Americans win Nobel physics prize

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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 1990. 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 8.

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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Furthermore, we do exist

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...

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

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*

![COBE Diagram]

- 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
The accepted model for matter ~ 1910 was due to J.J. Plum Pudding Model.

Positively charged jelly interspersed electrons.

At McGill he built an x-beam.

Photographic plate fuzzy as much as 2° deflection huge electric field inside... hmm.

Sheet of Mica 30 µm

Set about to study this at Manchester enlisted his "post-doc" Hans Geiger and student Ernest Marsden to study it using.

ZnSe coating on objective.
Rutherford, Geiger, and Marsden would sit in the dark and count the flashes of light—

fluorescence — Aries, 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:

Plum Pudding

A + charged, massive core.
In 1913, Geiger reported: "...complete verification..." of Rutherford's theory.

Eventually coined name "nucleus"...

```
pepositive, massive
core
```

"...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 is)

*There was a model due to Nagakura in 1934:
  *Saturnian Model*
$b$ is the "impact parameter" - the closest distance of approach.

Quantum situation:

\[ \Delta p = 2 |p| \sin \theta \]

\[ \frac{h}{p} = \sin \theta \]

\[ h = p \sin \theta \]

\[ h = \Delta p \sin \alpha \]

\[ h = \Delta p \tan \alpha = \Delta p \sin \left( \frac{\pi}{2} - \theta \right) = \Delta p \cos \theta \]

\[ p \sin \theta = \Delta p \cos \theta \]

\[ \Delta p = p \frac{\sin \theta}{\cos \theta} \]

\[ \Delta p = 2p \sin \theta \]

\[ |p| = m_0 \]
\[ \Delta p = \int F_{\Delta p} \, dt \quad \text{the impulse.} \]

In general \[ F = \frac{\vec{Z}_1 \vec{Z}_2 e^2}{4\pi\varepsilon_0 r^2} \]

\( \Delta p \) is along \( z' \) so, need component of \( \vec{F} \) in that direction \[ \vec{F}_z = F \cos \phi \]

So, \[ \Delta p = 2mv_0 \sin \theta \frac{d\phi}{dt} = \int F \cos \phi \, d\phi \]

\[ = \frac{Z_1 Z_2 e^2}{4\pi \varepsilon_0} \int \frac{\cos \phi \, d\phi}{r^2} \]

Angular conservation of momentum. \[ m r^2 \frac{d\phi}{dt} = m v_0 b \]

\[ r^2 = \frac{v_0 b}{d\phi/dt} \]

So \[ 2mv_0 \sin \theta \frac{d\phi}{dt} = \frac{Z_1 Z_2 e^2}{4\pi \varepsilon_0} \int \frac{\cos \phi \, d\phi}{v_0 b} \]

\[ = \frac{Z_1 Z_2 e^2}{4\pi \varepsilon_0 v_0 b} \int \cos \phi \, d\phi \phi_i \]
The extremes of angle are

when \( r \to \infty \), so \( \varphi + \Phi + \theta = \pi \)

\[ \varphi = \frac{\pi - \theta}{2} \quad \text{and} \quad \int_{\Phi_i}^{\varphi_f} \varphi \, d\varphi \]

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

so,

\[ 2mu_0 \sin \theta \frac{\pi}{2} = \frac{Z_{i}Z_{e}e^{2}}{4\pi \varepsilon_0 c_0 b} \int_{\Phi_i}^{(\pi - \theta)/2} \cos \varphi \, d\varphi \]

\[ = \frac{Z_{i}Z_{e}e^{2}}{4\pi \varepsilon_0 c_0 b} \left( 2 \cos \frac{\pi}{2} \right) \]

Solving for \( b \):

\[ b = \frac{Z_{i}Z_{e}e^{2}}{4\pi \varepsilon_0 \mu_0 c_0^2} \frac{\cot \frac{\pi}{2}}{2K} \]
Look at extremen:

\[ \theta = 0 \quad \cot \theta/2 = \infty \quad \Rightarrow \quad b = \infty \quad \text{forward} \]

\[ \theta = 90^\circ \quad \cot \theta/2 = 1 \quad \Rightarrow \quad \frac{2 \lambda_2 e^2}{8 \pi \hbar K} \]

\[ \theta = 180^\circ \quad \cot \theta/2 = 0 \quad \Rightarrow \quad b = 0 \quad \text{backward} \]

\[ \Rightarrow \quad \text{smaller impact parameter (} b \text{)} \Rightarrow \text{larger scattering angle} \]

\[ \vec{b}, \quad \vec{b}_1 \rightarrow \quad \text{any particle hitting the area around the nucleus of } T \text{ will scatter to a finite angle } \theta. \]

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.

![Diagram of a cylinder with a target area highlighted.](image)

total area of the real target object.

$n$: number of atoms per unit volume

$T$: thickness of target

$A$: area presented to the beam

$N_m$: number of atoms per molecule

\[
 n = \frac{\text{atoms}}{\text{w} \cdot \text{mole}} \cdot \frac{\text{mole}}{\text{gram}} \cdot \frac{\text{gram}}{\text{volume}} \cdot \frac{\text{volume}}{\text{mole}} \cdot \frac{1}{\text{gram molecular weight}} \\
= \frac{N_A}{M_g}.
\]

\[
\frac{\text{atoms}}{\text{w} \cdot \text{mole}} = \left( \frac{\text{atoms}}{\text{mole}} \right) \cdot \left( \frac{\text{mole}}{\text{w} \cdot \text{mole}} \right) = N_m \cdot N_A
\]

\[
 n = N_m \cdot N_A \cdot \frac{1}{M_g} \cdot \rho
\]

\[
 [n] = [N_m] [N_A] \left[ \frac{1}{M_g} \right] [\rho] = \left( \frac{\text{atoms}}{\text{mole}} \right) \cdot \left( \frac{\text{mole}}{\text{w} \cdot \text{mole}} \right) \cdot \left( \frac{1}{\text{gm} \cdot \text{w} \cdot \text{mole}} \right) \cdot \left( \frac{1}{\text{cm}^3} \right)
= \frac{\text{atoms}}{\text{cm}^3}
\]
*atoms per unit area = \( nT = \frac{\rho N A N M T}{M_g} \)

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

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

\[
f = \frac{N_T \sigma}{A}
\]

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

\[
f = nT \pi \left( \frac{Z_1 Z_2 e^2}{8\pi \varepsilon_0 K} \right) \cot^2 b/2
\]
Remember the experimental situation—very typical
(from above, for Rutherford)

only detect scatters
in telescope
scatters happen everywhere

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

a "differential cross section"
or "differential scattering probability"

differentiate

\[ df = -\pi n T \left( \frac{2z^2x^2}{8\pi^2cK} \right) \cot \frac{\theta}{2} \cos \theta \csc \frac{\theta}{2} \ d\theta \]

"\dfrac{\theta}{2}\" means that decrease in \( b\) means
an increase in \( \theta \)
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 $2\pi r^2 \sin \theta r d\theta$

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

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

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

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
TABLE II
Variation of Scattering with Angle, (Collected results.)

<table>
<thead>
<tr>
<th>I. Angle of deflexion, f</th>
<th>II. ( \frac{\sin^4a}{2} )</th>
<th>III. Number of scintillations, N</th>
<th>IV. ( \frac{\sin^4f}{2} )</th>
<th>V. Number of scintillations, N</th>
<th>VI. ( \frac{\sin^4f}{2} )</th>
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<td>33.1</td>
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<td>...</td>
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</tbody>
</table>
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, but bends differently.

\[ \frac{1}{\sin \theta / 2} \rightarrow \alpha \frac{1}{(1 - \cos \theta)^2} \]

\[ \text{Prob} \]

\[ \text{Rutherford} \]

\[ \text{Evidence of size.} \]

\[ \text{Small angle;} \quad \frac{\pi}{2} \]

\[ \text{Small } b \quad \text{Large } b \]

Suppose nucleus is large — change spread out in space.

\[ \rightarrow \text{can get closer to charge distribution of a proton, even, or nucleus as a whole with large } K \]
This happened -- in 1950's

studies of nuclear charges and nuclear charge
distributions ⇒ nuclear sizes

by deviation from “Rutherford”

more Energy:
Then -- late 1950's

began to see individual protons

⇒ which looked point-like ⇒ Rutherford

more Energy:
Then -- in 1960's

got diffuse again --

more Energy:
THEN:

“Rutherford” returned -- point-like changed
objects within the proton

⇒ quarks

more Energy:
NOW:

still looking

individual quarks scatter

STILL RUTHERFORD!
How close can you go?

\[ \alpha \quad \rightarrow \quad N \]

far away.

\[ \text{just stopped... all potential} \]

\[ E_{\text{before}} = E_{\text{after}} \]

\[ K = \frac{1}{4\pi \varepsilon_0} \frac{Z_1 Z_2 e^2}{R_{\text{min}}} \]

\[ R_{\text{min}} = \frac{Z_1 Z_2 e^2}{4\pi \varepsilon_0 K} \]

Rutherford used \( X \)'s of about 7.7 MeV.

the target was gold.

\[ R_{\text{min}} = \left( \frac{8.87 \times 10^{-9}}{(2)(19)(1.6 \times 10^{-19})^2} \right) \]

\[ \frac{1}{2} \left( \frac{7.7 \times 10^5}{4 \times 10^{-19}} \right) \]

\[ \approx 3 \times 10^{-14} \text{ m} \]

as close as it gets

The radius of a gold nucleus is about \( 0.7 \times 10^{-14} \text{ m} \),
so Rutherford was not quite probing the structure of the nucleus.
What about the impact parameter, $b$?

a) Very forward scattering, $\theta \approx 1^\circ$

\[
b = \frac{2\frac{h^2}{e^2}}{8\pi\hbar K} \cot \theta/2
\]

\[
= \left(\frac{8.59 \times 10^9}{2}\right) \left(\frac{2}{1.6 \times 10^{-19}}\right)^2 \left(\frac{7.7 \times 10^{-4}}{1.6 \times 10^{-19}}\right) \cot (0.5^\circ)
\]

\[
b = 1.48 \times 10^{-14} \cot (0.5^\circ)
\]

\[
b \approx 1.7 \times 10^{-12} \text{ m}
\]

b) Large angle? $\theta = 90^\circ$?

\[
b = 1.5 \times 10^{-14} \cot \frac{\pi}{4}
\]

\[
\approx 1.5 \times 10^{-14} \text{ m}
\]