What Satellites See:
Eyes Above the Skies

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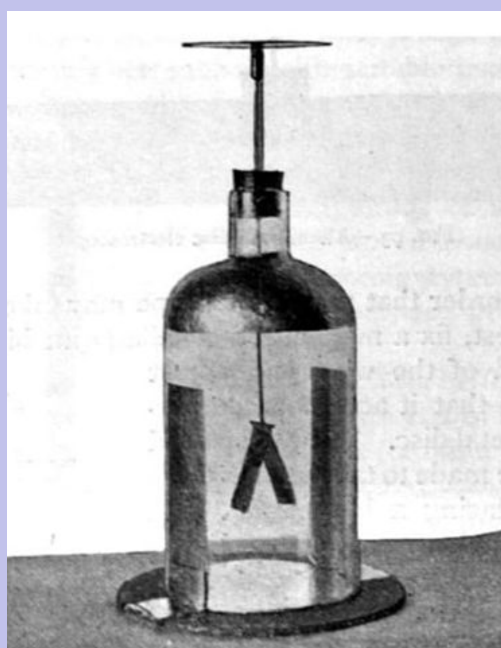
Wind Crest Learners

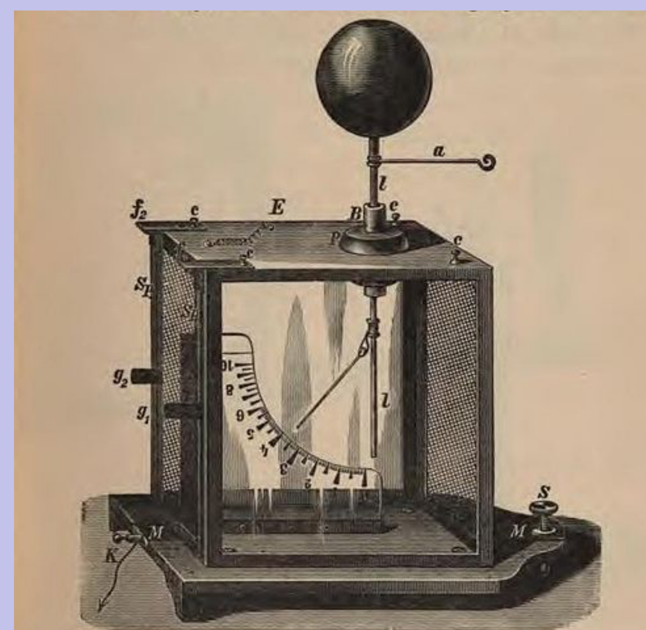
Academy for Lifelong Learning

Electroscopes

- ~1600: William Gilbert (1544-1603)
- 1787: Gold leaf electroscope

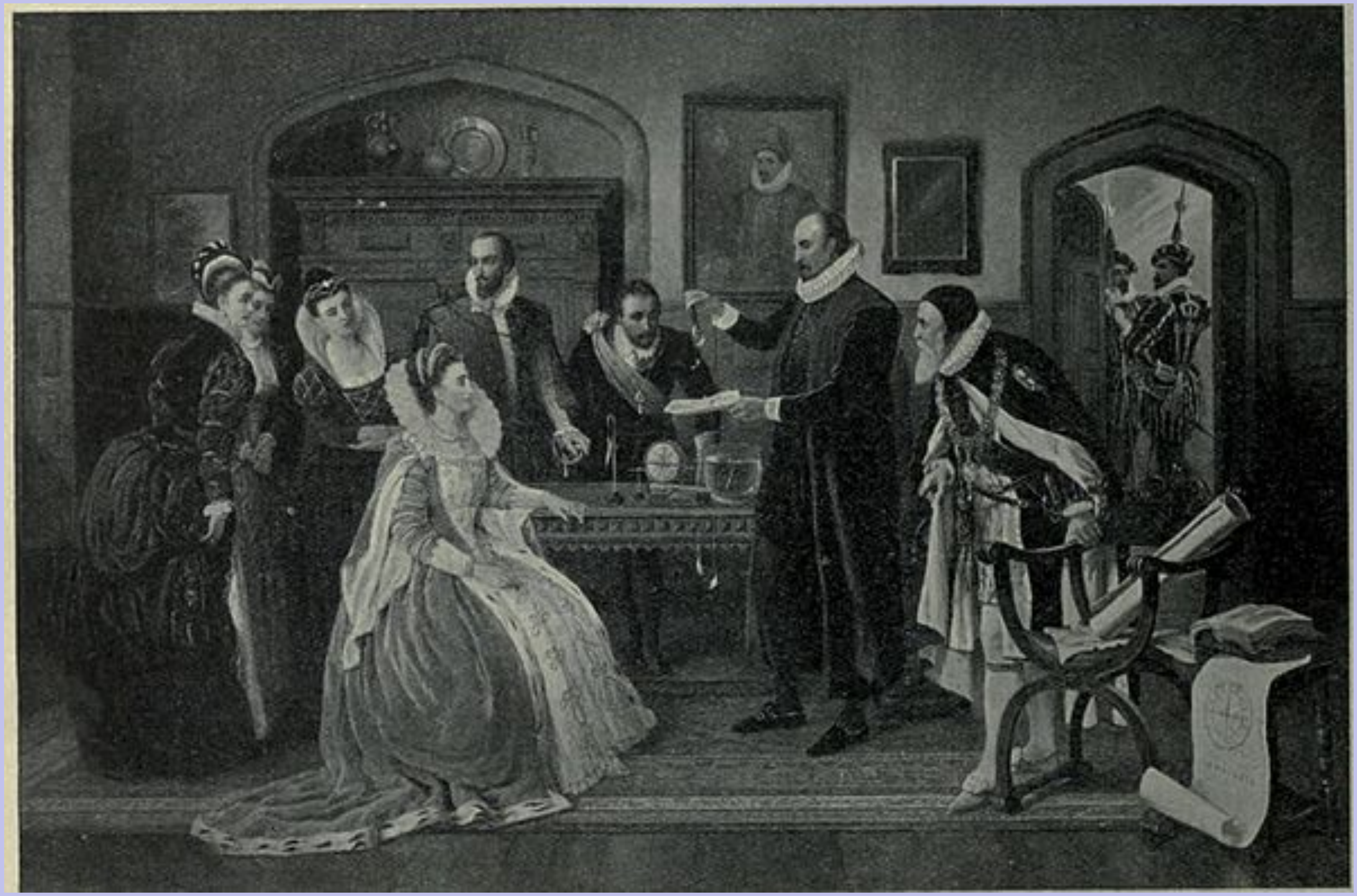


Homemade 1910



Kolb electroscope, ca. 1900

Gilbert demonstrating to Queen Elizabeth



Painting by A. Auckland Hunt

So what was known in 1900?

- Newton's basic laws of force and why planets go around the sun in elliptical orbits
- Mechanical laws of macroscopic objects
- Maxwell – electricity and magnetism
- Electron had been discovered – J. J. Thompson 1897
- Radioactivity – Marie Sklodowska-Curie
- X-rays discovered

Maxwell (1831-1879)

Nobel 1903

Curie (1867 – 1934)

Nobel 1906

Thompson (1885-1940)

Nobel 1901

Roentgen (1845-1923)

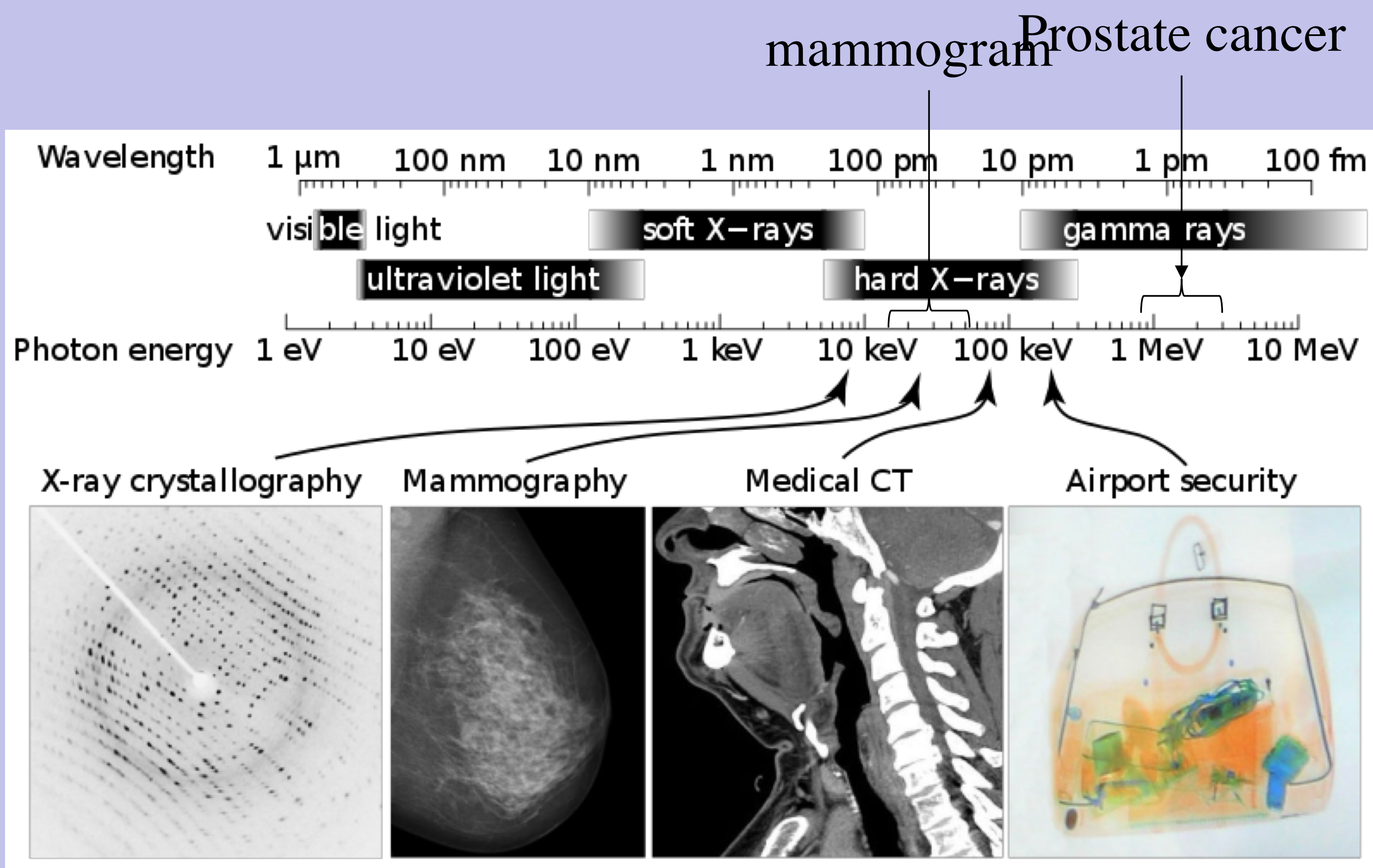
Radioactivity

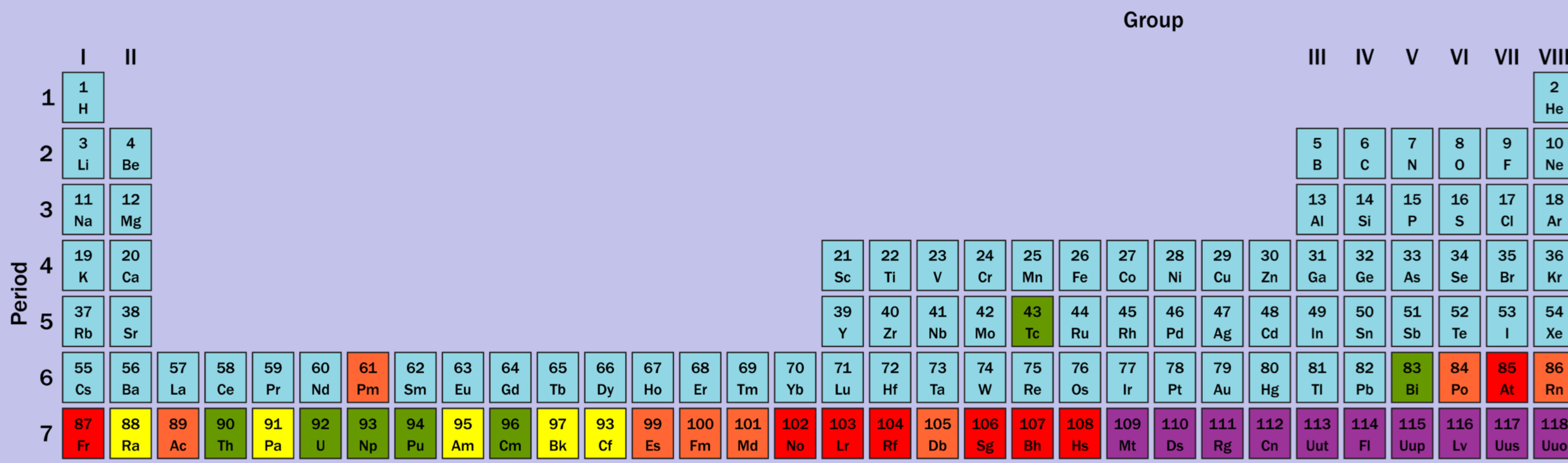
- Alpha particles – He nuclei without electrons; He^{++}
  - Stopped by sheet of paper
- Beta decay (aka electrons e^-)
- Positron emission (e^+)
- Gamma-ray emission (γ-rays)
  - largest range (use Pb)
- Fission –smallest range

} Range few mm to cm (Beta decay and Positron emission)

All these particles can be emitted by the radioactive decay of different nuclei. They tend to have energy from 100 keV to a few Mev.

Not all x-rays are created equal





Elements with at least one stable isotope are shown in light blue. Green shows elements whose most stable isotope has a half-life measured in millions of years. Yellow and orange are progressively less stable, with half-lives in thousands or hundreds of years, down toward one day. Red and purple show highly and extremely radioactive elements where the most stable isotopes exhibit half-lives measured on the order of one day and much less.

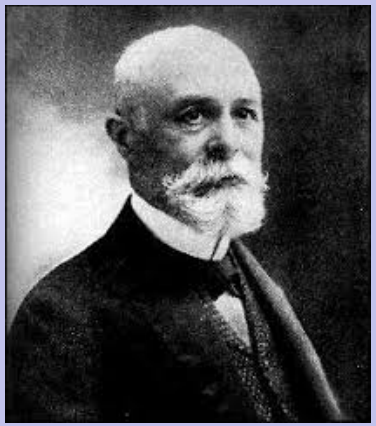
So what was not known in 1900?

- Discovery of atomic nuclei 1911 (Ernest Rutherford)
- Protons not discovered until 1919 (Goldstein/Rutherford)
- Neutrons discovered in 1932 (James Chadwick)
- Cloud chambers (Charles T. R. Wilson) – opps 1894

https://www.youtube.com/watch?v=apCUlYqGUA0

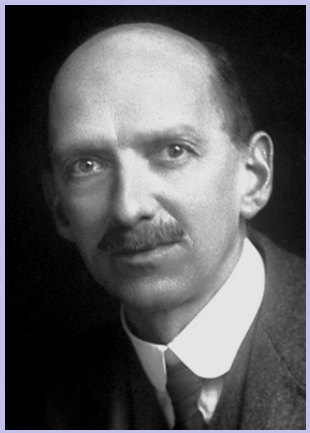
Nobel 1908 (ch)

Rutherford (1871-1937)



Eugen Goldstein (1850-1930)

Nobel 1927



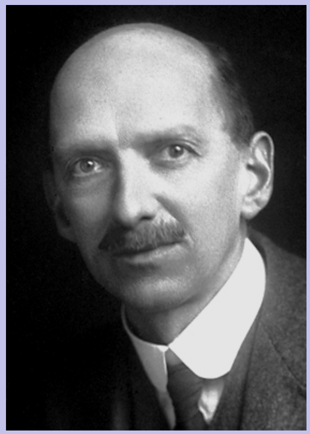
Wilson (1869-1959)

Nobel 1935

Chadwick (1891-1974)

What is all this radiation?

Nobel 1927



Wilson (1869-1959)

Wilson had speculated in 1901 paper that there was *penetrating radiation of some kind* not coming from the Earth.

They knew about radioactivity. Certainly this was part of the radiation.

So a debate raged for 10 years or more.

Where was proof?

Electroscopes were the tool of choice.

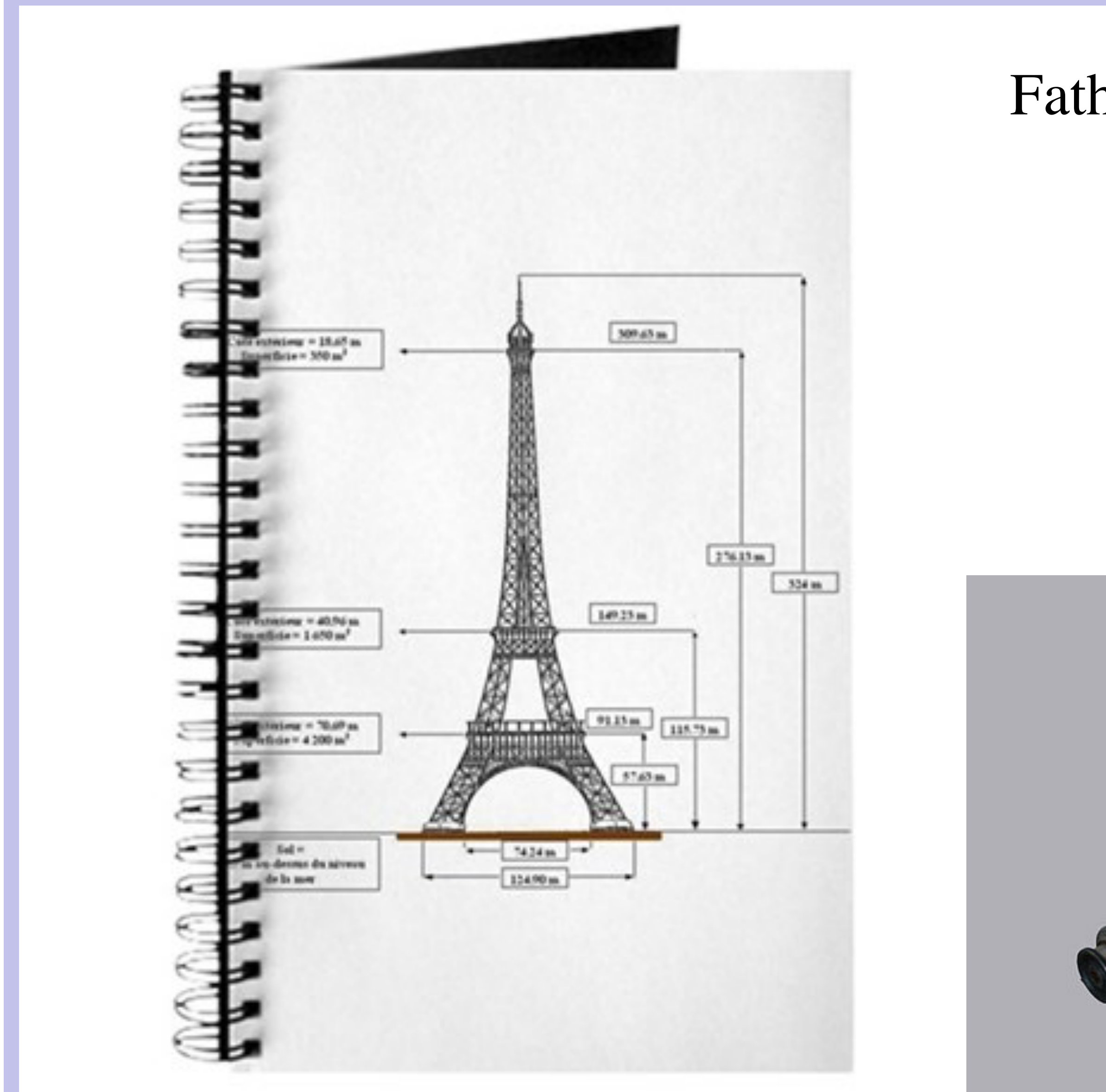
Electroscopes

Charged particles going through the atmosphere cause ionization of the air. Ions in the air discharge the electroscopes. The more ions, the faster the electroscopes discharge. So the discharge rate is a measure of the number of ions in the air.

So the electroscope is the "first" eye we had in the sky.
It isn't quite above the sky yet, but it's how it all started.

Father Theodor Wulf, 1909

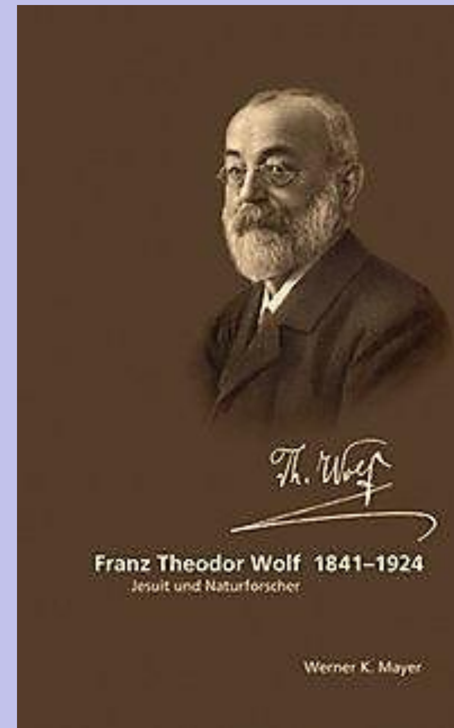
Datum	Ort	Ionen ccm sec
28. März	Valkenburg	22,5
29. "	Paris, Boden	17,5
30. "	" Eiffelturm	16,2
31. "	" "	14,4
1. April	" "	15,0
2. "	" "	17,2
3. "	" Boden	18,3
4. "	Valkenburg	22,0



Eiffel Tower, opened 1889

Theodor Wolf's 1909 electroscope

German scientist and Jesuit priest



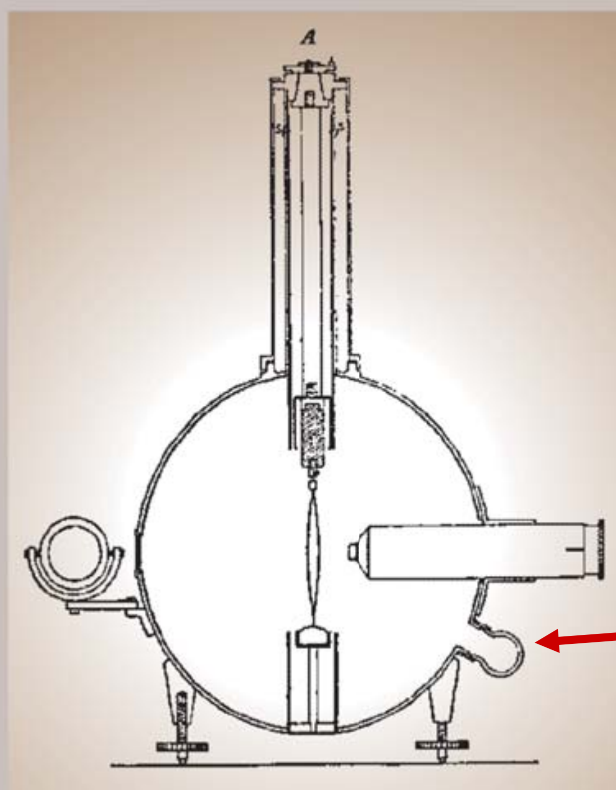


Figure 2. Theodor Wulf's 1909 electroscope. Shown in cross section is the instrument's 17-cm-diameter zinc cylinder with its pair of flexible wires below the access tower *A*. The wires are pushed apart by static electricity, and the microscope peering in from the right measures their separation, illuminated by light from the mirror at left. The air in the cylinder was kept dry by sodium in the small recess below the microscope. (Adapted from ref. 1.)

Eiffel tower (300 m)
Less radiation

Sodium to keep the air dry

An uncalibrated electroscope
A Univ. of Denver technician

Electroscopes going everywhere

Measuring the natural radioactivity of the elements of Earth

- up mountains
- over lakes
- over sea
- underwater (3 m depth)

Mme Curie had discovered this Natural radiation.

The story of cosmic rays:

- Discovery of cosmic rays
- Role of Colorado Mountains
- The beginnings of “high energy physics” and the study of particles on a microscopic scale

Let’s build a simple electroscope.

https://www.wikihow.com/Make-an-Electroscope

Domenico Pacini. (1879 – 1934)

Electroscopes going everywhere
- up mountains
- over lake
- over sea
- underwater

In an experiment performed in June 1911, in a submarine supplied by the Italian Navy, Pacini took an electroscope to a depth of 3 m in the Bay of Livorno.

Livorno, Italy

Not far from Pisa and connected to Florence by the Arno River. Ferrys to Corsica, Sardinia and Sicily.

Domenico Pacini, June 1911

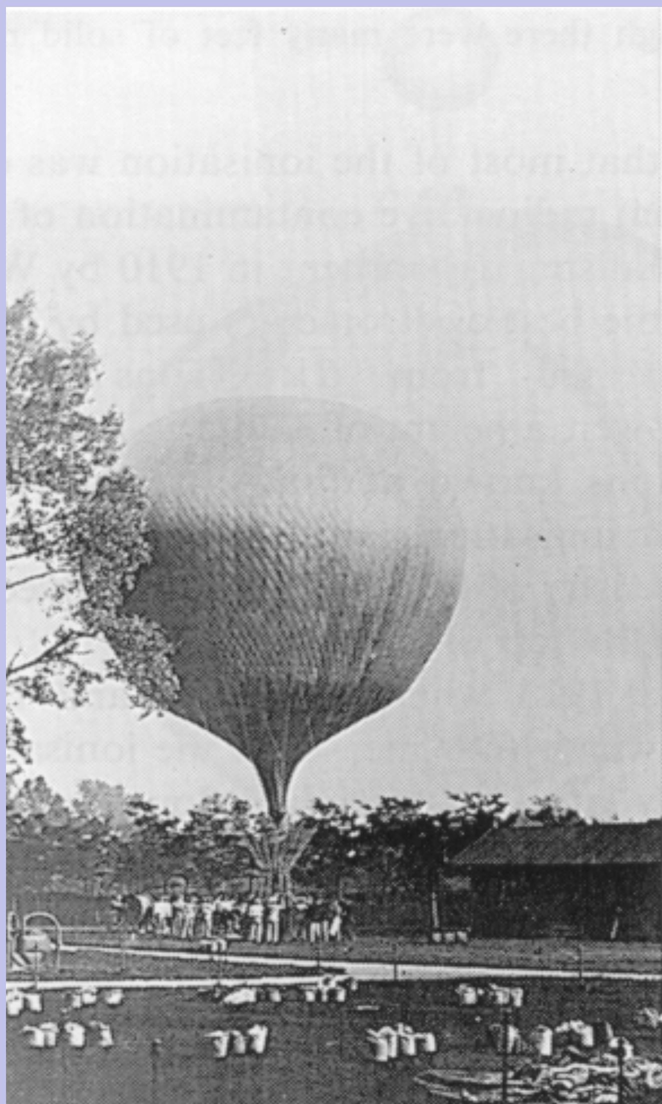
He concluded: *"a sizable cause of ionization exists in the atmosphere, originating from penetrating radiation, independent of the direct action of radioactive substances in the soil."*

1879 – 1934

D. Pacini (1912). *La radiazione penetrante alla superficie ed in seno alle acque*. Il Nuovo Cimento Serie VI, Tomo 3: 93-100.

(from translation by De Angelis, 2017)

Victor Hess in a hot air balloon
7 August, 1912, Aussig, Bohemia (Czech Republic)




Where the heck is this?

Aussig -> Ústí nad Labem

North of Prague, near the German border.

Found this photo on the web – never seen before

How high did they go?

Crew of 2 men

17,400 ft!!

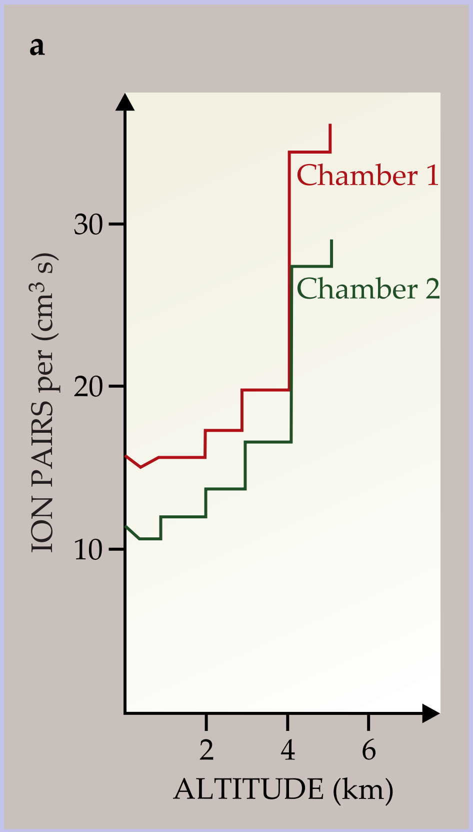
Lots of flights
2 in 1911
7 in 1912 and
1 in 1913
(5 at night)

During a solar eclipse
Not due to the sun.

Landed near Bad Saarow-Pieskow, Germany
about 200 km to the north

Discovery of Höhenstrahlung

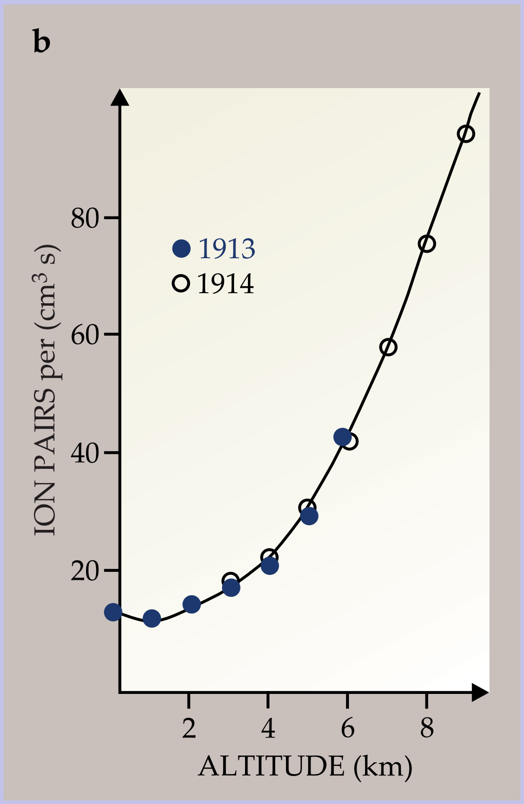
radiation at heights, high altitude radiation



V. Hess, 1912

"The results of the present observations seem to be most readily explained by assuming that radiation of very high penetrating power enters the atmosphere from above, and can still produce a part of the ionization observed in closed vessels at the lowest altitudes."

Electromagnetic radiation??



W. Kolhörster, 1913 & 1914

What is this radiation?

- First question: is the radiation charged or neutral?
- Electrons and gamma rays were known and radioactivity had been discovered
- Protons and neutrons were not identified yet, but radioactivity had been discovered
- WW1 slows research

History of Pikes Peak

- The Ute Indians, also known as the Blue Sky People, referred to the mountain as *Sun Mountain Sitting Big*. They believed that the entire world was created at this location by the Great Spirit who poured ice and snow through a hole in the sky to make the mountain.
- 1806: Pike saw the mountain from Pueblo. He called it Grand Peak. They only got to the top of Mt. Rosa one cold Nov. day and turned back.
- First known ascent 1820: Dr. Edwin James, a naturalist, so it was called James Peak until it was overridden in army annals as Pikes Peak.

History of Pikes Peak

- 1873 Weather station established by Army Signal Service. It was manned summer and winter. Access by mule.
- 1887: First crude road up the mountain. Built by the Cascade and Piles Peak Toll Road Company.
- 1888: Weather station closed. No correlation between weather at 14,115 ft and in Colorado Springs.
- 1889: A homestead act claim was filed for the summit by the mayor of Manitou Springs. He hauled dirt to grow corn, wheat, oats and potatoes. His claim was denied.
- 1890: Cog Railroad built to summit

It’s just rocks at the summit

but the view of the plains and mountains to the west is fantastic.

View from summit - east

View from summit - west

Katharine Lee Bates

- "We stood at last on the gate of heaven's summit….and gazed in wordless rapture over the far expanse of mountain ranges and the sea-like sweep of plain." (1893)
- "America the Beautiful"

The competition

Caltech (Robert Millikan) vs.

The U. of Chicago (Arthur Holly Compton)

Two Nationally famous scientists

In a competition to understand the cosmic rays.

This quest led to the discovery of new particles

and the beginnings of *high energy physics*.

This modern name for the field of study has led to the great accelerators and discoveries of quarks and the Higgs particle.

The problem

The problem was to figure out what was coming into the Earth by looking at the charged particles in the atmosphere. And not knowing what the penetrating particle was.

- Colorado’s accessible mountains played a big role in the research.

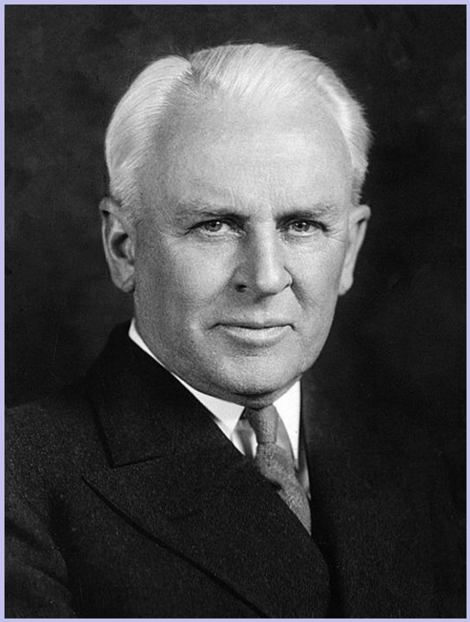
Instruments that sees ionization

- Electroscopes
- Wilson cloud chamber
- Ion chambers
- Photographic emulsions

These devices all measure basically the same thing,
the amount of ionization caused by energetic charged particles.

Let's detour to understand ionization tracks that allow charged particles to be visualized

Robert A. Millikan famous for his measurement of the charge of an electron Nobel prize, 1923



Starts studying cosmic rays with an ion chamber.

He thinks this mysterious radiation is neutral.

R. A. Millikan

Pikes Peak summer 1923

R. A. Millikan
Proc. Nat. Acad. Sci., **12**, 48; 1926
Pikes Peak summer 1923

"In a word, our Pikes Peak observations showed that if rays of cosmic origin existed at all they must be of different characteristics from any as yet suggested, and they further showed most interestingly that a very copious soft radiation of unknown origin existed at the altitude of Pikes Peak."

"soft radiation" was local and easily absorbed in a lead shield around the apparatus. It had been shown that this was not the "highly penetrating" radiation that was the subject of the discussion. More on this component later.

Another quote, same paper

"Unfortunately the psychics will of course be explaining all kinds of telepathies with the aid of these cosmic rays."

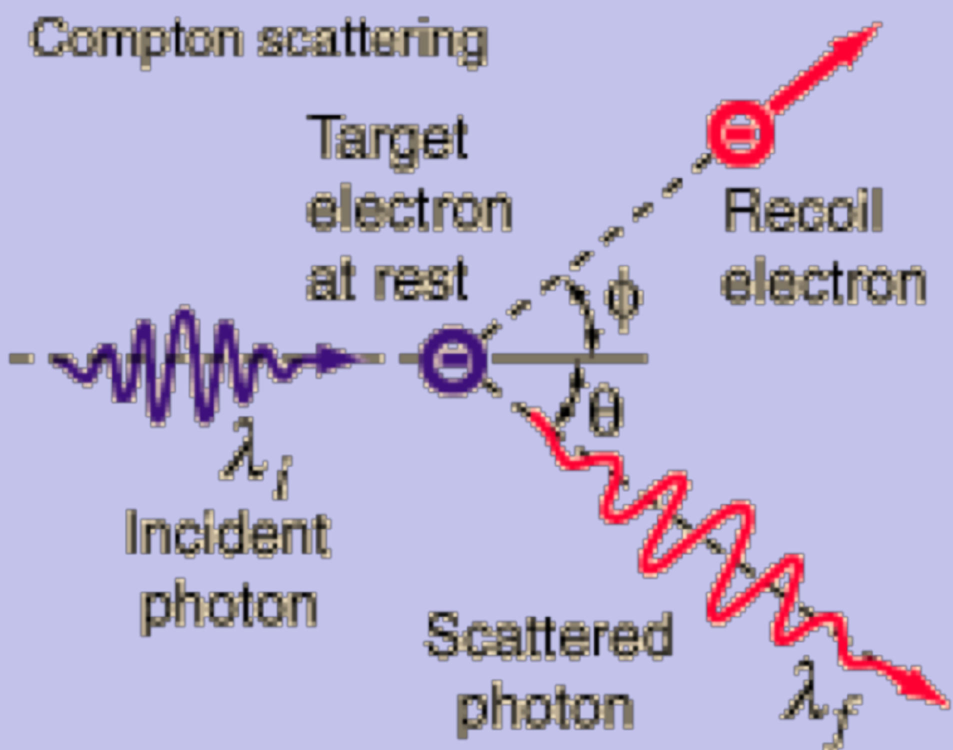
I looked on the web to find an image of a psychic to put here.

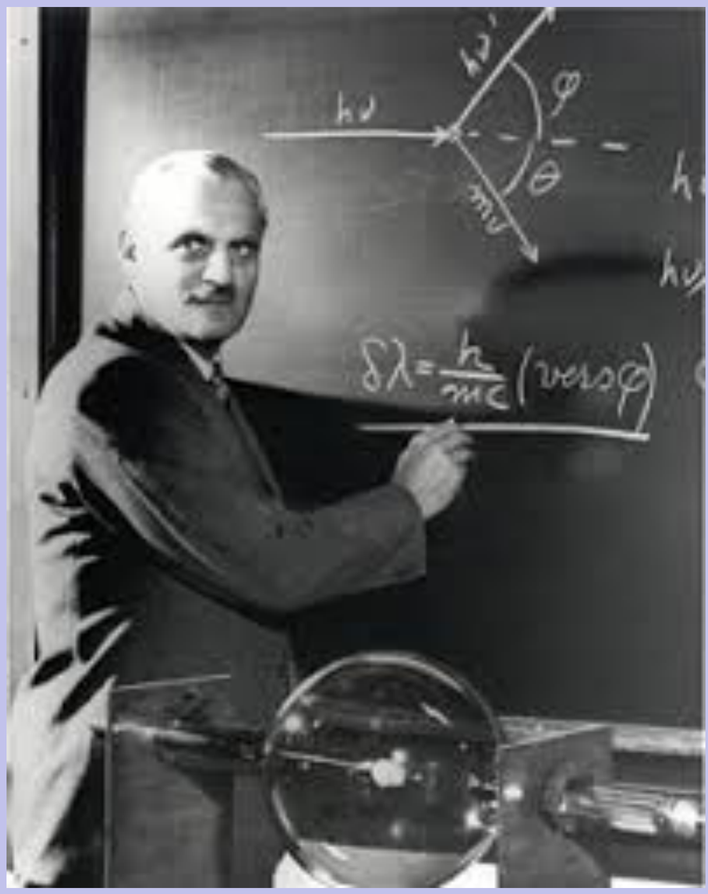
Hubble Space Telescope
image of the Helix Nebula.
A dying star about to become a white dwarf.

aka “The Eye of God”

Arthur Holly Compton

He showed how photons can collide with e- as balls on a pool table.





This theory is known as Compton Scattering

The press making news

Millikan coined the term cosmic rays. He though they were *neutral* and the “birth cries of atoms” in the galaxy.

Compton thought they were charged particles based on his latitude measurements.

1932

The New York Times

MILLIKAN RETORTS HOTLY TO COMPTON IN COSMIC RAY CLASH

Debate of Rival Theorists Brings Drama to Session of Nation's Scientists.

THEIR DATA AT VARIANCE

New Findings of His Ex-Pupil Lead to Thrust by Millikan at 'Less Cautious' Work.

Millikan vs. Compton

- Millikan was skeptical about radiation being extraterrestrial in origin
  - Texas balloon flight
- He did a latitude survey but saw little effect
  - Survey was at high geomagnetic latitudes where the effect at sea level is small
- 1932: Compton measured latitude effect larger for lower energy particles
- 1933: Millikan caved when he saw latitude effect in airplane flights

from: Friedlander, M.W., Cosmic Rays, Harvard Univ. Press., 1989

Figure 3.3
Victor Hess examining equipment used by Arthur Compton during his worldwide survey. Note the heavy shielding around the apparatus, housed on the ship deck. (Courtesy of Washington University Archives.)

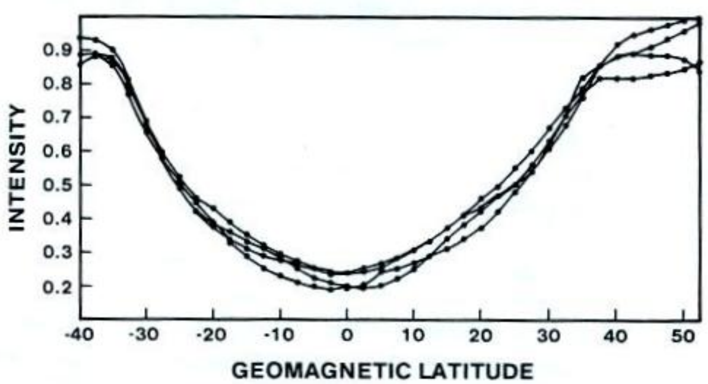


Figure 3.4
Results of Compton's survey, showing cosmic ray intensity at sea level for various geomagnetic latitudes. The four curves represent data taken during different seasons. (Adapted from Physical Review *52 [1937]: 808.)*

Latitude surveys, using heavily shielded ion chambers on-board ships, to remove radioactive background, proved cosmic rays were charged particles.

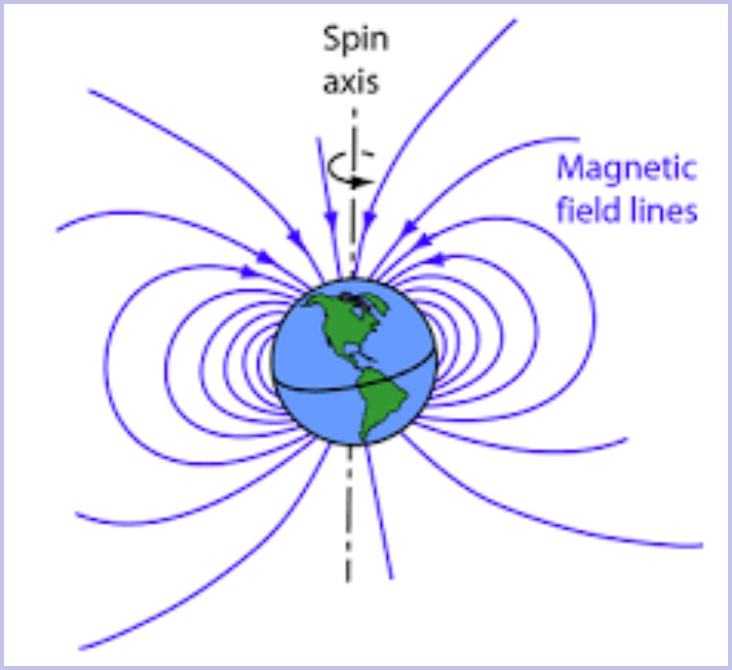
Millikan had a blind-spots.

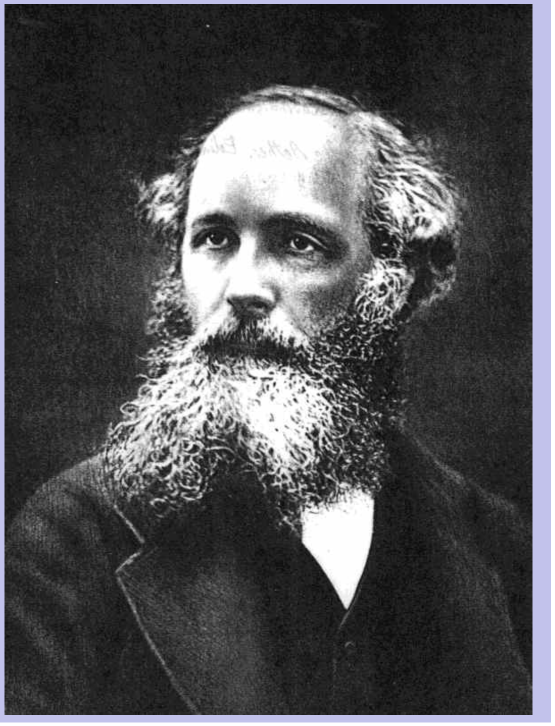
He thought the radiation was some kind of ultra-high energy photon, e.g. a gamma-ray. If that's correct, then you don't think too much about the effects of the magnetic field because photons don't have charge.

What are those effects.

It was known at the time that the Earth had a magnetic field like a bar magnet and that charged particles had curved trajectories in magnetic fields.

James Clerk Maxwell
1831 - 1879





Let's see what the Magnetic field does

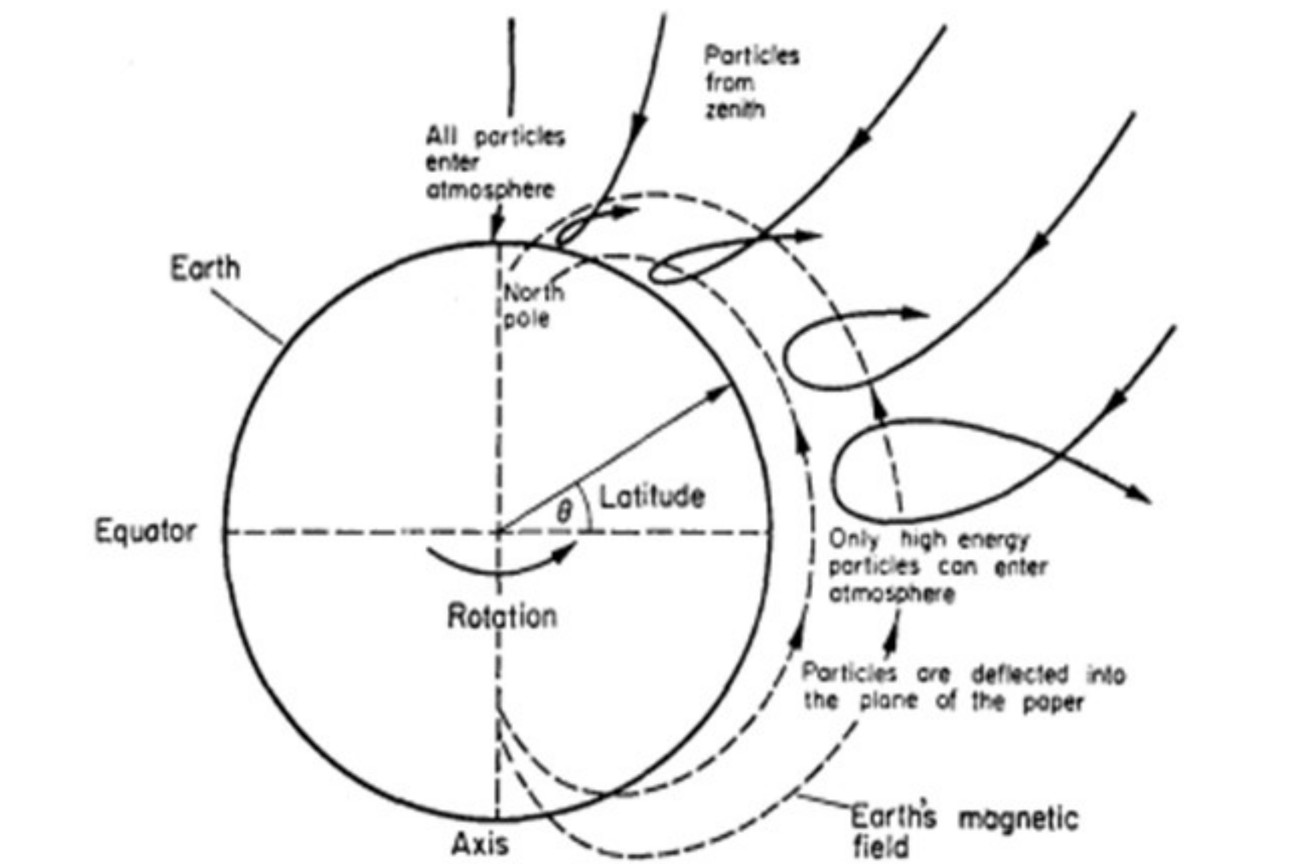


Fig. 25.3 Deflection of cosmic ray particles approaching from zenith showing action of earth's magnetic field.

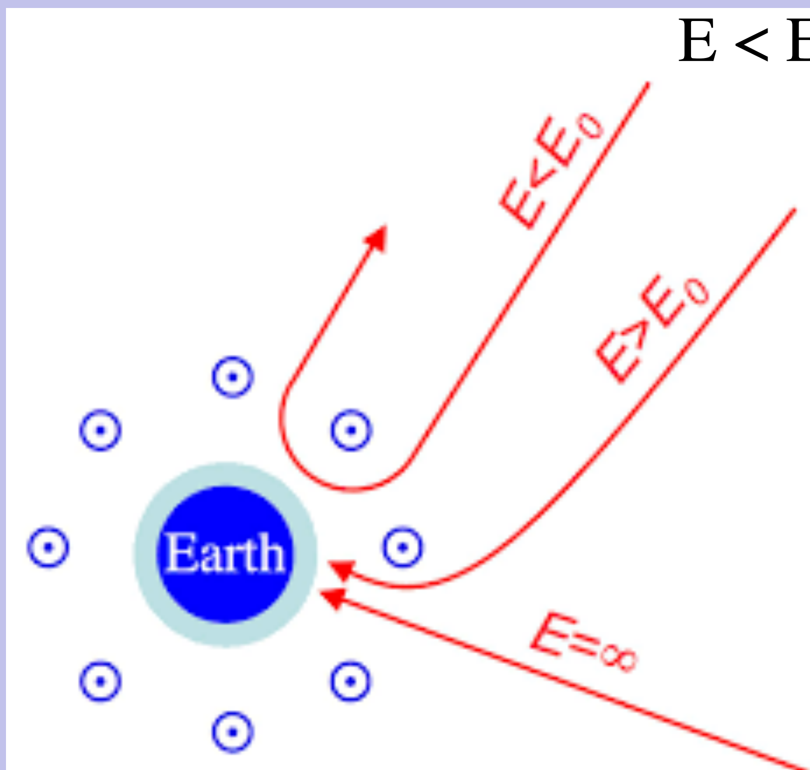
Near the poles, cosmic rays had easy access;
near the equator more cosmic rays would be bent back to space.

At really high energy the particles could come through this magnetic field.

Most of the cosmic rays are deflected back to space, especially at low latitudes. This provides a shield of the Earth from this radiation.

Earth's magnetic cutoff

There are lots more low energy particles than high energy particles so Earth is pretty well protected.

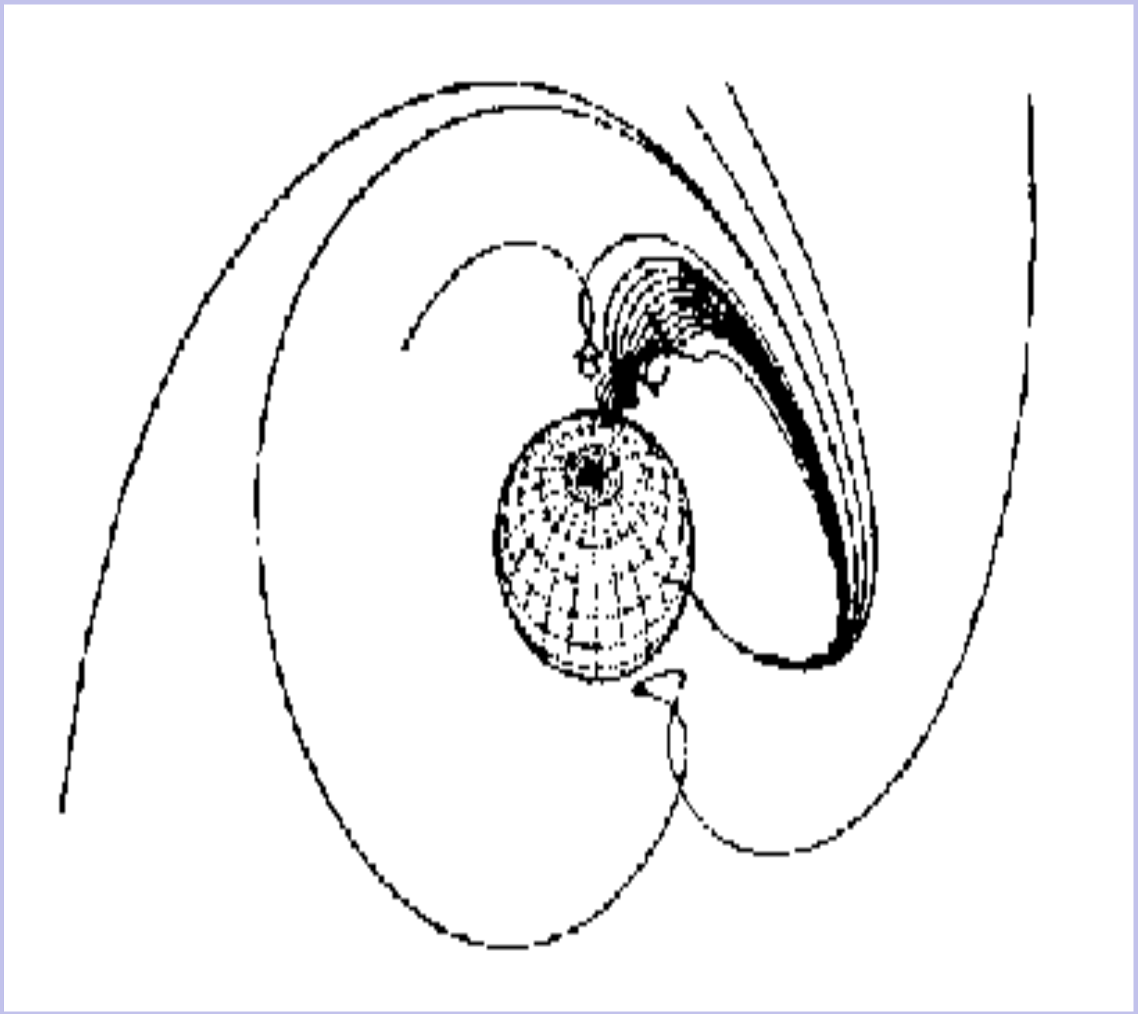


$E < E_o$ Particles bent away

$E > E_o$ Particles bent but make it to Earth's surface

Very high E, Particles don't bend and thus make it to Earth's surface

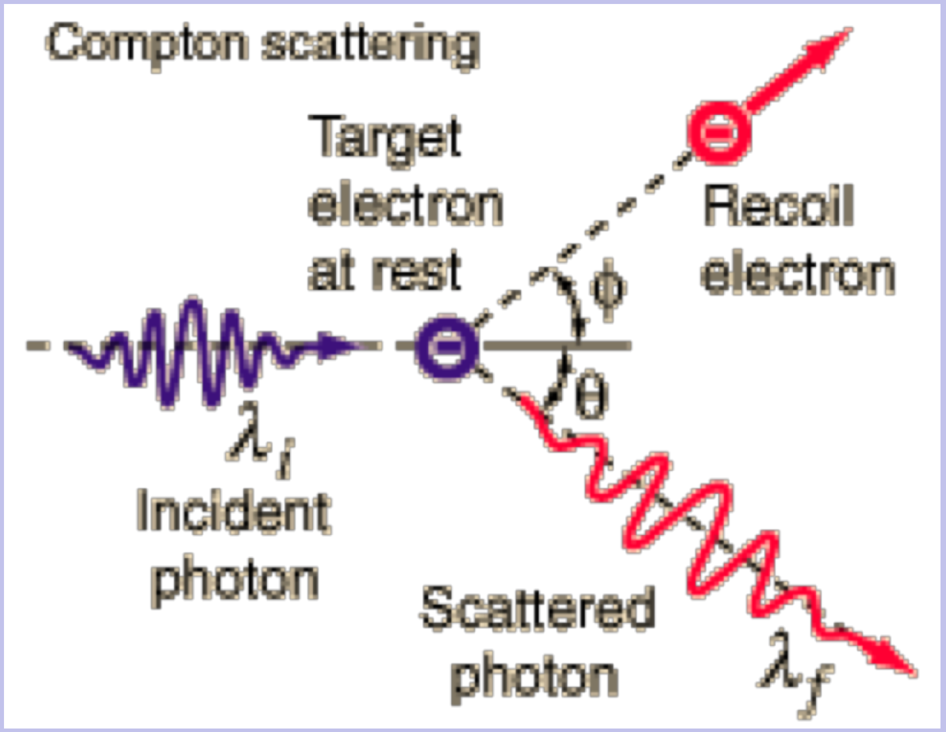
Cosmic ray trajectories in the Earth's magnetic field.



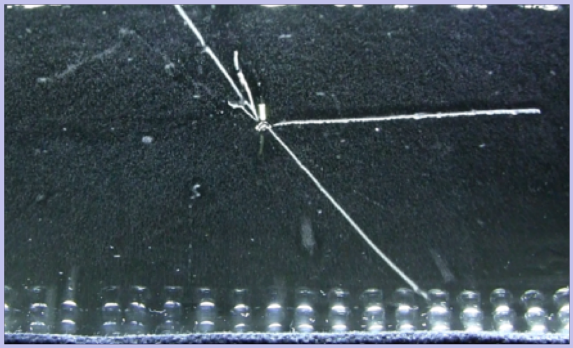
Arthur Holly Compton: Nobel Prize 1927:

famous for his development of the theory of interactions between electrons and particles.

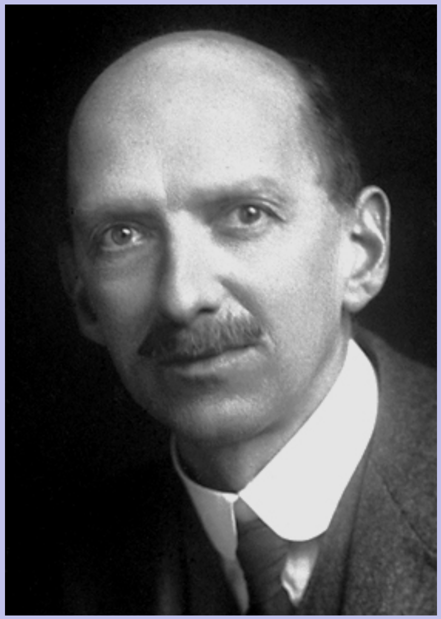
"for his discovery of the effect named after him"



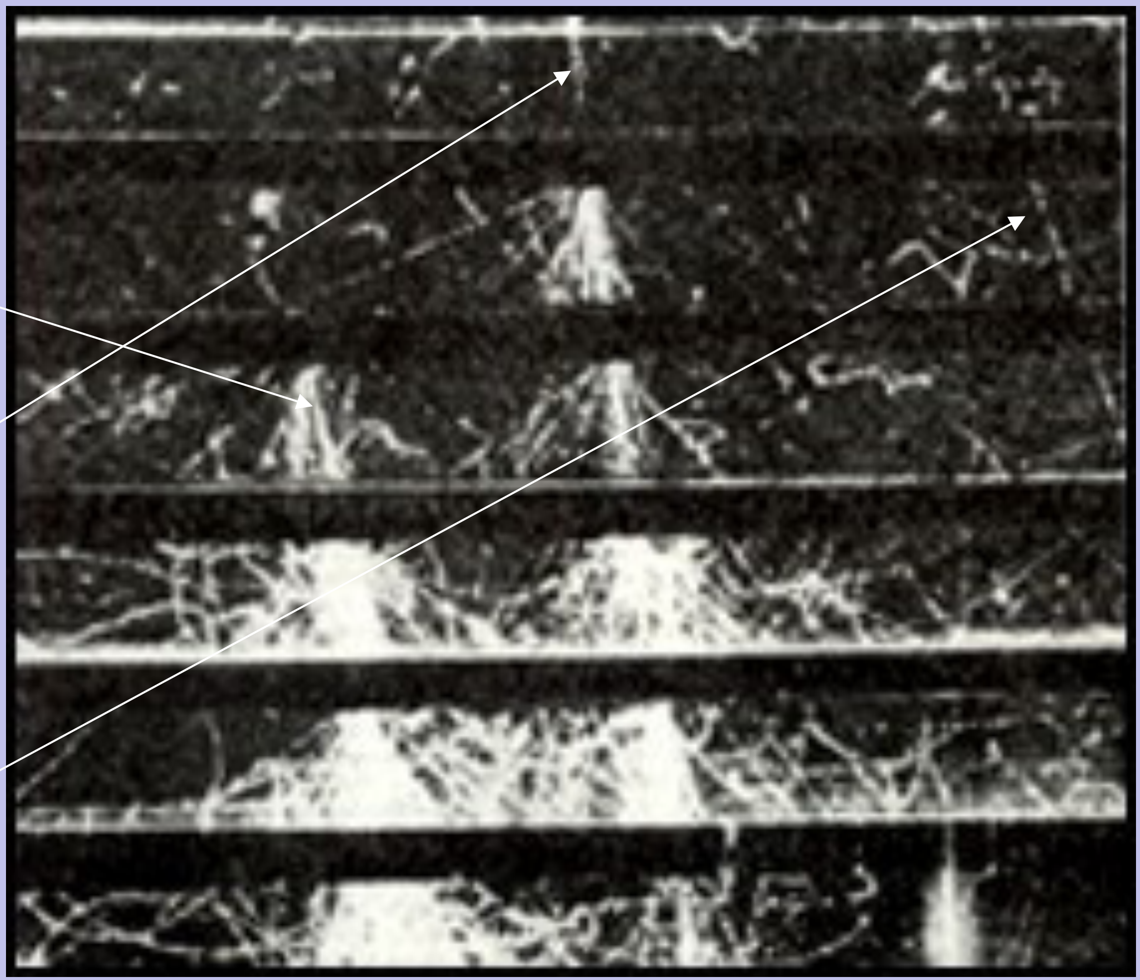
Nobel Prize 1927: Charles Thomson Rees Wilson



Radium source in a cloud chamber



"for his method of making the paths of electrically charged particles visible by condensation of vapour"



Using the Wilson cloud chamber, in 1927, Dimitr Skobelzyn photographed the first ghostly tracks left by cosmic rays.

We will come back to gamma-ray showers later.

The problem

The problem was to figure out what was coming into the Earth by looking at the charged particles in the atmosphere without knowing what the penetrating particle was.

- Colorado’s accessible mountains played a big role in understanding the shower of particles and the “penetrating radiation.

- Understanding the Earth’s magnetic field allowed the character of the radiation above the atmosphere to be understood.

The competition

Caltech (Robert Millikan) vs.

The U. of Chicago (Arthur Holly Compton)

Two Nationally famous scientists in a competition to understand the cosmic rays.

This quest led to the discovery of new particles and the beginnings of *high energy physics*.

High Energy Physics is the modern name for the field of study has led to the great accelerators (Fermilab and CERN) and discoveries of quarks and the Higgs.

Consequences of the magnetic field

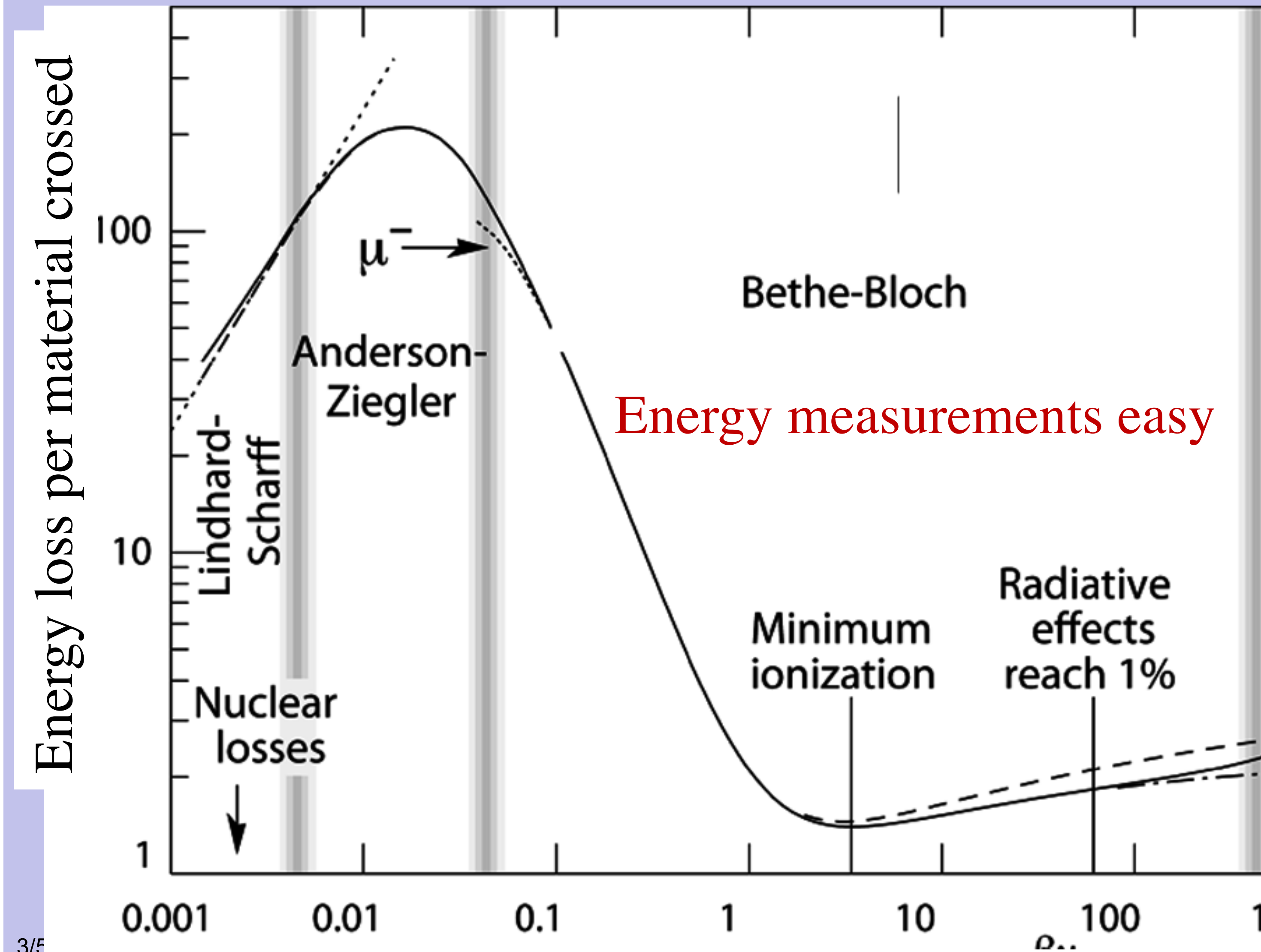
- The cosmic articles are charged
  - variation of flux with magnetic latitude.
- More particles come from the west
  - Particles are positively charged (e.g. protons or other nuclei)

The particles come from beyond the solar system and are positively charged, just like the nuclei of the familiar Earth based atoms.

If they are "atoms", *What happened to the electrons*?

Digress to slides on ionization loss

Energy loss vs. energy



Relativistic Energy (~GeV for proton)

Energy measurements hard

Instruments that sees ionization

- Total radiation measurements
  - Electroscopes
  - Ion chambers
- Images of ionizing tracks
  - Wilson cloud chamber
  - Photographic emulsions

These devices all measure basically the same thing,
the amount of ionization caused by energetic charged particles.
Studying the details of these tracks allowed us to determine the charge Z and the energy E of the particles.

(If the particle was going at a speed above about 0.7 the speed of light,
We had to determine the energy by a different method.)

What is this radiation?

- Compton 1930s did latitude surveys on board ship proved the incident radiation was charged and was being affected by the large scale of the Earth's magnetic field.

- First question is answered: the radiation is **charged**

  Gamma rays (photons) were eliminated

- Second question: What is the sign of the charge?
  - Electrons or protons or an unknown particle?

Consequences of the magnetic field

- If particles are neutral (e.g. neutrons or very energetic gamma-rays), there would be no variation of flux with magnetic latitude.

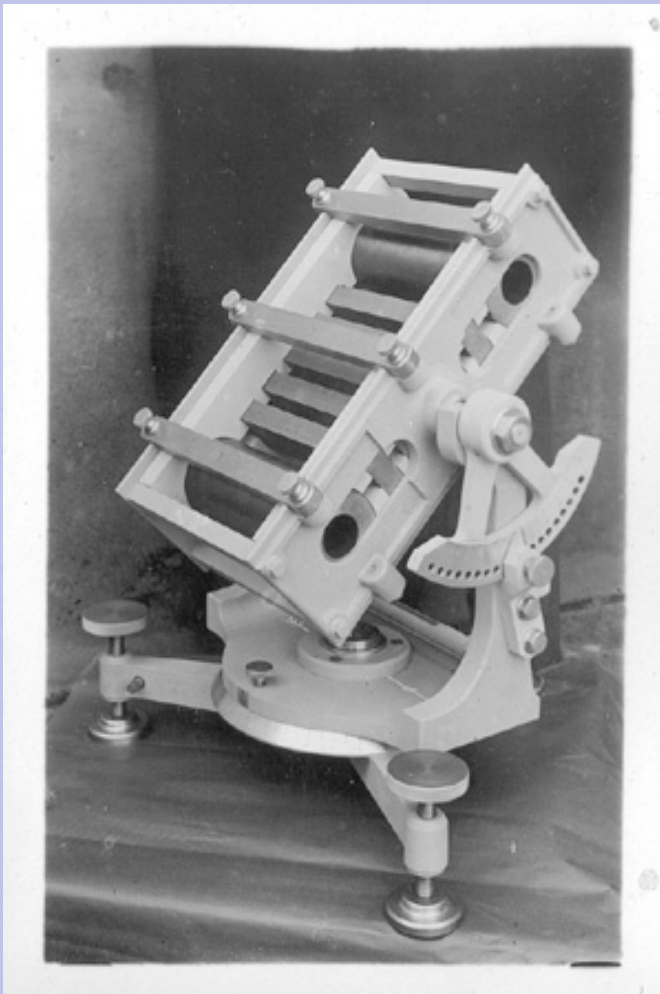
- Bending in Earth's magnetic field – well understood since mid-19^{th} century
  - If particles are negatively charged (e.g. electrons) then more would arrive from the east.
  - If particles are positively charged (e.g. protons or other nuclei) then more would arrive from a westerly direction.

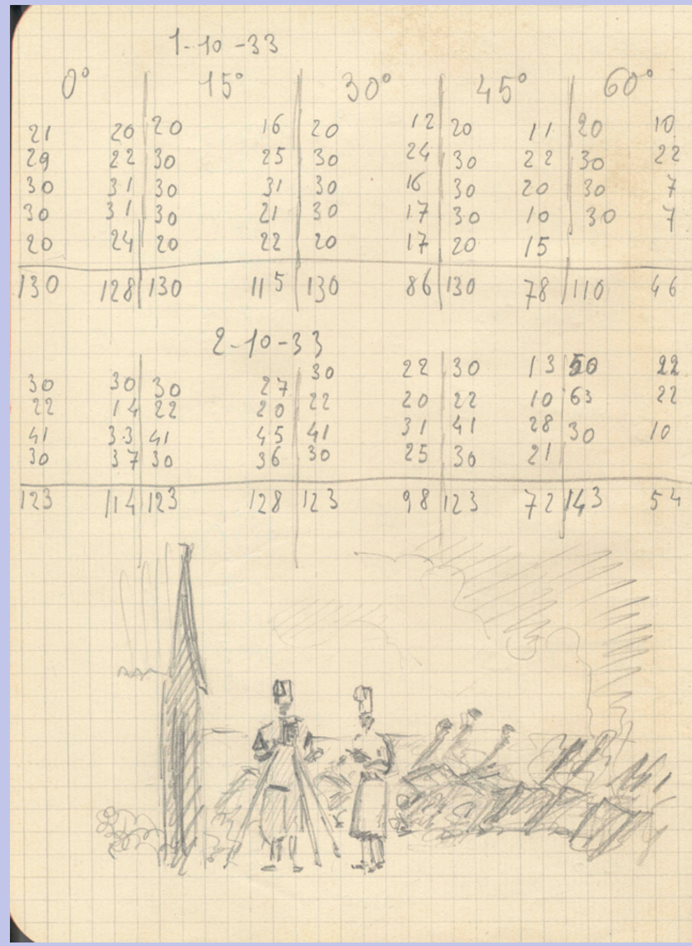
East-west effect proves particles are positive

- 1931: Bruno Rossi, in Italy, predicted an east-west flux asymmetry if the particles were charged
- 1932-33: Alvarez, Auger, Compton, T.H. Johnson, Leprince-Ringuet and Rossi all measured the east-west effect:

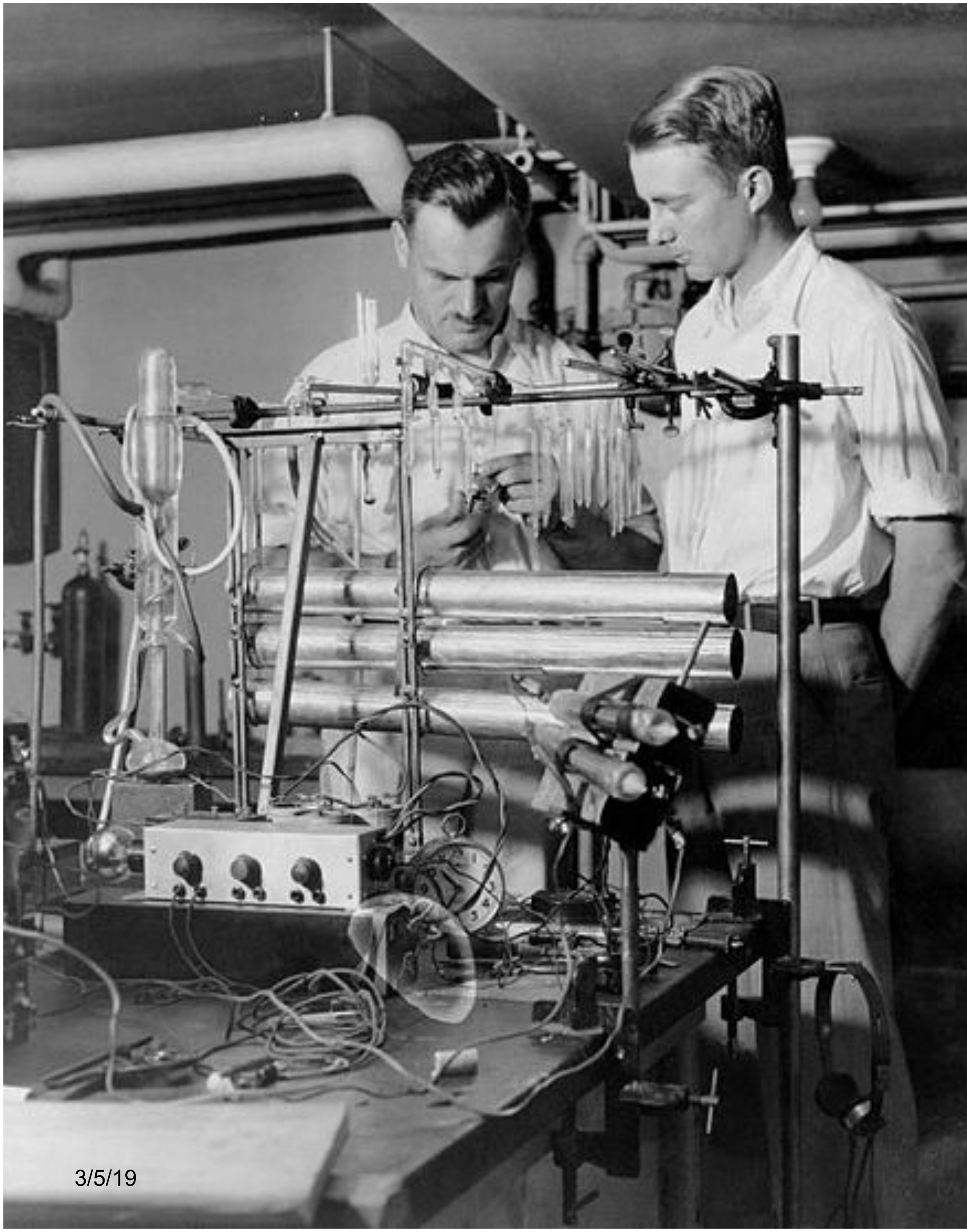
They all found more particles were coming from the west, and so cosmic rays must have positive charge

1933 Rossi's measurements in Eritrea helped establish the east-west effect proving the cosmic rays have positive charge





http://libraries.mit.edu/archives/exhibits/rossi/index.html



Compton & Alvarez

Bruno Rossi

Alvarez was an interesting guy

APSNEWS

This Month in Physics History

February 6, 1970: Luis Alvarez's paper in *Science* on cosmic rays and pyramids

When archaeologists confirmed their discovery of a hidden burial chamber in an Egyptian pyramid in 2017, it was in some respects the culmination of a project undertaken in the 1960s. A physicist named Luis Walter Alvarez came up with the idea of using cosmic rays to map dense structures like the Great Pyramid of Giza.

Alvarez was born in 1911 in San Francisco. His father and grandfather were both physicians, and his Aunt Mabel was an artist. When his father took a job at the Mayo Clinic, the family relocated to Minnesota for young Luis's high school years. He attended the University of Chicago, ultimately earning his PhD in physics in 1936. During his graduate studies, he built a cosmic ray telescope out of Geiger counter tubes and used it to determine that primary cosmic rays had a positive charge.

Alvarez's sister, Gladys, worked as a secretary for Ernest Lawrence, so after getting his PhD, he asked if there were any job openings at Lawrence's laboratory. Lawrence offered him a job, and Alvarez joined the University of California in Berkeley to work with the cyclotron. He designed experiments to study radioactive nuclei, specifically the detection of soft x-rays from a particular type of beta decay that had been predicted but not yet observed.

During World War II, Alvarez joined the newly formed Radiation Laboratory at MIT, where he developed military applications for microwave radar. He worked on several radar projects while there, and is best known for the Ground Controlled Approach (GCA) system, which used a dipole antenna for improved resolution. Even untrained pilots could be guided through a runway landing by ground-based operators using the GCA system. It was still in use in some countries as recently as the 1980s. While testing the GCA in England in the summer of 1943, Alvarez met a young Arthur C. Clarke, then a radar technician with the Royal Air Force, and they struck up a years-long friendship.

That fall, Alvarez joined the Manhattan Project. One of his first tasks was to find a means of discovering whether the Germans had any nuclear reactors in operation. Alvarez outfitted an airplane with a system capable of detecting the radioactive gases such reactors would produce. Germany didn't have any reactors at the time, so the mission found no such evidence, but the approach would prove to be extremely useful for intelligence gathering in the post-War era. His final task on the Manhattan Project: designing small instruments to measure the strength of the shock wave from an atomic bomb. He was present at the Trinity Test in 1945 and used his instruments aboard a B-29 to measure the blast energy of the atomic bombs dropped on Hiroshima and Nagasaki.

After the war, Alvarez applied his radar exper-

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Nobel Laureate Arthur Compton, left, with young graduate student Luis Alvarez at the University of Chicago in 1933

Nobel Prize in Physics in 1968: "For his decisive contributions to elementary particle physics, in particular the discovery of a large number of resonant states, made possible through his development of the technique of using hydrogen bubble chambers and data analysis."

His earlier cosmic ray research eventually led to his 1965 proposal that one could use muon tomography to hunt for previously undiscovered chambers in Egyptian pyramids. Alvarez and his interdisciplinary team of physicists and archaeologists placed spark chambers in a known chamber beneath the second pyramid of Chephren to detect incoming cosmic rays and measure their deflections as they hit the solid bricks of the structure. The muons would pass right through a chamber, however, registering a void in the resulting image.

The Arab-Israeli Six Day War of 1967 interrupted the experiment briefly, but things resumed soon after, and Alvarez's team continued taking cosmic ray data for the next two years. At a 1969 APS meeting, Alvarez reported that they had successfully surveyed about 19 percent of the pyramid, but had found no hidden chambers. He and his colleagues also published a paper in *Science* to that effect in February 1970.

Alvarez's natural curiosity often took him well outside the physics laboratory. When *Life* magazine published photographs in 1966 of President John F. Kennedy's assassination, Alvarez applied his expertise in optics and photo-analysis to the images. His conclusions, outlined in an informal tutorial

An article in the February edition of *Physics News*

Giant meteor caused demise of the dinosaurs 65 Mya

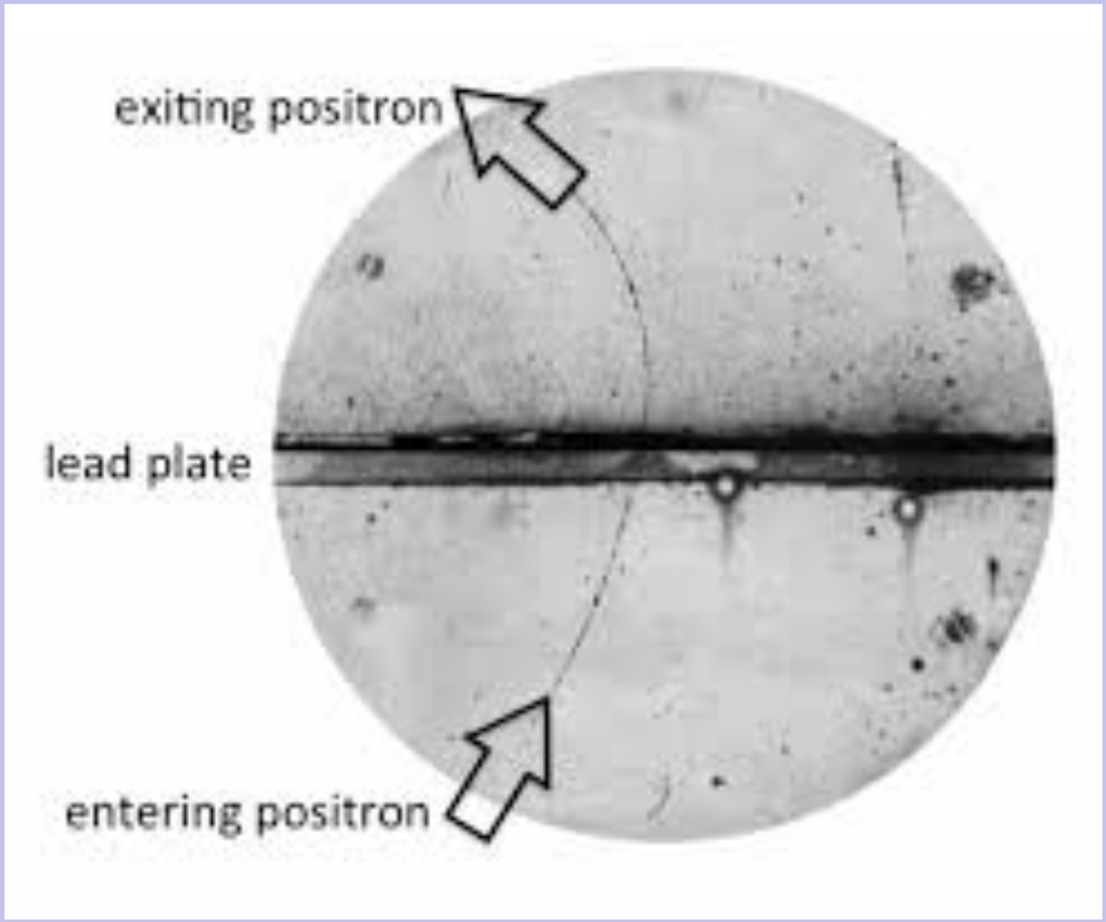
But we digress …

Carl Anderson

Dirac had predicted antimatter from symmetry arguments (Nobel Prize 1933)

Millikan commissioned his graduate student Carl Anderson to build a cloud chamber inside a magnetic field

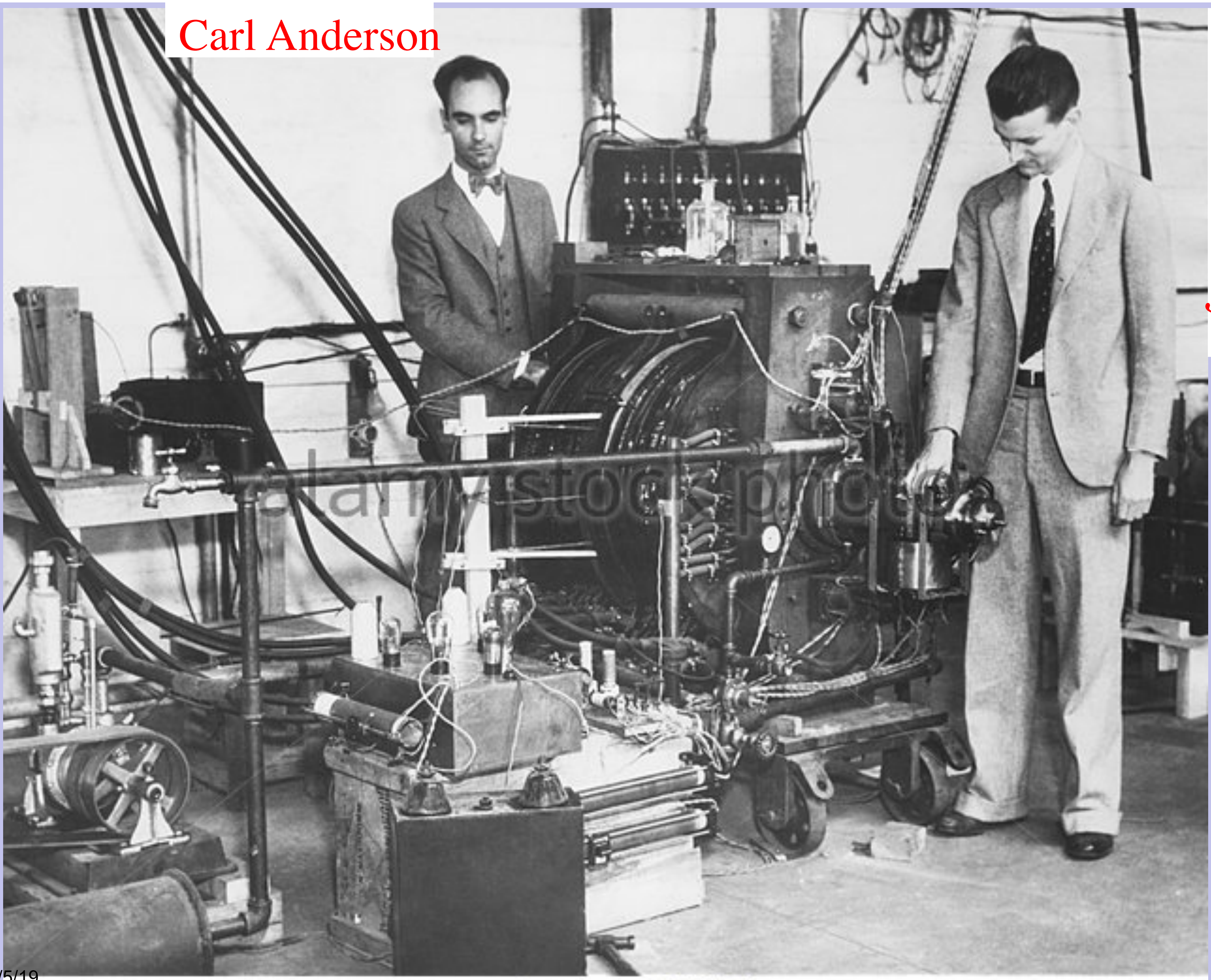
Discovery of the positron, an antielectron (e^+)



Carl Anderson and Robert Millikan preparing to take the Manitou and Pikes Peak Railroad to the top of Pikes Peak, Colorado Springs, CO 1935.

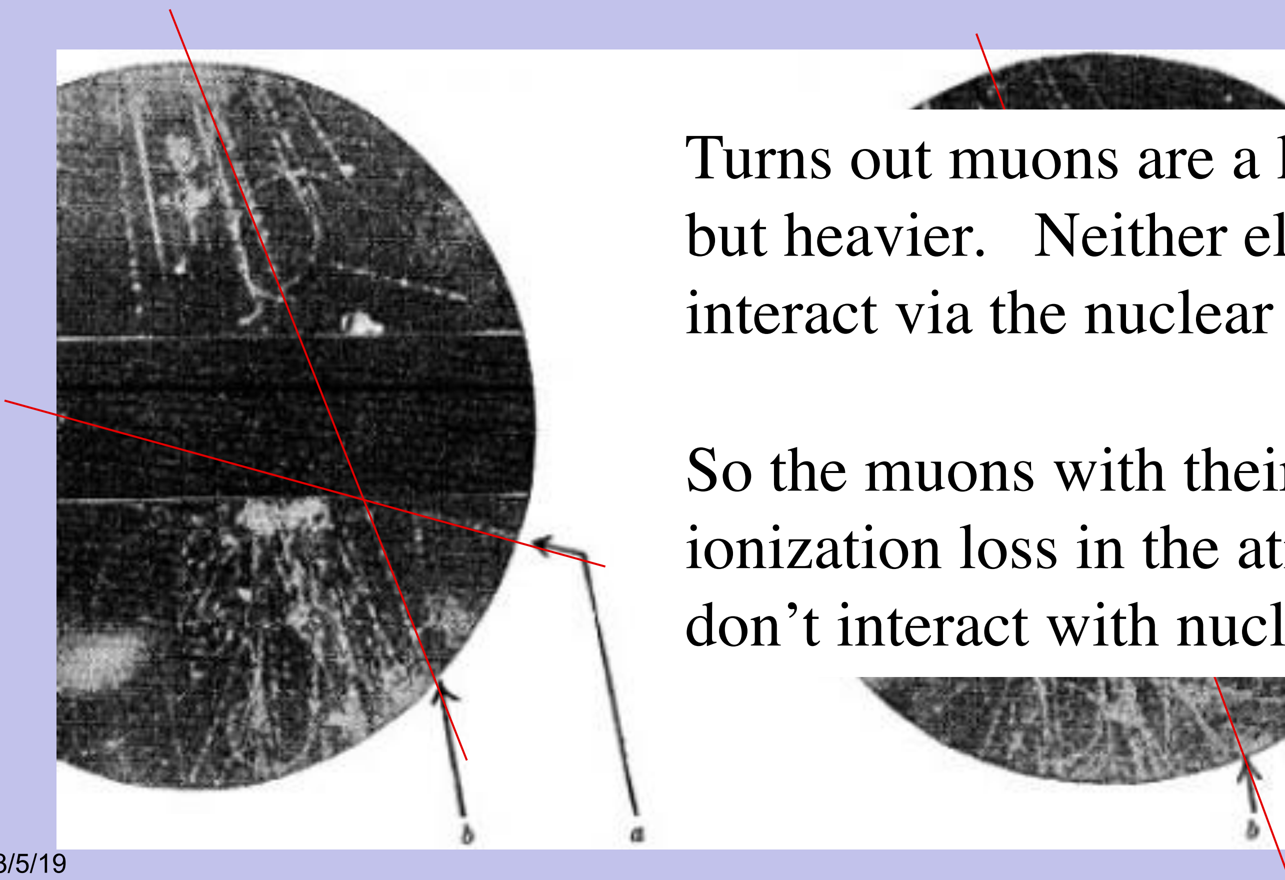
Carl Anderson

Seth Neddermeyer



Discovery of the muon: the highly penetrating part of the shower of particles.

Some tracks are stopped by the lead. Some are multiplied in the lead. Can you find the straight tracks?



Turns out muons are a lot like electrons but heavier. Neither electrons or muons interact via the nuclear force.

So the muons with their charge make ionization loss in the atmosphere, but they don't interact with nuclei.


μ track continued from A
A
μ
π
μ
A

Muons
(accelerator people call them "cosmics")

Comparison of tracks at Pikes Peak and Pasadena led to the identification of a particle with mass intermediate between the electron and the proton, initially known as the "mesotron". It was originally thought to be the "Yukawa" particle, the carrier for the strong force. For a while they were called "mu mesons". "Meson" meaning intermediate in mass. They later were found to not interact with the nuclear force, and were shown to be leptons, a class of particles including electrons. The "meson" part of their name was dropped and they are now known as muons.

Now we know

- The penetrating particles have been found to be a previously unknown particle.
  - Named “muons”
- The original particles from the “cosmos” are positively charged.
- There are showers of particles in the atmosphere and it includes a “soft component” from gamma-rays that shower in lead.
- The time comes to honor someone for the discovery of this extraterrestrial radiation.

What we came to understand by the end of the 1930s

- Cosmic rays at ground level
  - Most abundant are electrically charged muons, μ^+ and μ^-, which penetrate through the atmosphere, moving at the speed of light
    - Their lifetimes are extended by special relativity so they survive the journey to the ground
  - The “soft component” consists of e^- and e^+ and is easily removed with some lead shielding
  - There are some neutrons and a few protons, survivors of “stars” from above.

What was added after the WWII -1

- Cosmic rays at very high altitudes >100,000 ft
  - Airplanes fly at ~30,000 ft
  - The incoming particles interact with atmospheric nuclei and produce pions (π^+, π^- and π^o). The π^+, π^- are charged pions. The π^o (pi-zero) is neutral and decays into two gamma-ray photons
    - Their lifetimes are very short and they decay almost immediately after they are produced.
  - The π^+, π^- decay almost immediately into our more familiar muons, μ^+ and μ^- respectively.
    - Their lifetimes are extended by special relativity so they survive the journey to the ground

What was added after the WWII - 2

The π^o -> 2 gamma-ray photons initiated the soft component of the shower of particles coming through the air. The soft component is also called the electromagnetic shower.

– The "soft component" consists of gamma ray photons, electrons and positrons, (γ, e^- and e^+) and is easily removed with some lead shielding or water

What are cosmic rays in space?

OK, that was a 20 year quest to find out that cosmic rays were ordinary protons, albeit ones of tremendous energy coming from beyond the solar system.

“Cosmic ray” turns out to be an inappropriate name. Rays are usually neutral.

Now we faced a new set of questions, usually known as “What is the origin of cosmic rays?

- Where do they come from?
- How do they get their tremendous energy?

Who gets the prize and why?

- Pacini

“a sizable cause of ionization exists in the atmosphere, originating from penetrating radiation, independent of the direct action of radioactive substances in the soil.”

- Hess

“*The results of the present observations seem to be most readily explained by assuming that radiation of very high penetrating power enters the atmosphere from above, and can still produce a part of the ionization observed in closed vessels at the lowest altitudes.*”

Wind Crest Nobel Committee meets

Note that 3 m of water will absorb any electrons and gamma-rays. Sometimes they used lead shielding to accomplish the same thing.

So the "penetrating radiation" is that which goes through the water or the lead.

Votes for Pacini

Votes for Hess

Compton nominates Hess for Nobel

Arthur Compton, in his letter nominating Hess for the prize, wrote, "*The time has now arrived, it seems to me, when we can say that the so-called cosmic rays definitely have their origin at such remote distances from the Earth, that they may properly be called cosmic, and that the use of the rays has by now led to results of such importance that they may be considered a discovery of the first magnitude*."

1936 Nobel Prize

The Nobel Committee for Physics pointed out that Hess's discovery opened new vistas for the understanding of the structure and origin of matter.

Of course, you have to be alive to get a Nobel Prize. Pacini had died in 1932. "It's better to be lucky than good."

Debye (chemistry), Anderson, Hess