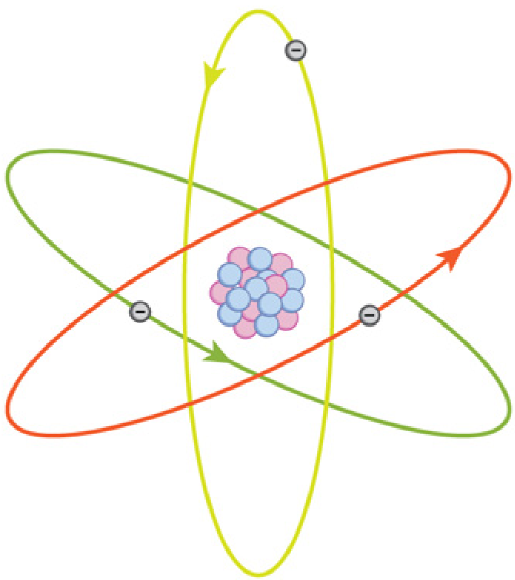
David J. Thouless, (1934-2019)
(**Nobel Prize 2016**)

牛谦(UT Austin)

吴飙(PKU)

李武(SZU)

Chapter 1
The Configuration of the Atom: Rutherford Model



atomic planetary model
Rutherford, 1911

Lecture 02 Background

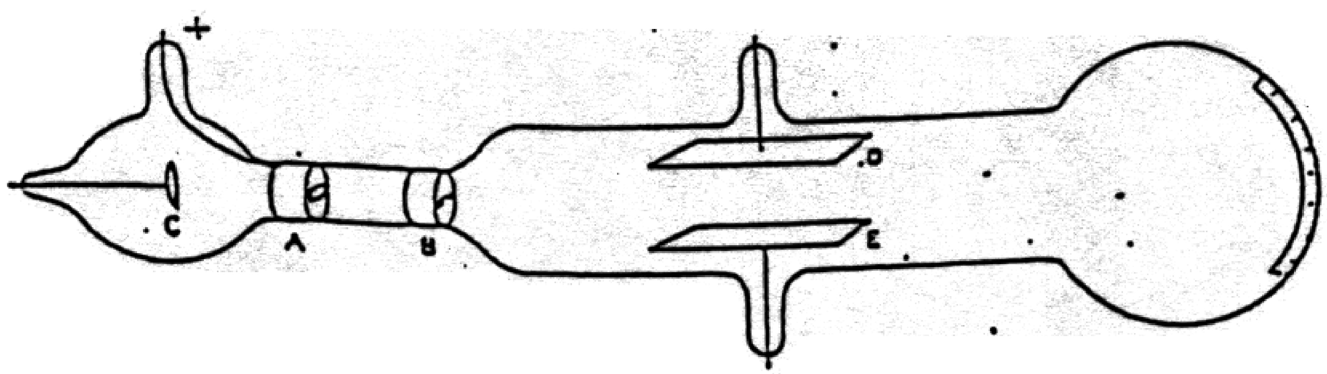
3 discoveries in the late 19th century

X-ray (Rontgen, 1895)
Radioactivity (Becquerel, 1896) **beginning of nuclear physics**
Electron (Joseph J. Thomson, 1897)

Electron Discovery Experiment

In 1874 G. J. Stoney introduced the concept "*fundamental unit quantity of electricity*", and proposed the term "*electron*" in 1891.

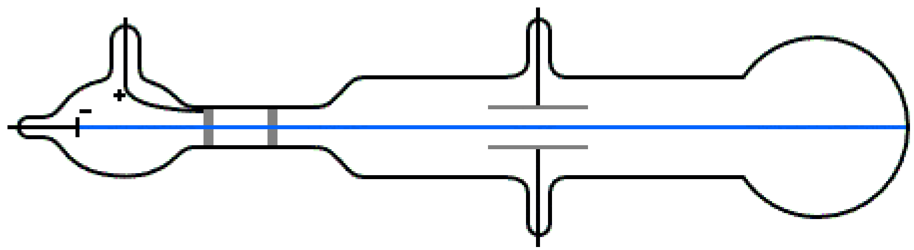
In 1897, Thomson discovered and identified electron in Crookes tube (discharge tube)



Cathode rays were emitted from the cathode C, passed through slits A (the anode) and B (grounded), then through the electric field generated between plates D and E, finally impacting the surface at the far end.

Electron Discovery Experiment

Cathode rays could be deflected electrically => Cathode rays are negatively charged.

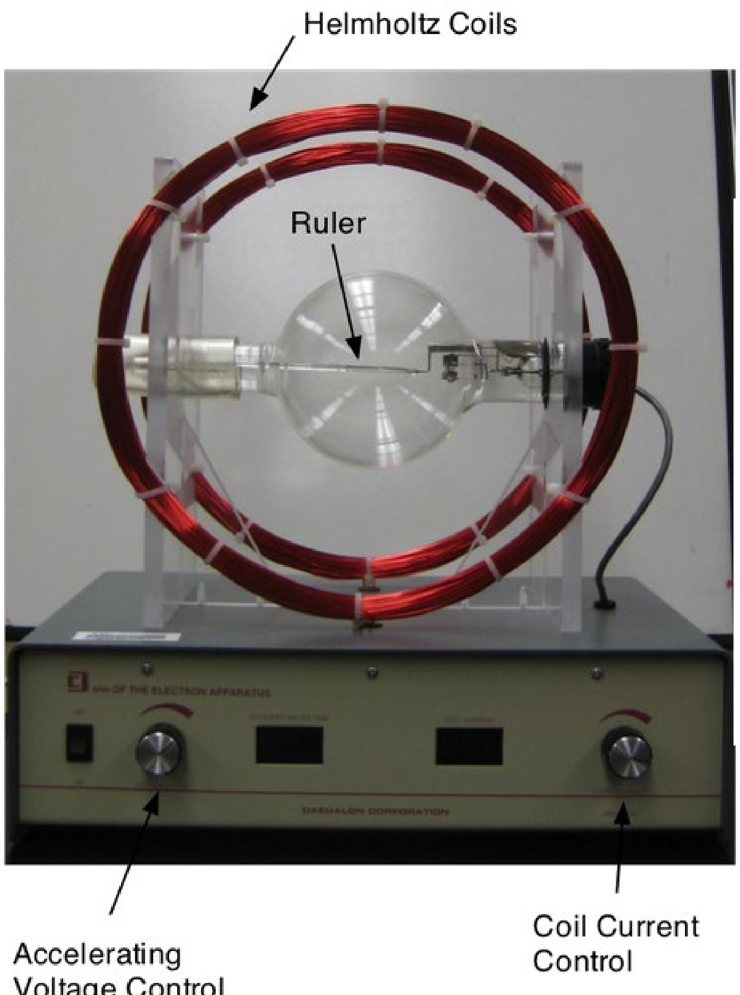


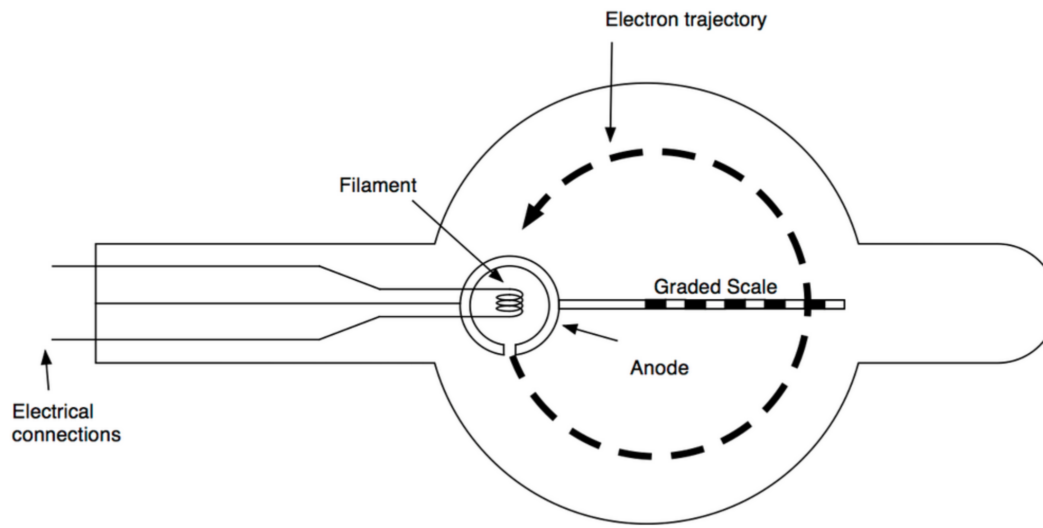
If further applying magnetic field H normal to screen,

$$v=E/H$$

Electron Discovery Experiment

In the absence of electrical field and presence of magnetic field, the particles will travel along a circular arc.





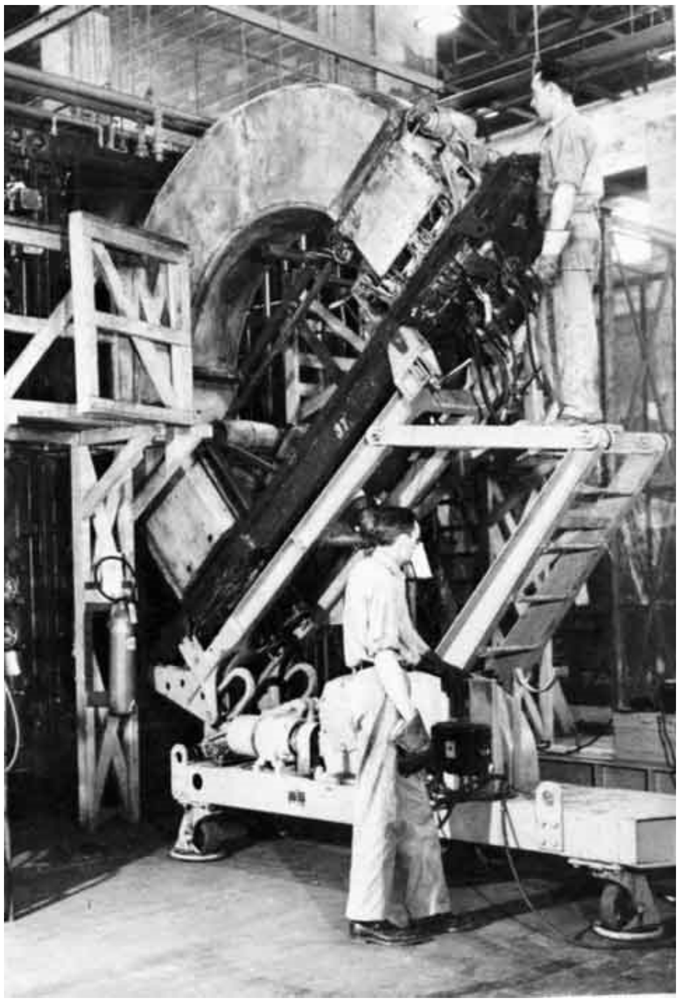
Electron Discovery Experiment

In 1890, A. Shuster observed a much larger charge-to-mass ratio for the cathode ray than that of H^+ (referred to as *proton* in 1920 by Rutherford).

In 1897, W. Kaufman obtained much more accurate charge-to-mass ratio than J. Thomson did, and also discovered the velocity dependence of mass of the electron.

Mass Spectrometry

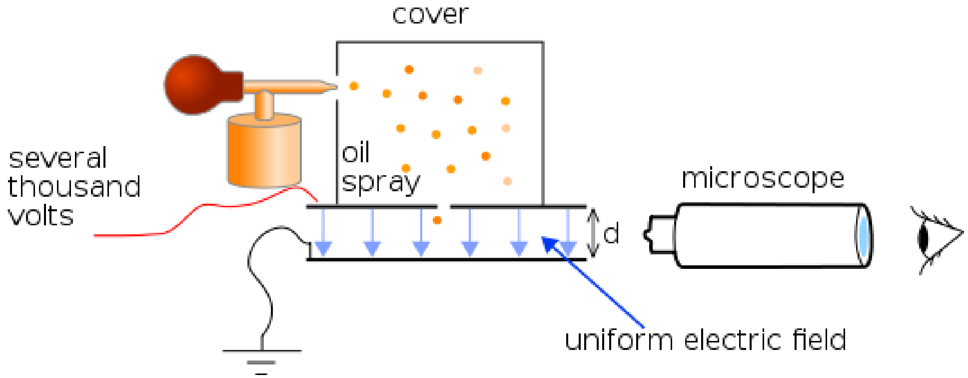
principle: mass to charge ratio



Calutron mass spectrometers were used in the Manhattan Project for uranium enrichment.

Inductively coupled plasma mass spectrometry

Charge and Mass of the Electron



The drag force from Stokes's law

$$F_d = 6\pi r \eta v_1$$

and the effective weight

$$\boldsymbol{w} = \frac{4\pi}{3} r^3 (\rho - \rho_{air}) \boldsymbol{g}$$

should cancel out, suggesting

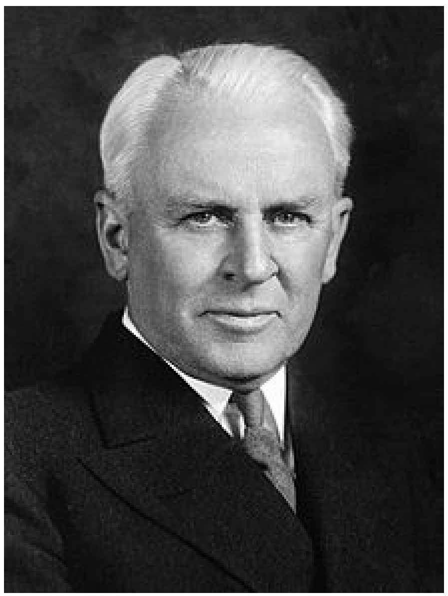
$$r^2 = \frac{9\eta v_1}{2g(\rho - \rho_{air})}.$$

Turn on an electric field E, so that a new upwards terminal velocity is reached. Then

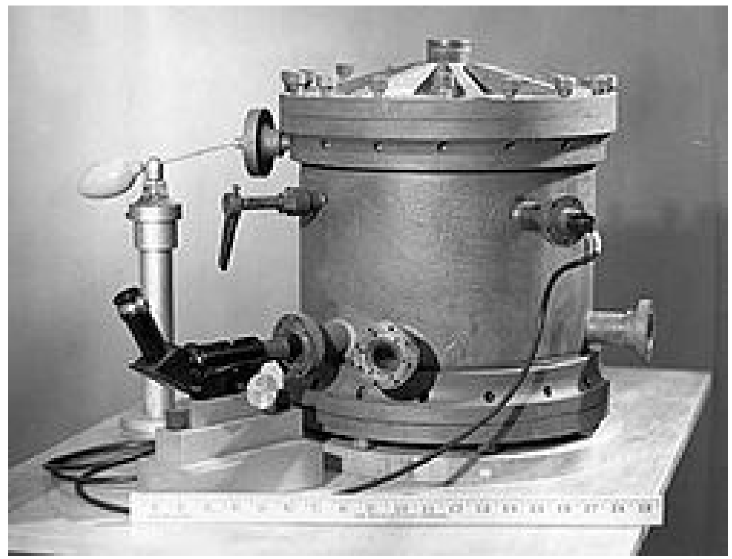
$$q\boldsymbol{E} - \boldsymbol{w} = 6\pi\eta(\boldsymbol{r} \cdot \boldsymbol{v}_2) = \left|\frac{\boldsymbol{v}_2}{\boldsymbol{v}_1}\right| \boldsymbol{w}.$$

Charge and Mass of the Electron

1910, Robert A. Millikan, Oil-drop experiment
Nobel prize in 1923



(1868-1953)



Student: Chung-Yao Chao (赵忠尧), anomalously high scattering cross-section of Gamma rays (1930).

Charge and Mass of the Electron

Electron charge reported by Robert A. Millikan:

e=1.59E-19 C,

Which is 1% less than the modern value:

e=1.60217662E-19 C.

Further from measured mass-to-charge ratio, one can obtain the **rest mass energy**

m_e =9.10938215(45)E-31kg

approximately 0.51 MeV/c2

Other things we learn from oil-drop experiments

Quote from Richard Feynman:

We have learned a lot from experience about how to handle some of the ways we fool ourselves. One example: Millikan measured the charge on an electron by an experiment with falling oil drops, and got an answer which we now know not to be quite right. It's a little bit off because he had the incorrect value for the viscosity of air. It's interesting to look at the history of measurements of the charge of an electron, after Millikan. If you plot them as a function of time, you find that one is a little bit bigger than Millikan's, and the next one's a little bit bigger than that, and the next one's a little bit bigger than that, until finally they settle down to a number which is higher.

Why didn't they discover the new number was higher right away? It's a thing that scientists are ashamed of—this history—because it's apparent that people did things like this: When they got a number that was too high above Millikan's, they thought something must be wrong—and they would look for and find a reason why something might be wrong. When they got a number close to Millikan's value they didn't look so hard. And so they eliminated the numbers that were too far off, and did other things like that...

Other properties of the Electron

LETTER

Nature, 473, 493 (2011) doi:10.1038/nature10104

Improved measurement of the shape of the electron

J. J. Hudson[1], D. M. Kara[1], I. J. Smallman[1], B. E. Sauer[1], M. R. Tarbutt[1] & E. A. Hinds[1]

Shape:

perfect sphere

radius smaller than 1E-17 cm (C.C. Ting).

Spin

magnetic moment

spin-orbit interaction

作者：邱傲文 来源：澎湃新闻 发布时间：2016/9/2 13:38:54 选择字号：小 中 大

丁肇中：过去四十多年，我一直在找电子的半径

Avogadro constant

In 1811, A. Avogadro first proposed that the volume of a gas is proportional to the number of atoms or molecules regardless of the nature of the gas.

In 1909 Jean Perrin (Nobel laureate in 1926) proposed naming the constant in honor of Avogadro.

The earliest accurate method was based on **Coulometry**

$$N_A = \frac{F}{e}$$

where F is Faraday constant (1833).

k_B introduced by Planck (1900-1901) in *law of black body radiation*

It also links the gas constant R and Boltzmann constant:

$$R = k_B N_A$$

X-ray crystal density (XRCD) methods: the ratio of the molar volume V_m to the atomic volume V_{atom}

International Avogadro Coordination

(Further reading) Estimation of Avogadro constant

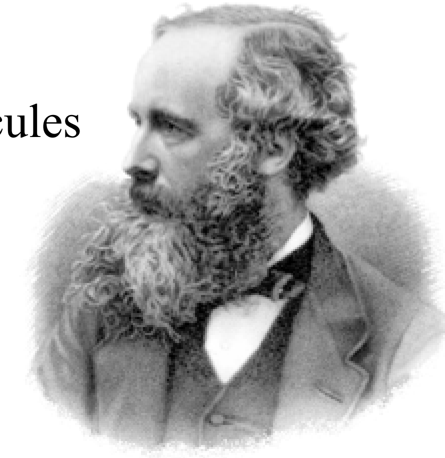
Loschmidt constant (number density in the ideal gas)

$$n_0 = \frac{p_0 N_A}{RT_0}$$ connection with N_A

It can be estimated from the mean free path and diameter of molecules

$$\ell = \frac{3}{4 n_0 \pi d^2}$$

Kinetic theory



James Clerk Maxwell
(1831–1879)

Its modern value $n_0 = 2.686\ 7805 \text{ x } 10^{25}\ \text{m}^{-3}$

Loschmidt's estimate $n_0 = 1.81\times10^{24}\ \text{m}^{-3}$

The diameter can be further related to the *condensation coefficient*

$$d = 8 \frac{V_l}{V_g} \ell$$

yielding $$n_0 = \left(\frac{V_g}{V_l}\right)^2 \frac{3}{256 \pi \ell^3}$$

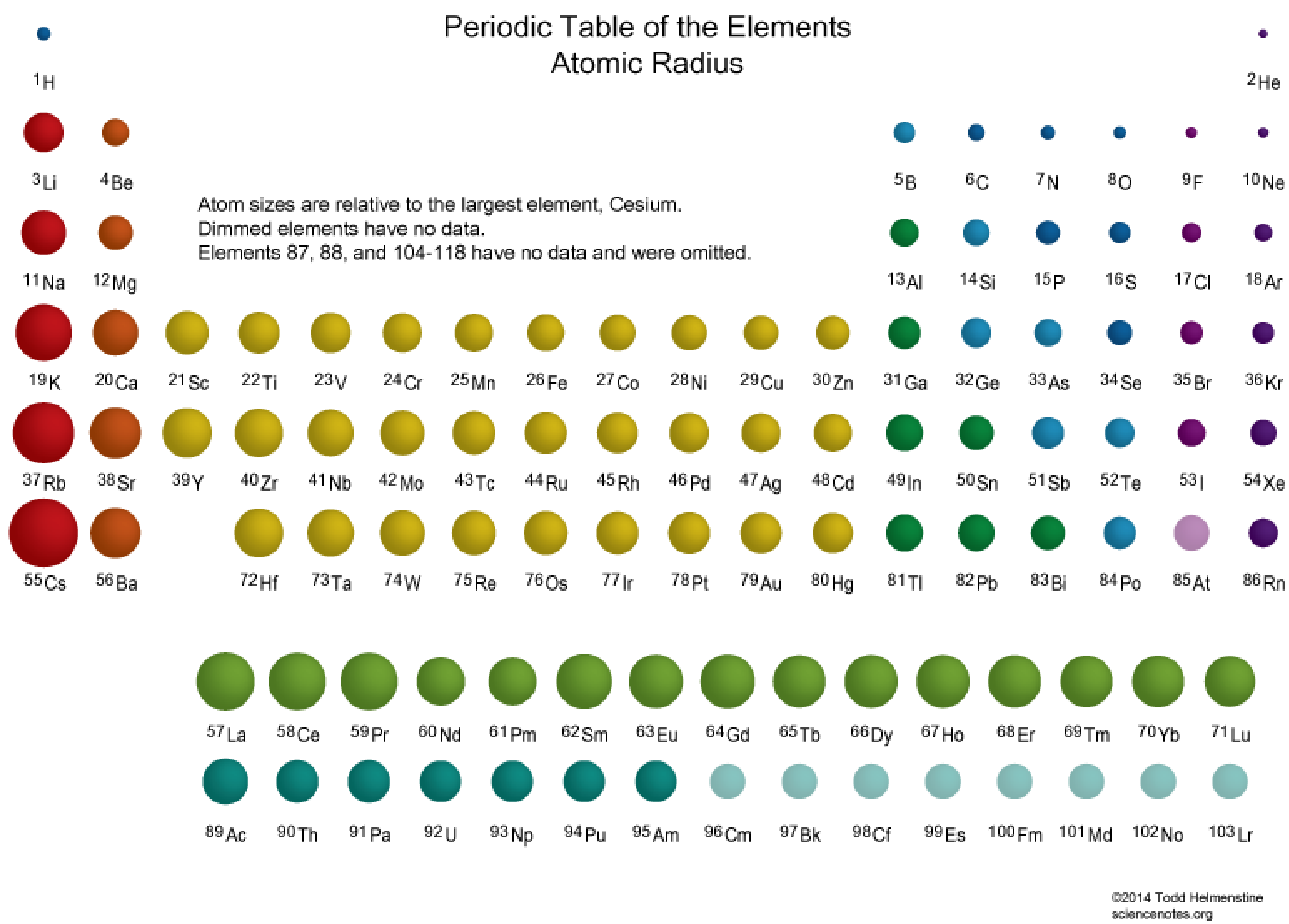
Size of the Atom

For an arbitrary atom ^{A}X, the atomic radius r of X can be estimated as

$$\frac{4}{3}\pi r^3 N_A = \frac{A}{\rho}$$

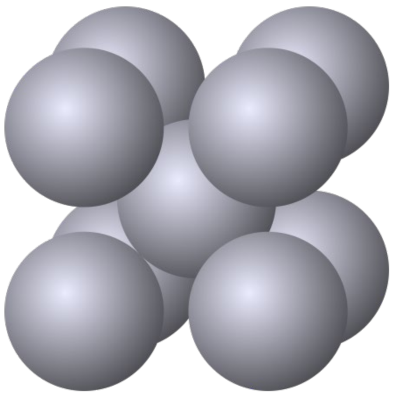
Size of the Atom

Atomic size: few angstroms



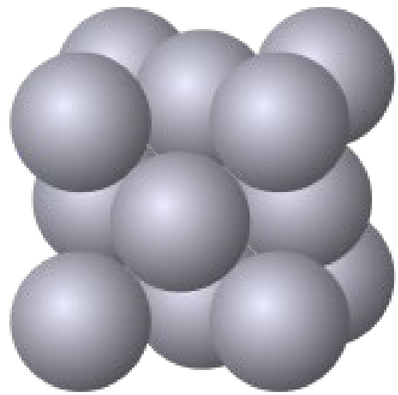
(Further Reading) Size of the Atom

body centered cubic (BCC)



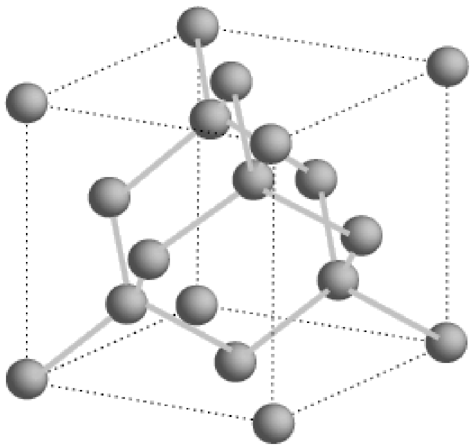
lithium

face centered cubic (FCC)



aluminum, lead, copper

diamond cubic



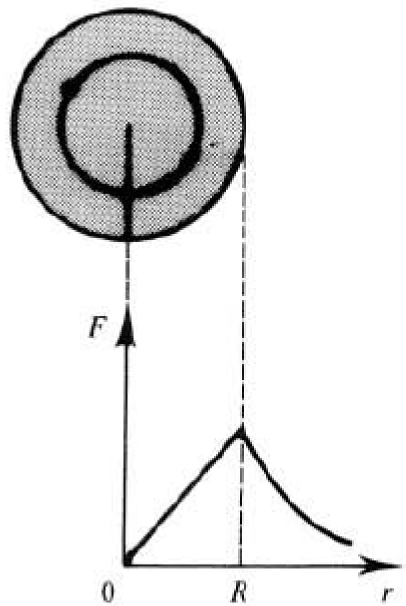
diamond, silicon

	atomic packing factor
simple cubic	0.524
bcc	0.680
fcc	0.740
diamond cubic	0.34

The **largest** packing factor

$$\frac{\pi}{3\sqrt{2}} \simeq 0.74048.$$

Plum pudding model (Thomson)



The positive charge in an atom was uniformly distributed in the spherical atom, and the electrons were embedded.

To explain the periodic table of elements, Thomson further assumed the electrons were distributed in rings.

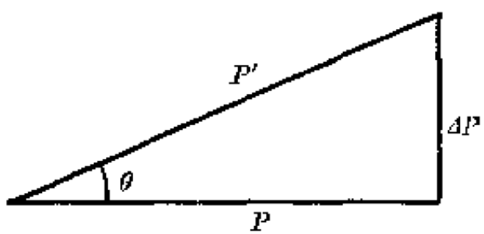


图 2.2 散射引起的动量变化

contribution from positive charges

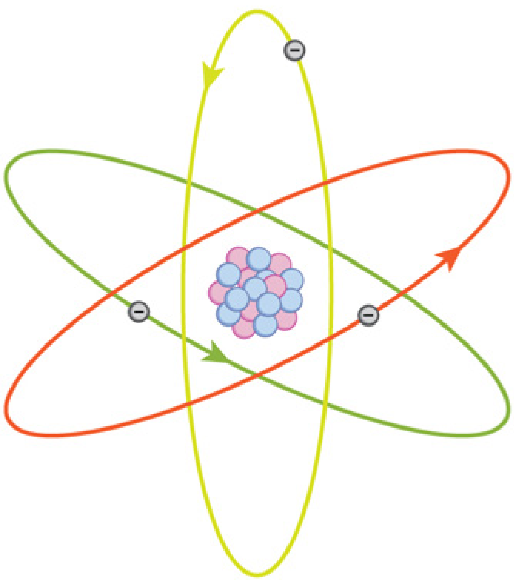
$$\frac{\Delta p}{p} = \frac{F\,2R/\mathrm{v}}{m_\alpha \mathrm{v}} = \frac{2Ze^2/R}{\frac{1}{2}m_\alpha \mathrm{v}^2} \simeq \frac{2Z \times 1.44\ \mathrm{fm}\cdot\mathrm{MeV}/1\,\mathrm{\AA}}{E_\alpha(\mathrm{MeV})}$$

$$\simeq 3 \times 10^{-5}\frac{Z}{E_\alpha} \quad \text{radian}$$

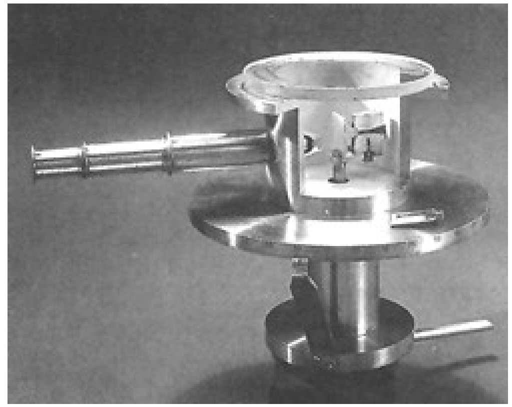
negligible contribution from electrons

$$\frac{\Delta p}{p} \simeq \frac{\mathrm{m}_e}{m_\alpha} \sim \frac{1}{8000} \sim 10^{-4}$$

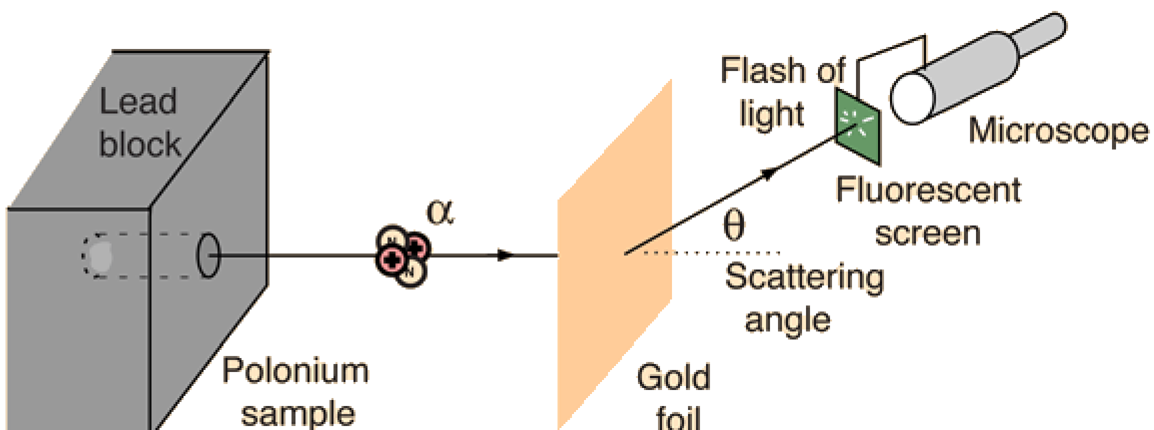
Lecture 03 Rutherford Model



atomic planetary model
Rutherford, 1911



Geiger–Marsden experiment (1908-1913)

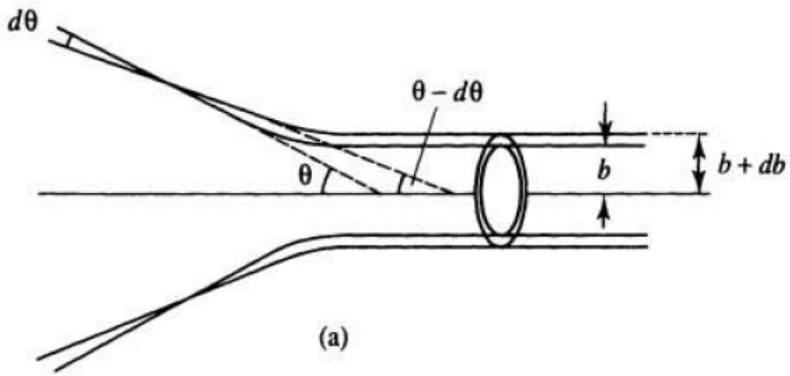


differential (scattering) cross-section

differential (scattering) cross-section

$$\frac{d\sigma}{d\Omega} = \frac{1}{j_i}\left(\frac{\mathrm{d}n}{\mathrm{d}\Omega}\right)$$

*单位时间有dn个粒子*沿（θ, φ）方向的立体角dΩ出射



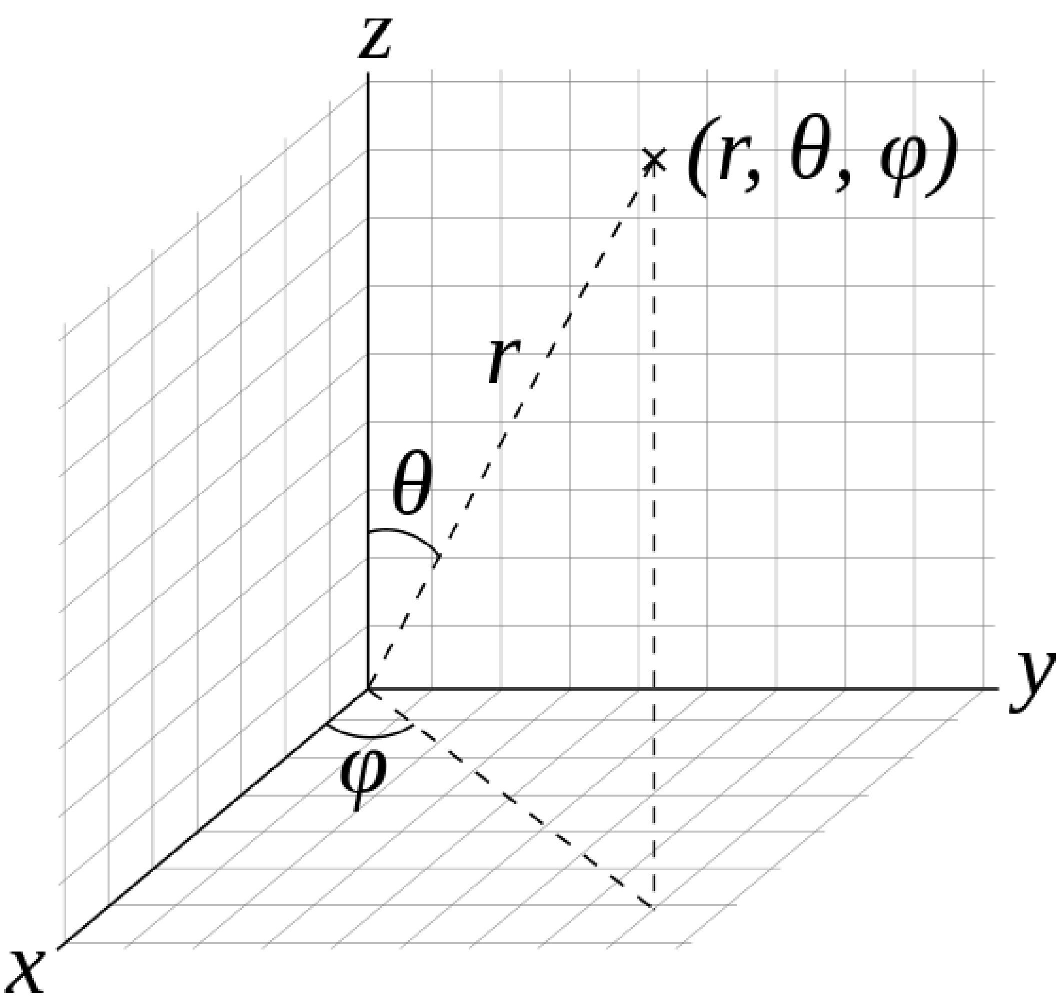
(a)

j_i: 粒子入射密度 (单位时间穿过单位面积的粒子数)

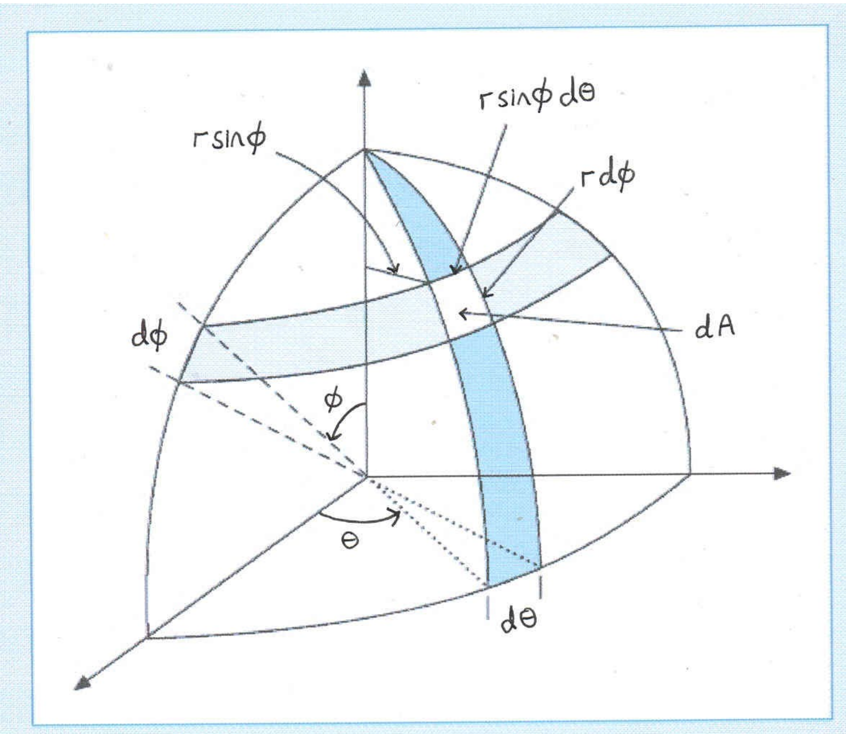
$$\mathrm{d}\Omega = \sin\theta\,\mathrm{d}\theta\,\mathrm{d}\varphi$$

$$\frac{d\sigma}{d\Omega} = \left|\frac{b\,\mathrm{d}b}{\sin\theta\,\mathrm{d}\theta}\right|$$

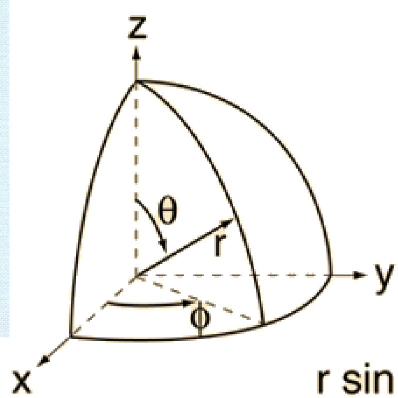
Spherical Coordinate System

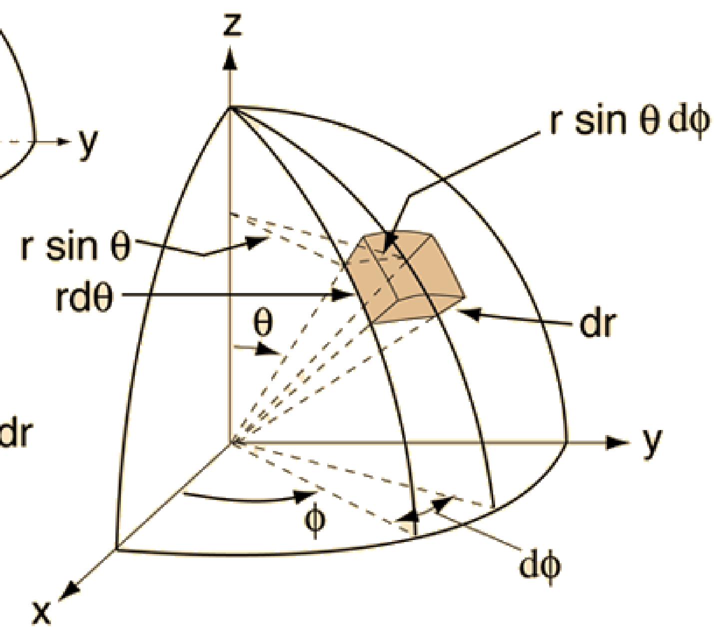


Spherical coordinates (r, θ, φ) as commonly used in physics: radial distance r, polar angle (极角) θ and azimuthal angle (方位角) φ .



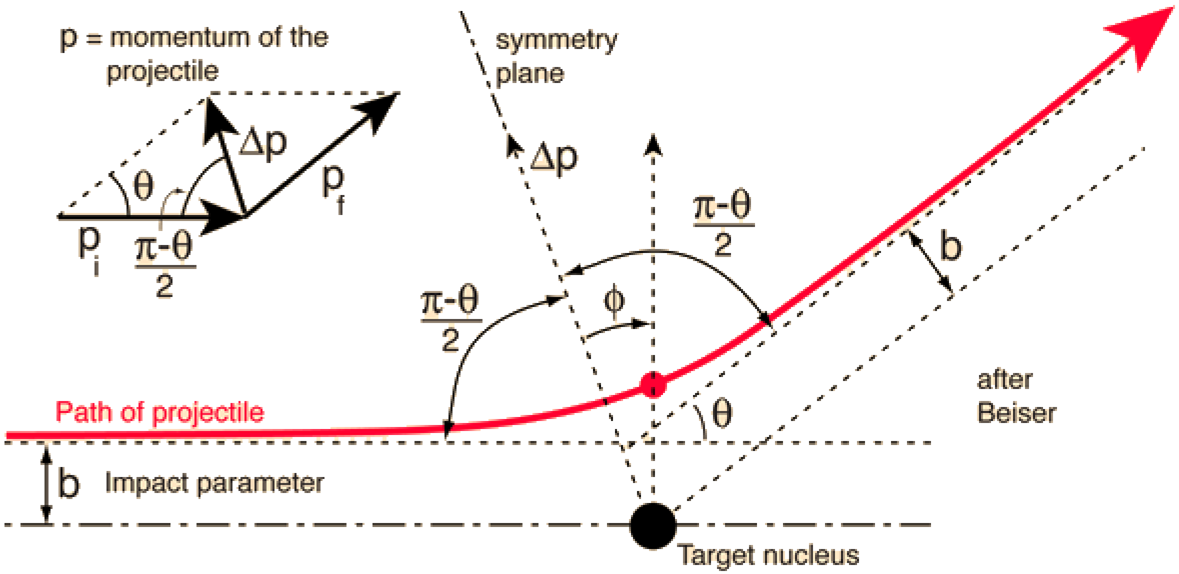
$dA = r^2 \sin\theta \, d\theta \, d\phi$





Volume element

$dV = r^2 \sin\theta \; d\theta \; d\phi \; dr$



Coulomb scattering formula $b = \frac{a}{2} \cot \frac{\theta}{2}$ **with** $a \equiv \frac{Z_1 Z_2 e^2}{E}$

Impact parameter, b (fm)	Angle of scattering, θ (deg)
10	112
100	16.9
1000	1.7

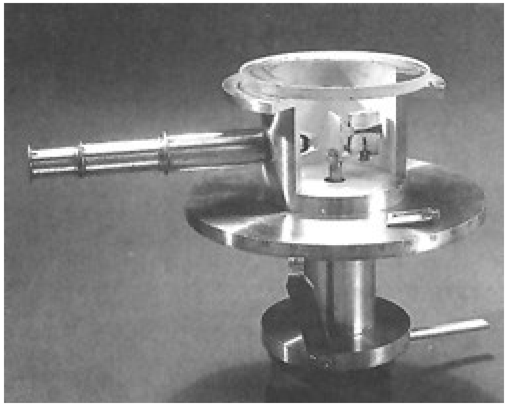
Scattering Cross Section

Rutherford's Formula

$$\frac{d\sigma}{d\Omega} = \left(\frac{Z_1 Z_2 e^2}{8\pi\epsilon_0 m v_0^2}\right)^2 \csc^4\left(\frac{\Theta}{2}\right)$$

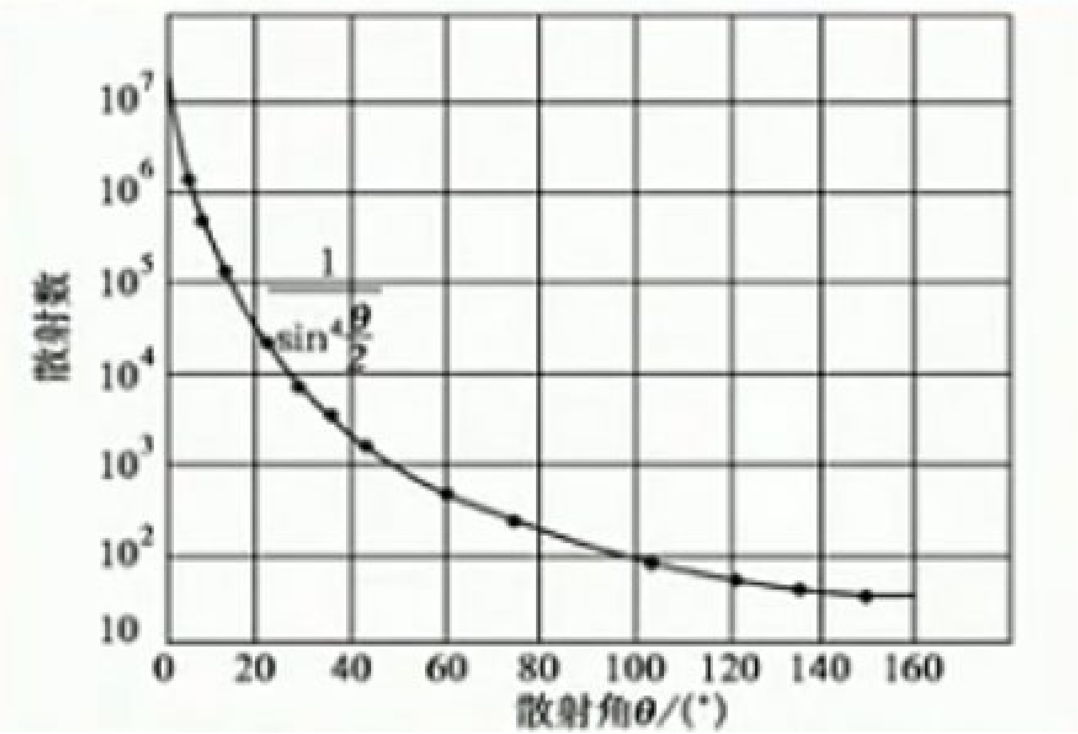
Experimental Verification of Planetary Model

$$\frac{d\sigma}{d\Omega} = \left(\frac{Z_1 Z_2 e^2}{8\pi\epsilon_0 m v_0^2}\right)^2 \csc^4\left(\frac{\Theta}{2}\right)$$

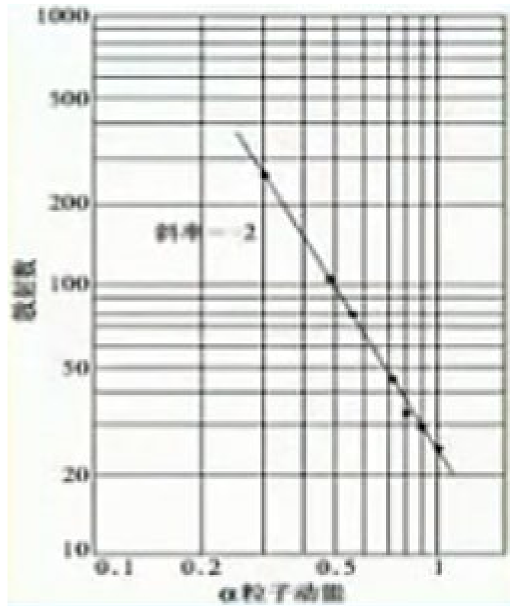


Geiger–Marsden experiment (1908-1913)

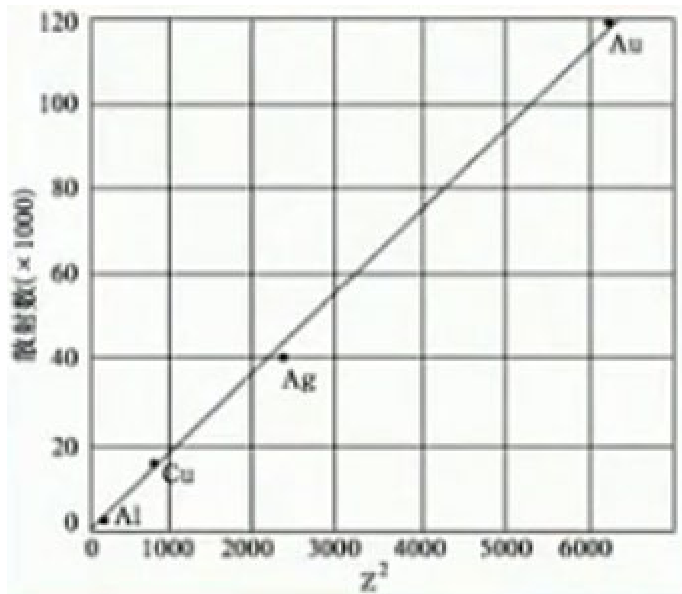
Angle Dependence



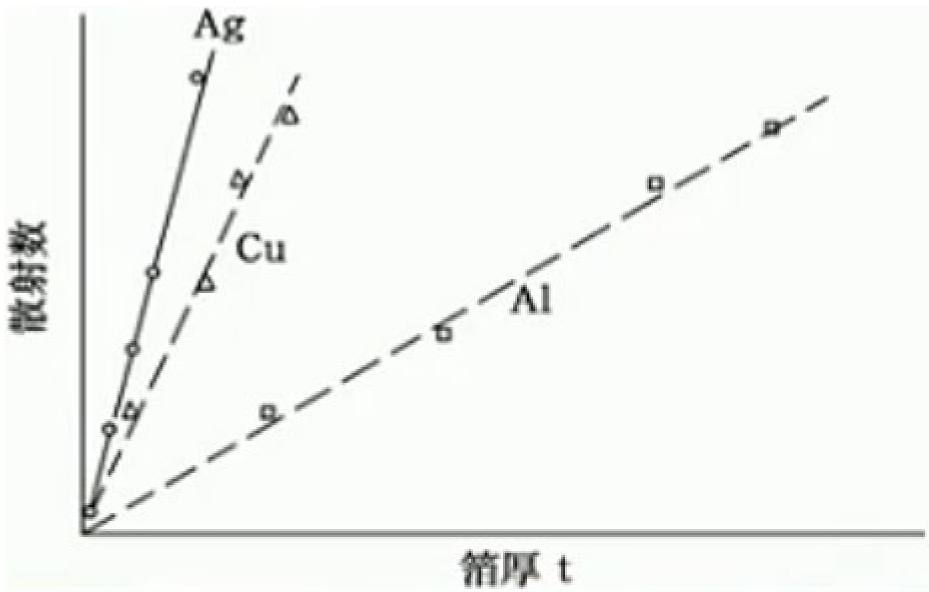
Energy Dependence



Atomic Number Dependence



Thickness Dependence



Estimation of the Nuclear Radius

At **180°** scattering angle (**if Rutherford's formula still holds**)

$$\frac{1}{2}mv^2 = \frac{1}{4\pi\epsilon_0}\cdot\frac{q_1 q_2}{b}$$

$$b = \frac{1}{4\pi\epsilon_0}\cdot\frac{2q_1 q_2}{mv^2}$$

For an alpha particle:

m = 6.64424×10^{-27} kg

$\mathbf{q_1}$ = $2\times(1.6\times10^{-19})$ C

$\mathbf{q_2}$ (for gold) = $79\times(1.6\times10^{-19})$ C

v (initial velocity) = 2×10^{7} m/s 8.28MeV

$b=2.7\times10^{-14}$ m. (The true radius is about $\mathbf{7.3\times10^{-15}}$ **m**.)

1 fm(**femtometre**) = 1×10^{-15} m in nuclear physics

Multiple Scattering Events

Gold foil:

nuclear radius: **~7 fermis**

atomic radius: **~ 0.13 nm**.

The geometrical cross section of the nucleus: **~154 fm^2**

The cross sectional area of the atom is then about 3.45 x 10^8 times the area of the nucleus. The probability of an alpha particle hitting the nucleus would be ~ one in 345 million!

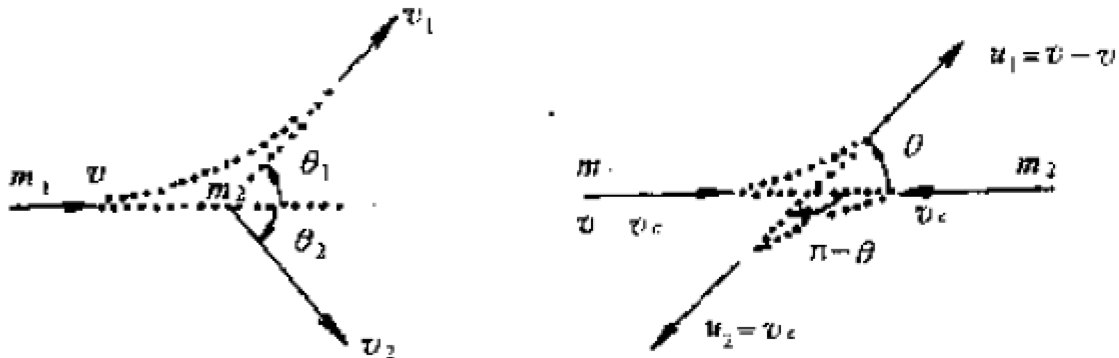
3.45 x 10^6 layers of Gold (900 micrometers) is required to cover 1% of the area to have a 1% probability of a second scattering event.

The actual cross section for scattering above 30° is ~**15730 fm^2**, implying that the thickness is **9 micrometers**.

1 micrometer in Rutherford's experiment.

Scattering Cross Section

When the target nucleus cannot be regarded as fixed,



lab frame vs center of mass frame
two-body => one-body

the reduced mass $$\mu = \frac{mM}{m+M}$$

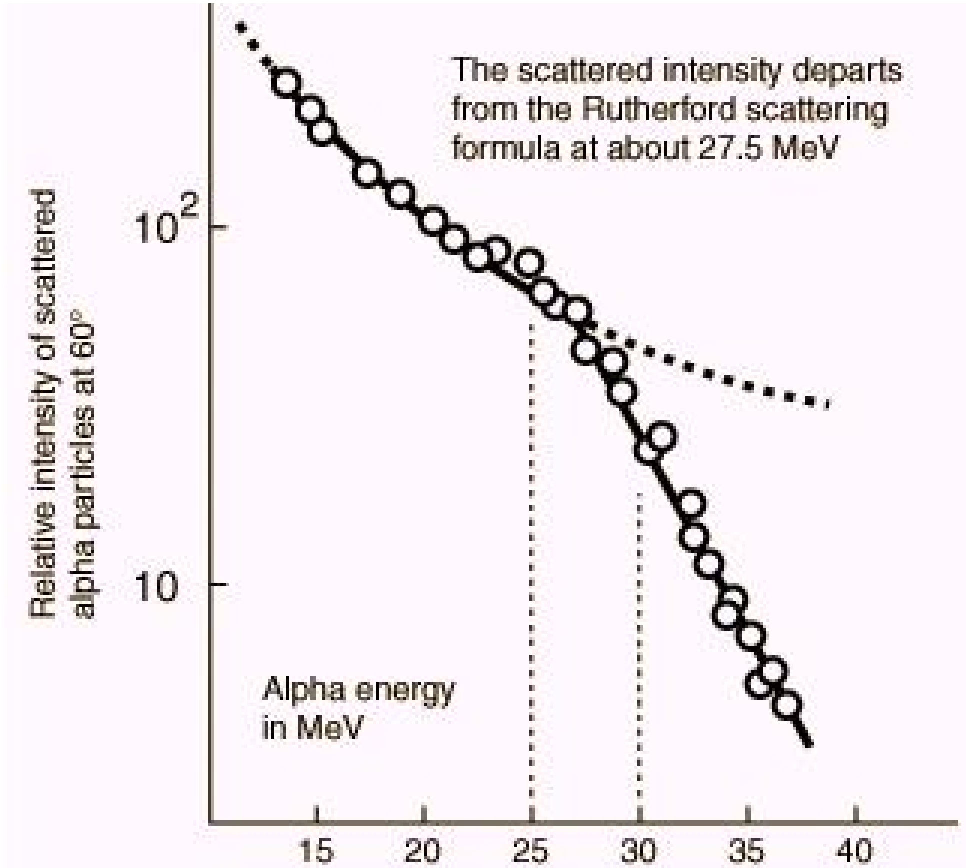
Failure at small angles

$$\frac{d\sigma}{d\Omega} = \left(\frac{Z_1 Z_2 e^2}{8\pi\epsilon_0 m v_0^2} \right)^2 \csc^4\left(\frac{\Theta}{2}\right)$$

long range **nature of Coulomb potential**

screened **Coulomb potential (electron)**

Deviation from Rutherford's Formula



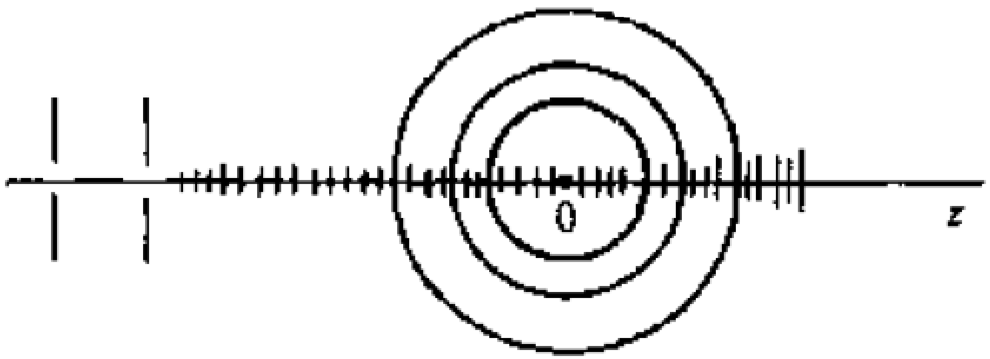
at a fixed angle of 60°

The relativistic correction has been obtained by N. F. Mott within the framework of QED

$d\sigma(\theta,E)/d\Omega = [(Ze^2E)/(2|\mathbf{p}|^2c^2)]^2 \{[(1 - \beta^2\sin^2(\theta/2)]/\sin^4(\theta/2)\}$ ---------- (38d)

where **p** is the momentum of the incident particle, $E = (m_o{}^2c^4+p^2c^2)^{1/2}$, and $\beta=|\mathbf{p}|c/E$.

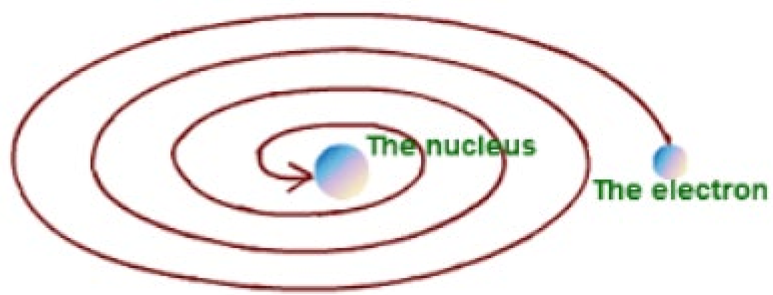
Quantum Mechanical Description



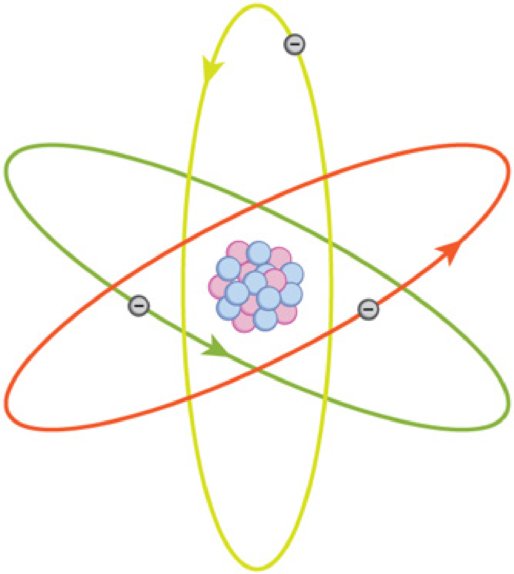
$$\psi \xrightarrow{r \to \infty} \exp[ikz] + f(\theta)\frac{\exp[ikr]}{r}$$

$$\frac{d\sigma}{d\Omega} = |f(\theta)|^2$$

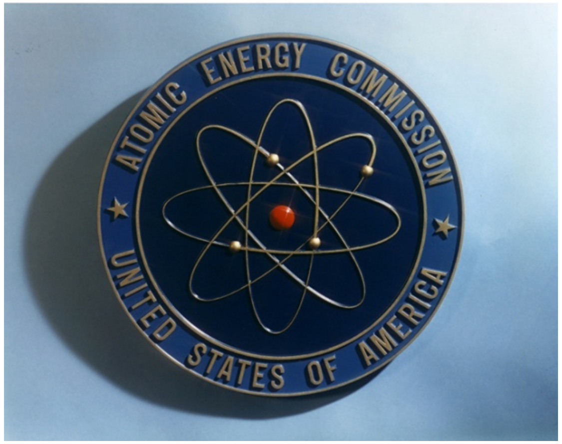
Difficulties



Significances



atomic planetary model
Rutherford, 1911



USA Atomic Energy Commission
1946-1975

Significances

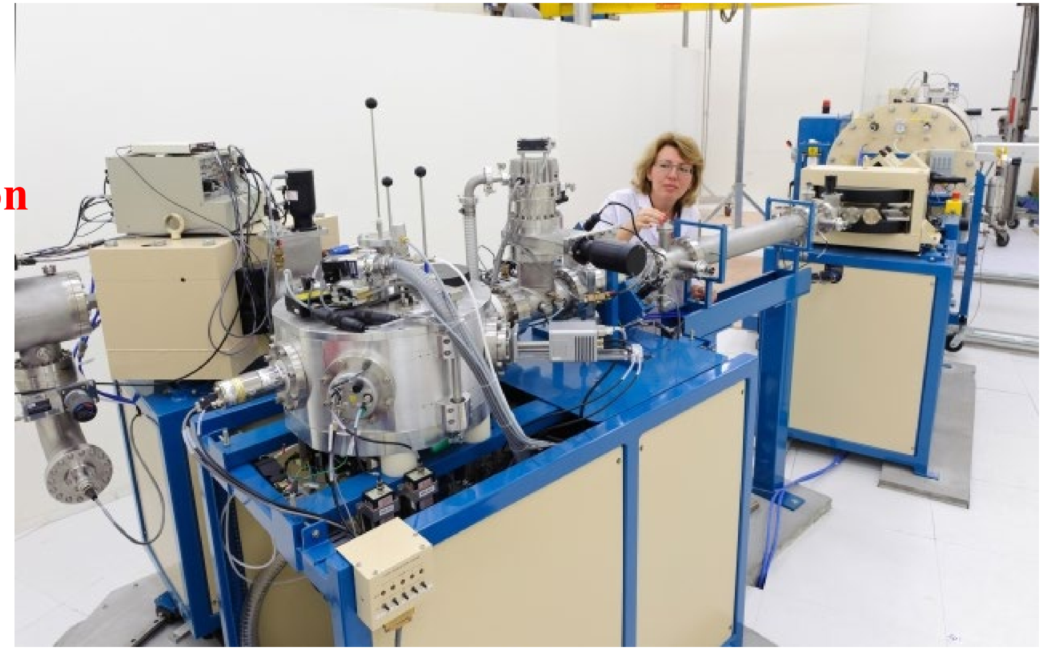
The most beautiful experiments voted from *Physics World* (2002):

(1) Young's double-slit experiment applied to the interference of single electrons;
(2) Galileo's experiment on falling bodies (1600s);
(3) Millikan's oil-drop experiment (1910s);
(4) Newton's decomposition of sunlight with a prism (1665–1666);
(5) Young's light-interference experiment (1801);
(6) Cavendish's torsion-bar experiment (1798);
(7) Eratosthenes's measurement of the Earth's circumference (3rd century BC);
(8) Galileo's experiments with rolling balls down inclined planes (1600s);
(9) Rutherford's discovery of the nucleus (1911);
(10) Foucault's pendulum (1851).

Scattering Spectroscopy

Rutherford back scattering spectrometry

principle: Z dependence of cross section



Neutron backscattering spectroscopy

X-ray spectroscopy

Electron spectroscopy

Collider

Accelerator	Centre, city, country	First operation	accelerated particles	max energy per beam, GeV
VEPP-2000	INP, Novosibirsk, Russia	2006	e^+e^-	1.0
VEPP-4M	INP, Novosibirsk, Russia	1994	e^+e^-	6
BEPC II	IHEP, Beijing, China	2008	e^+e^-	3.7
DAFNE	Frascati, Italy	1999	e^+e^-	0.7
KEKB	KEK, Tsukuba, Japan	1999	e^+e^-	8.5 (e-), 4 (e+)
RHIC	BNL, United States	2000	pp, Au-Au, Cu-Cu, d-Au	100/n
LHC	CERN	2008	pp, Pb-Pb, p-Pb	6500 (planned 7000), 1580/n (planned 2760/n)

Super Collider in China?

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cost: 20 billion $

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