Americans win Nobel physics prize

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Mather, 60, works at the NASA Goddard Space Flight Center in Greenbelt, Maryland.

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STOCKHOLM, Sweden (AP) -- Americans John C. Mather and George F. Smoot have won the 2006 Nobel Prize in physics for work that helped cement the big-bang theory of the universe.

Mather, 60, works at the NASA Goddard Space Flight Center in Greenbelt, Maryland, and Smoot, 61, works at the Lawrence Berkeley National Laboratory in Berkeley, California.

Their work was based on measurements done with the help of the NASA-launched COBE satellite in 1989. They were able to observe the universe in its early stages about 380,000 years after it was born. Ripples in the light they detected also helped demonstrate how galaxies came together over time.

"The very detailed observations that the laureates have carried out from the COBE satellite have played a major role in the development of modern cosmology into a precise science," the academy said in its citation.

Last year, Americans John L. Hall and Roy J. Glauber and German Theodor W. Haensch won the prize for work that could improve long-distance communication and navigation.

This year's award announcements began Monday with the Nobel Prize in medicine going to Americans Andrew Z. Fire and Craig C. Mello for discovering a powerful way to turn off the effect of specific genes. RNA interference opens a potential new avenue for fighting diseases as diverse as cancer and AIDS.

The winner of the Nobel Prize in chemistry will be named Wednesday. The Bank of Sweden Prize in Economic Sciences in Memory of Alfred Nobel will be announced October 9.

The winner of the peace prize -- the only one not awarded in Sweden -- will be announced October 13 in Oslo, Norway.

A date for the literature prize has not yet been set.

The prizes, which include a $1.4 million check, a gold medal and a diploma, are presented on December 10, the anniversary of Nobel's death in 1896.

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Dynamite and diplomacy

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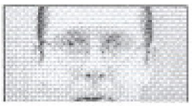
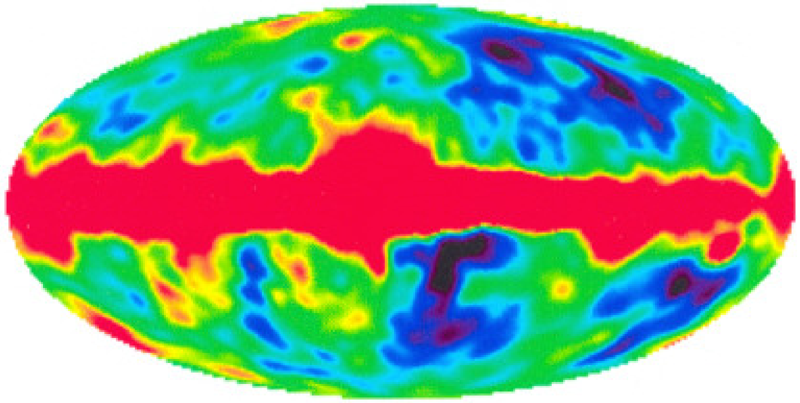
TOP STORY



Police hunt for a motive

Police on Tuesday were trying to determine what happened 20 years ago to spur Charles Carl Roberts IV

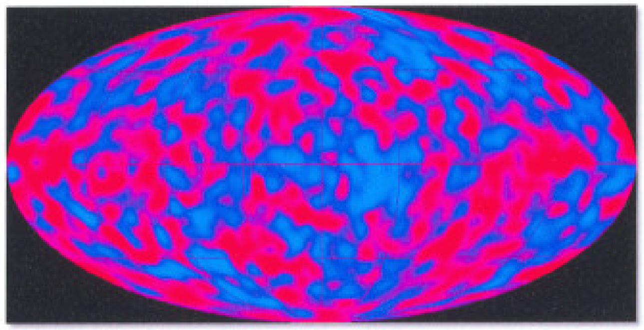
furthermore, we do exist



2.7279 (blue)-2.7281 (red) K x 25000Zoom

An all-sky image (like a Mercator projection) of the sky...notice the Galactic halo across the midline...

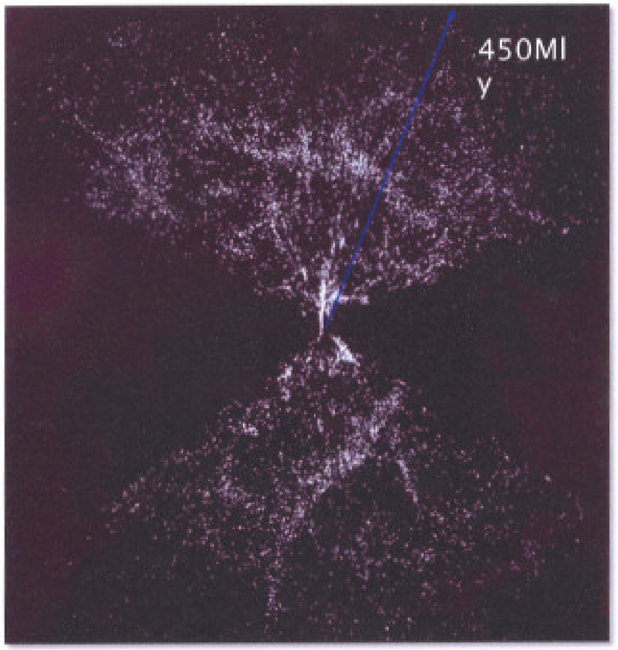
Then this large-scale structure is digitally removed...



fluctuations are 0.000030 K

This is incredible.

It is decisive evidence that the Big Bang model is correct and...the ripples are primordial density fluctuations consistent with that required to form galaxies.



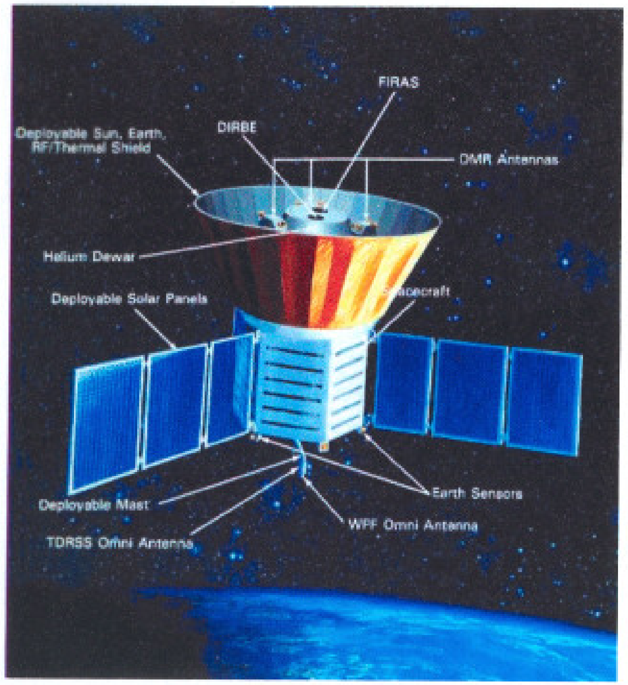
And, that's true. There is non-random structure: These filament-like strands are combinations of 11,000 galaxies (MW at the center).

The Cosmic Background Explorer (COBE)

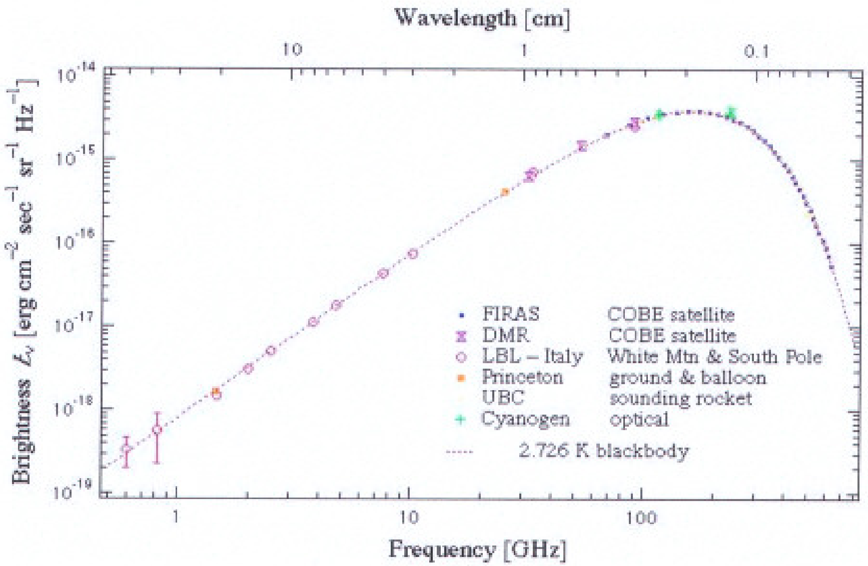
Specifically, a mission launched in 1989 to measure the CBM...and it's uniformity - the hot soup must start out uniform...BUT

- ...I mean, clumps do happen (us, Milky Way, etc)
- Now, it's incredibly precise...this plot has data points with error bars

COBE measured E&M radiation as a function of frequency outside of the earth's atmosphere



showing precisely the blackbody spectrum for a temperature of 2.726K



CHAPTER 4

"Structure of the Atom"

When did the notion of an atomic nucleus happen?

not until 1911...

The situation was confused.

An atom had:

- some + electricity
- balanced by electrons ← only known particle until 1907
- propensity to eject

  electrons (β "radiation")

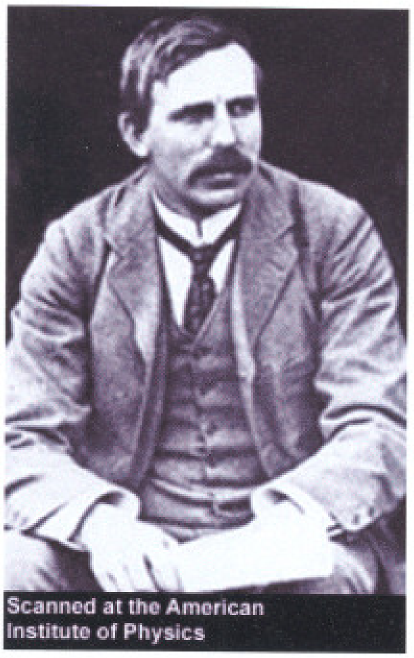
  He ions (α "radiation") ← found by Rutherford in 1907

In fact, "nuclear" physics was all-Rutherford from ~1898 – 1930's

1898 - 1907 McGill University

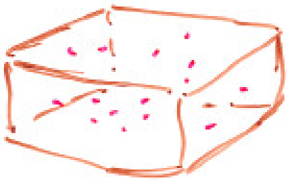
1907 - 1919 University of Manchester

1908: Nobel in Chemistry! & 1914: Knighthood


Scanned at the American
Institute of Physics

The accepted model for matter ~ 1910 was

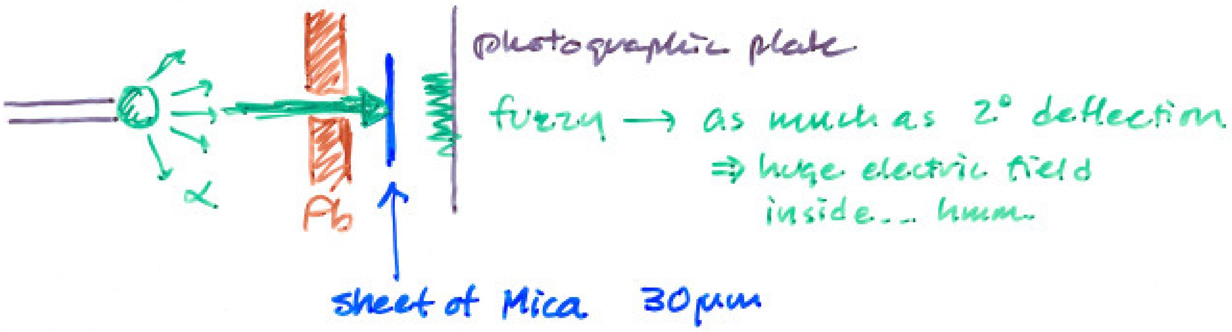
due to J.J.   Plum Pudding Model



positively charged jelly interspersed

electrons...

@ McGill he built an α beam...

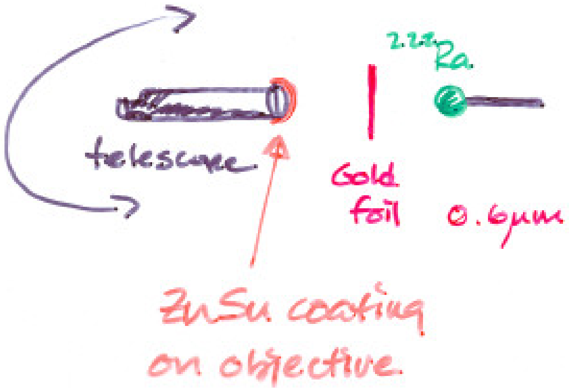


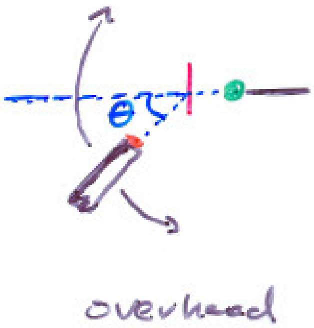
Set about to study this at Manchester

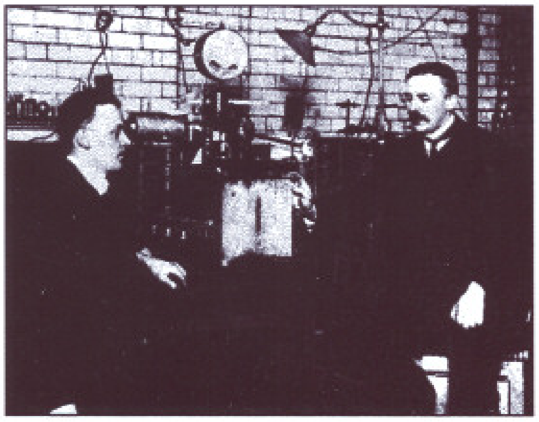
enlisted his "post doc" Hans Geiger

and student Ernest Marsden

to study it using







Rutherford,
Geiger, and Marsden would sit in the dark and count the flashes of light –

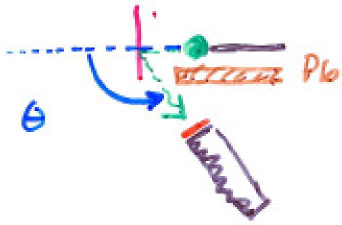
flouresance – Curies, 1903

could only work for about a minute

needed 100,000's of counts...

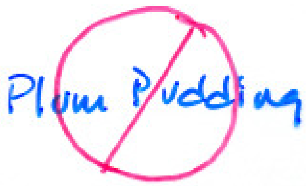
→ large, spurious backgrounds... why?

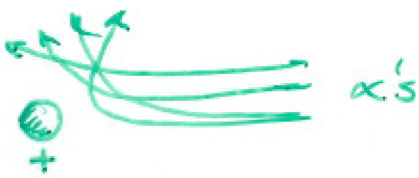
Rutherford thought Marsden needed a small project of his own... 1909: look at large scattering angles.



found particles at $\theta > \pi/2$!

Rutherford set out to understand this & in 1911 he had a proposal:

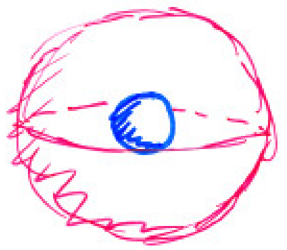




A + charged, massive core.

In 1913, Geiger reported: "...complete verification..." of Rutherford's theory*

eventually coined name "nucleus"...

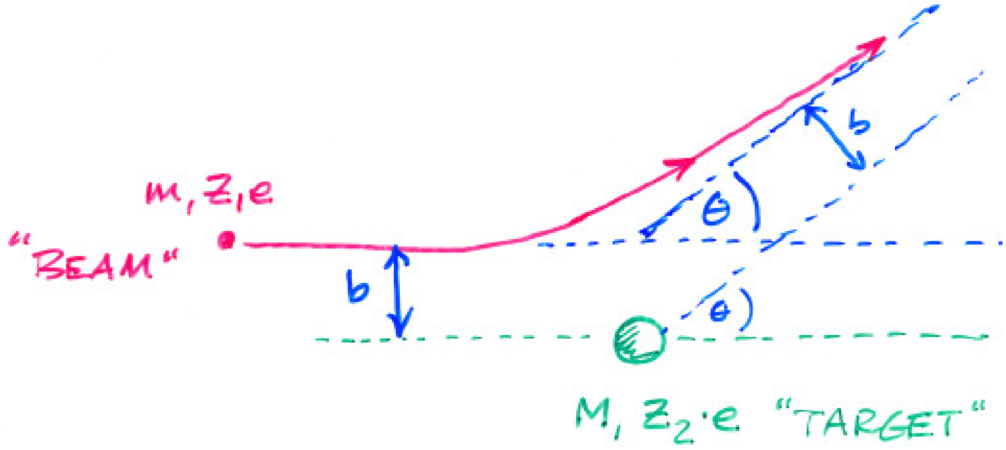


"... a central electric charge concentrated at a point and surrounded by a uniform spherical distribution of opposite electricity equal in amount."

translation: not so clear about what to do with electrons.

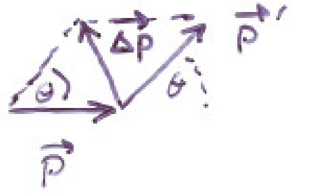
Let's go through Rutherford's theory – took him a year (and a model :-))

* There was a model due to Nagaoka in 1904:
Saturnian Model

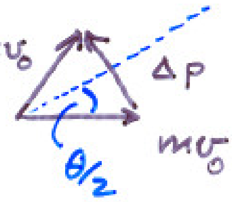


b is the "impact parameter" – the closest distance of approach

momentum situation:

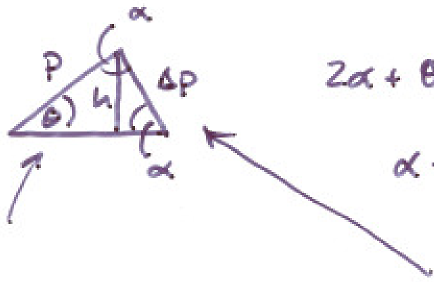


rearrange $|\vec{p}\,'| = mv_0$



$mv_0 = |\vec{p}|$

$$\Delta p = 2\,|p|\sin\theta/2$$



$$2\alpha + \theta = \pi$$

$$\alpha = \frac{\pi - \theta}{2}$$

$$\frac{h}{p} = \sin\theta \qquad\qquad \frac{h}{\Delta p} = \sin\alpha$$

$$h = p\sin\theta \qquad\qquad h = \Delta p \sin\alpha = \Delta p \sin\left(\frac{\pi}{2} - \frac{\theta}{2}\right)$$

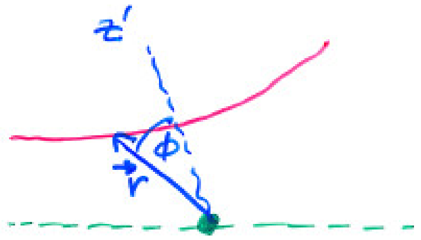
$$= \Delta p \cos\theta/2$$

$$p\sin\theta = \Delta p\cos\theta/2$$

$$\Delta p = p\,\frac{\sin\theta}{\cos\theta/2} \qquad\qquad \sin\theta = 2\sin\frac{\theta}{2}\cos\frac{\theta}{2}$$

$$\Delta p = 2p\sin\theta/2 \qquad\qquad |p| = mv_0$$

$$\Delta\vec{p} = \int \vec{F}_{\Delta p}\, dt \qquad \text{the impulse.}$$



In general $$\vec{F} = \frac{1}{4\pi\epsilon_0}\frac{z_1 z_2 e^2}{r^2}\hat{r}$$

$\vec{\Delta p}$ is along z'.. so, need component of $\vec{F}$ in that direction

$$\vec{F}: \quad F_{z'} = F\cos\phi$$

So,

$$\Delta p = 2mv_0 \sin\frac{\theta}{2} = \int F\cos\varphi\, d\varphi$$

$$= \frac{Z_1 Z_2 e^2}{4\pi\epsilon_0}\int \frac{\cos\varphi}{r^2}\, dt$$

Conserve angular momentum.

$$mr^2\frac{d\varphi}{dt} = mv_0 b$$

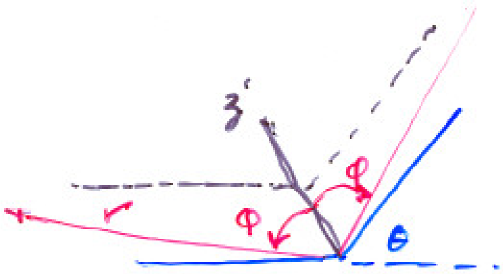
$$r^2 = \frac{v_0 b}{d\varphi/dt}$$

So

$$2mv_0\sin\theta/2 = \frac{Z_1 Z_2 e^2}{4\pi\epsilon_0}\int \frac{\cos\varphi}{v_0 b}\frac{d\varphi}{dt}\, dt$$

$$= \frac{Z_1 Z_2 e^2}{4\pi\epsilon_0 v_0 b}\int_{\phi_i}^{\phi_f}\cos\varphi\, d\varphi$$

The extremes of angle are



when $r \to \infty$, so $\varphi + \varphi + \theta = \pi$

$$\varphi = \frac{\pi - \theta}{2} \quad \text{and} \quad \int_{\varphi_i}^{\varphi_f}$$

goes from $-\left(\frac{\pi-\theta}{2}\right)$ to $+\left(\frac{\pi-\theta}{2}\right)$

so,

$$2 m v_0 \sin\theta/2 = \frac{Z_1 Z_2 e^2}{4\pi\epsilon_0 v_0 b} \int_{-(\pi-\theta/2)/2}^{(\pi-\theta)/2} \cos\varphi \, d\varphi$$

$$= \frac{Z_1 Z_2 e^2}{4\pi\epsilon_0 v_0 b} \, 2\cos\theta/2$$

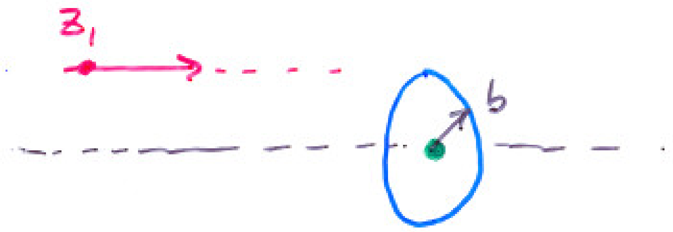
Solving for b:

$$b = \frac{Z_1 Z_2 e^2}{4\pi\epsilon_0 \underbrace{m v_0^2}_{2K}} \cot\theta/2$$

look at extremes:

$\theta = 0$	$\cot \theta/2 = \infty$	$\Rightarrow$	$b = \infty$	forward
$\theta = 90°$	$\cot \theta/2 = 1$		$\frac{z_1 z_2 e^2}{8\pi \epsilon_0 K}$	
$\theta = 180°$	$\cot \theta/2 = 0$	$\Rightarrow$	$b = 0$	backward

$\Rightarrow$ smaller impact parameter (b) $\Rightarrow$ larger scattering angle



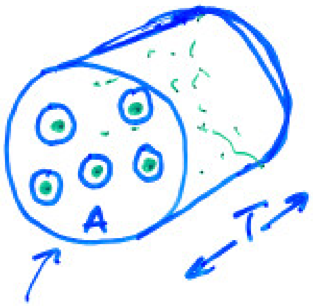
any particle hitting the area around the nucleus of πb^2 will scatter to a finite angle θ.

This is called the Scattering Cross Section

$$\sigma = \pi b^2$$

it's related to the probability that the particle is scattered by the nucleus (target)

But.. the "target" of an atom is actually lots of targets in a real material.



total area of the real target object.

n: # atoms per unit volume

T: thickness of target

A: area presented to the beam

N_M: # atoms per molecule

$$n = \left(\frac{\text{atoms}}{\text{mole}}\right)\left(\frac{\text{moles}}{\text{gram}}\right)\left(\frac{\text{grams}}{\text{volume}}\right)\cancel{\left(\frac{\text{atoms}}{\text{molecule}}\right)}$$

~~$= N_A$~~. $\left(\frac{1}{\text{gram molecular weight}}\right.$.

$$\frac{\text{atoms}}{\text{mole}} = \left(\frac{\text{atoms}}{\text{molecule}}\right)\left(\frac{\text{molecules}}{\text{mole}}\right) = N_M N_A$$

$$n = N_M N_A \frac{1}{M_g} \rho$$

$$[n] = [N_M][N_A]\left[\frac{1}{M_g}\right][\rho] = \left(\frac{\text{atoms}}{\cancel{\text{molecule}}}\right)\left(\frac{\cancel{\text{molecules}}}{\cancel{\text{mole}}}\right)\left(\frac{1}{\frac{\cancel{\text{gm}}}{\cancel{\text{mole}}}}\right)\left(\frac{\cancel{\text{g}}}{\text{cm}^3}\right)$$

$$= \frac{\text{atoms}}{\text{cm}^3}$$

atoms per unit area = $nT = \dfrac{\rho N_A N_M}{M_g} T$

So, the number of target atoms in a target of area A:

$$N_T = nTA = \frac{\rho N_A N_M T A}{M_g}$$

f : probability of a beam particle being scattered by target atom

$$f = \frac{(\#\text{ target atoms})(\text{area of each target atom})}{A}$$

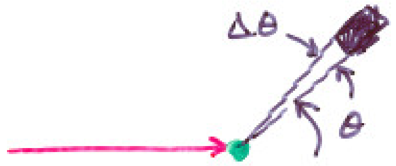
$$f = \frac{N_T \sigma}{A}$$

$$f = \frac{nTA\sigma}{A} = nT\pi b^2$$

$$f = nT\pi \left(\frac{Z_1 Z_2 e^2}{8\pi\epsilon_0 K}\right) \cot^2\theta/2$$

Remember the experimental situation — very typical

(from above, for Rutherford)



need the probability of scattering into the small angle slice of the telescope

a "differential cross section"

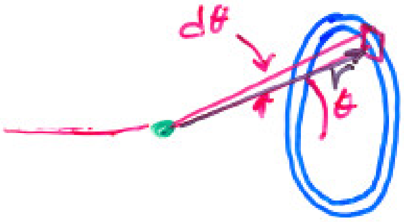
or "differential scattering probability"

differentiate

$$df = -\pi n T \left(\frac{z_1 z_2 e^2}{8\pi\epsilon_0 K} \right) \cot\frac{\theta}{2} \operatorname{cosec}^2\frac{\theta}{2}\, d\theta$$

"–" means that decrease in b means an increase in θ

actually account for scattering into an annulus – a ring..



Say that the beam has N_i beam particles.

scattered into the ring of width $d\theta$ is

$$N_i |df|$$

The area of the ring is $2\pi r \sin\theta \, r \, d\theta$

scattered per unit area between θ and $d\theta$ $= N(\theta)$

$$N(\theta) = \frac{N_i |df|}{2\pi r^2 \sin\theta \, d\theta}$$

$$N(\theta) = \frac{N_i n T}{16} \left(\frac{e^2}{4\pi\epsilon_0}\right)^2 \frac{Z_1^2 Z_2^2}{r^2 K^2 \sin^4 \theta/2}$$

Famous formula: "Rutherford Scattering" formula

- $\frac{1}{\sin^4 \theta/2}$, $\frac{1}{K^2}$ are characteristic features of "Rutherford Scattering"
- $\propto T$ for thin targets

Geiger & Marsden
Phil. Mag. 604, 1913

TABLE II

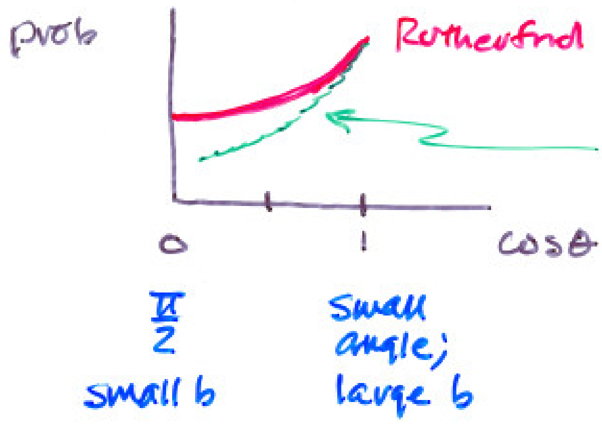
Variation of Scattering with Angle, (Collected results.)

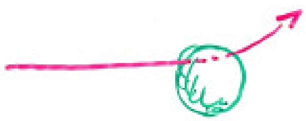
I.	II.	III.	IV.	V.	VI.
		SILVER.		GOLD.	
Angle of deflexion, f	1 / $\sin^4 a/2$	Number of scintil-lations, N	N / $\sin^4 f/2$	Number of scintil-lations, N	N / $\sin^4 f/2$
150	1.15	22.2	19.3	33.1	28.8
135	1.38	27.4	19.8	43.0	31.2
120	1.79	33.0	18.4	51.9	29.0
105	2.53	47.3	18.7	69.5	27.5
75	7.25	136	18.8	211	29.1
60	16.0	320	20.0	477	29.8
45	46.6	989	21.2	1435	30.8
37.5	93.7	1760	18.8	3300	35.3
30	223	5260	23.6	7800	35.0
22.5	690	20300	29.4	27300	39.6
15	3445	105400	30.6	132000	38.4
30	223	5.3	0.024	3.1	0.014
22.5	690	16.6	0.024	8.4	0.012
15	3445	93.0	0.027	48.2	0.014
10	17330	508	0.029	200	0.0115
7.5	54650	1710	0.031	607	0.011
5	276300	...	...	3320	0.012

A basic assumption — there is no size to the nucleus → classical Rutherford scattering is from point-like targets.

- electron scattering (much later) has the same form — just bends differently.

note $\frac{1}{\sin^4\theta/2} \rightarrow \propto \frac{1}{(1-\cos\theta)^2}$





suppose nucleus is large — charge spread out in space

→ can get closer to charge distribution of a proton, even, or nucleus as a whole with large K

This happened .. in 1950's

studies of nuclear charges and nuclear charge distributions ⇒ nuclear <u>sizes</u>

by deviation from "Rutherford"

more Energy:

Then .. late 1950's

began to see individual protons

→ which looked point-like → Rutherford

more Energy:

<u>Then</u> .. in 1960's

got diffuse again ..

more Energy:

<u>THEN</u>:

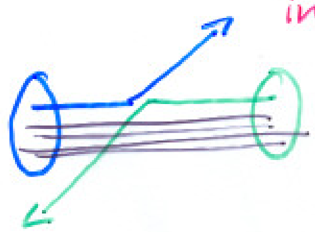
"Rutherford" returned .. point-like charged objects <u>within</u> the proton

→ quarks

more Energy:

NOW:

still <u>looking</u>



individual <u>quarks</u> scatter

STILL RUTHERFORD !

HOW CLOSE CAN YOU GO?

~ all kinetic

just stopped... all potential

$$E_{BEFORE} = E_{AFTER}$$

$$K = \frac{1}{4\pi\epsilon_0} \frac{Z_1 Z_2 e^2}{R_{min}}$$

$$R_{min} = \frac{Z_1 Z_2 e^2}{4\pi\epsilon_0 K}$$

Rutherford used α's of about 7.7 MeV...

the target was Gold.

$$R_{min} = \frac{(8.99\times10^{9})(2)(79)(1.6\times10^{-19})^2}{(7.7\times10^{6})(1.6\times10^{-19})}$$

$$\simeq 3\times10^{-14}\,m$$

as close as it gets

The radius of a gold nucleus is about 0.7×10^{-14} m, so Rutherford was not quite probing the structure of the nucleus.

What about the impact parameter, b?

a) very forward scattering. $\theta \sim 1°$

$$b = \frac{Z_1 Z_2 e^2}{8\pi\epsilon_0 K} \cot \theta/2$$

$$= \left(\frac{8.99\times10^9}{2}\right) \frac{(2)(79)(1.6\times10^{-19})^2}{(7.7\times10^6)(1.6\times10^{-19})} \cot(0.5°)$$

$$b = 1.48\times10^{-14} \cot(0.5°)$$

$$b \cong 1.7\times10^{-12}\ m$$

b) large angle? $\theta = 90°$?

$$b = 1.5\times10^{-14} \cot \pi/4$$

$$\cong 1.5\times10^{-14}\ m$$