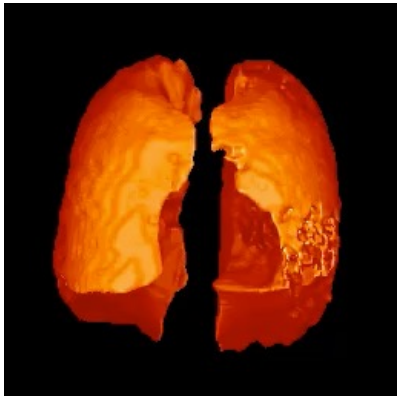
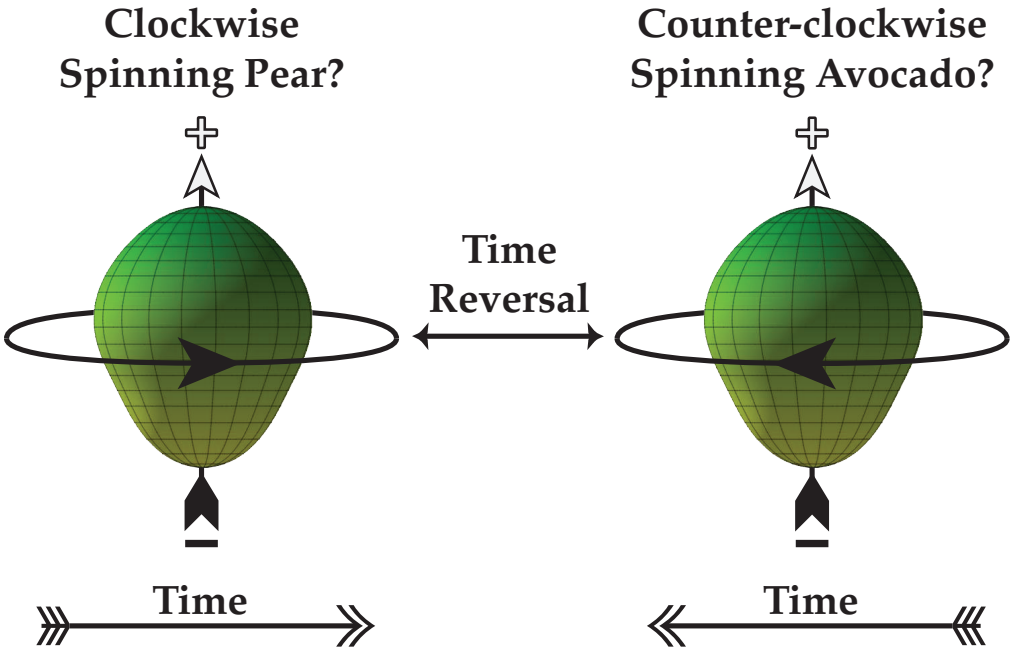
Why Is There Something Rather Than Nothing?



UVA Radiology



MSU Archives

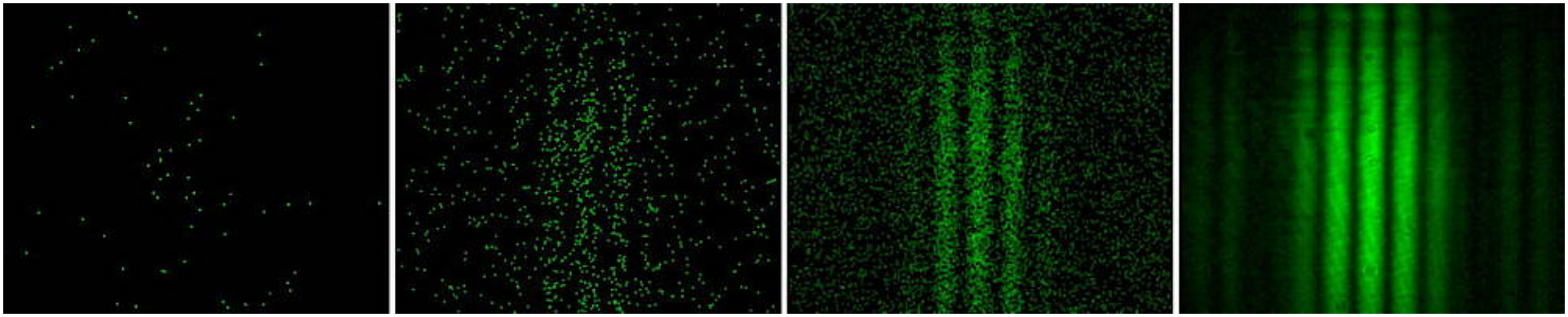
Prof. Thelma Irene Arnette (MSU 1960-1985) 1920-2017

Jaideep Taggart Singh (he/him/his)
FRIB/Michigan State University

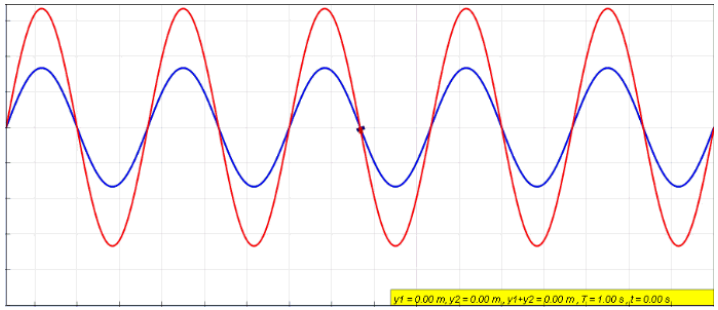
Astronomical Horizons
Abrams Planetarium, 2025-03-20, 19:30-20:30

SCAN ME

P1: Light is composed of particles (packets of Energy) called Photons.



dim → BRIGHT

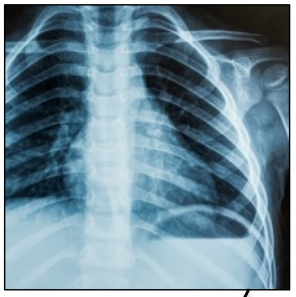


https://en.wikipedia.org/wiki/Wave_interference

Is Light a particle or wave? Both!

http://www.sps.ch/artikel/progresses/wave-particle-duality-of-light-for-the-classroom-13/
http://www.zacsky.com/blog/2011/03/attitude-dimmer-switch
http://www.feit.com

X-Rays are invisible light that are "more purple" (have more energy) than ultraviolet (UV) light.

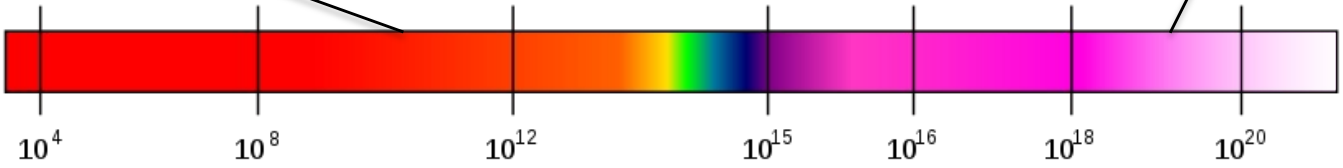


Infrared
Invisible

ROY G BIV
Visible

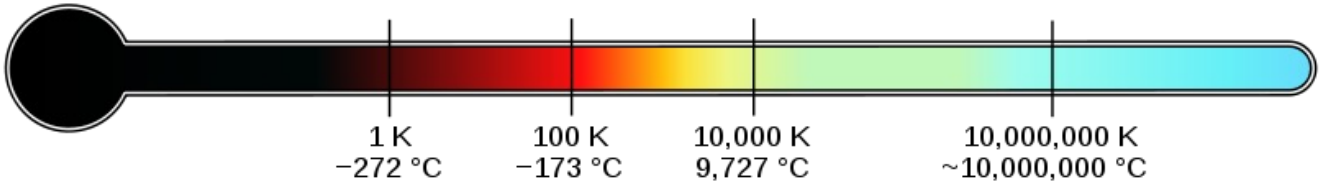
Ultraviolet
Invisible

Color



Energy and Temperature

Temperature of objects at which this radiation is the most intense wavelength emitted

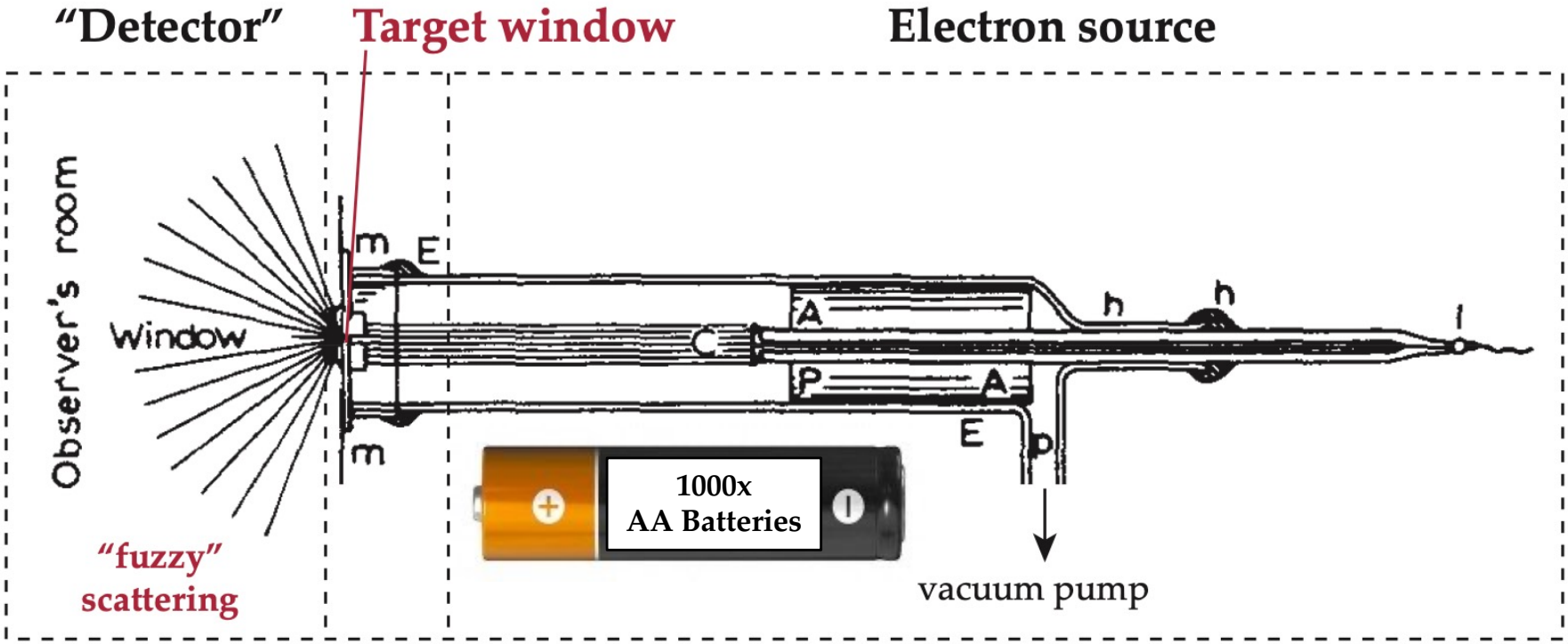


low energy
cold

HIGH ENERGY
HOT

https://en.wikipedia.org/wiki/Rainbow
https://en.wikipedia.org/wiki/Microwave_oven
https://medlineplus.gov/xrays.html
http://earthsky.org/space/what-is-the-electromagnetic-spectrum

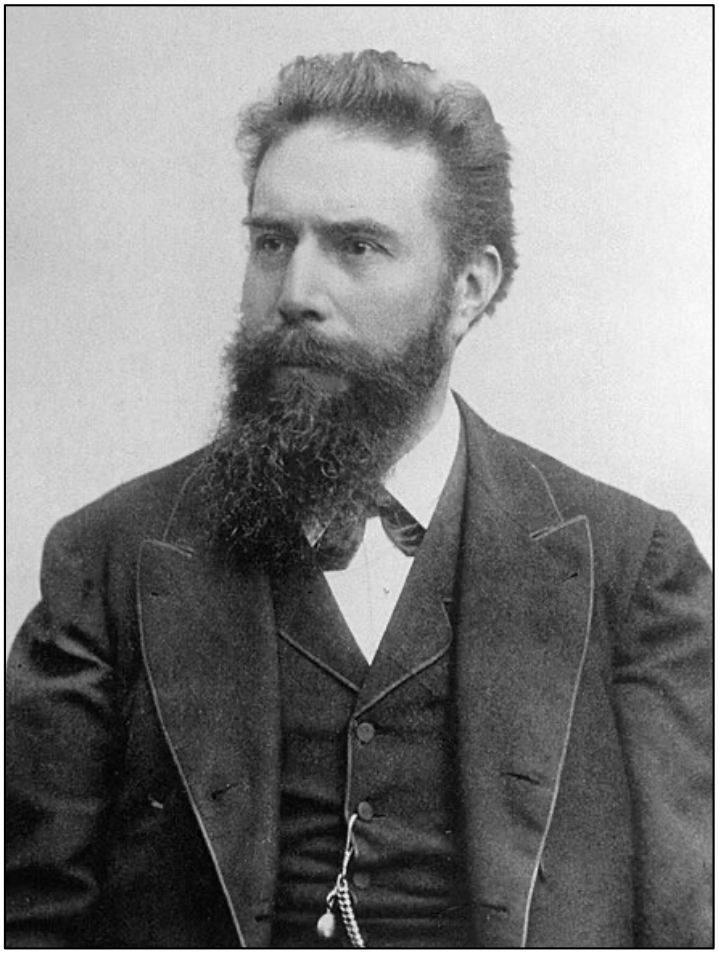
You can make X-rays using electricity! (November 1895)



Photographic film

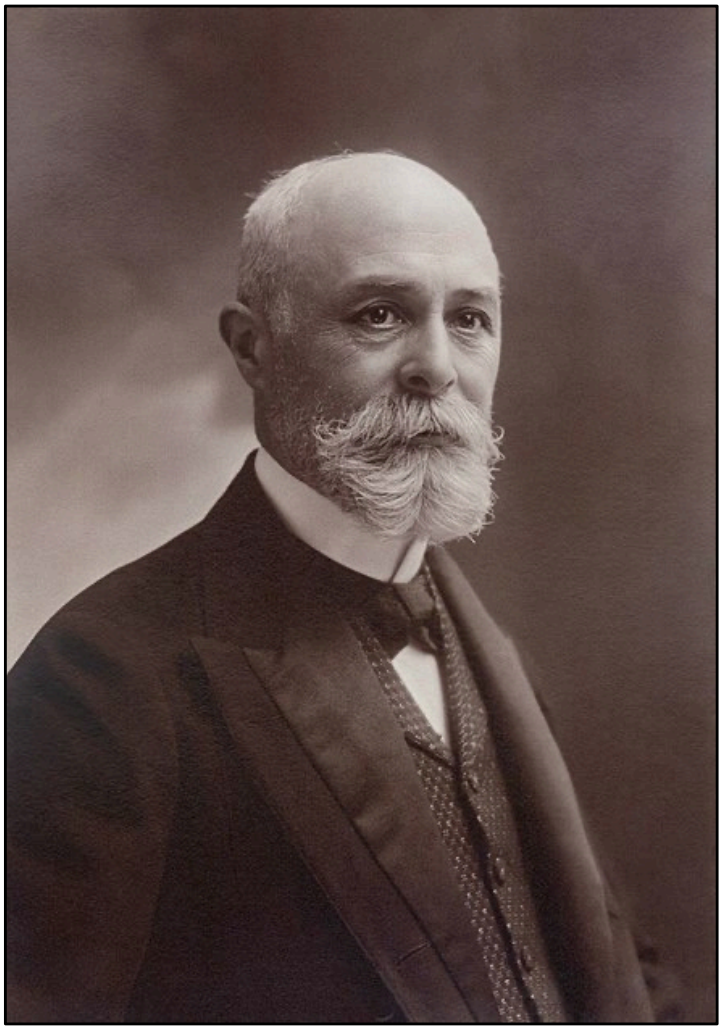
JTS PhD UVa (2010)
https://www.globaltestsupply.com/product/traceable-1111-aa-alkaline-battery?gad_source=1

You can use X-rays to make pretty and/or useful photographs. (December 1895)



Wilhelm Conrad Röntgen (1845-1923)
https://en.wikipedia.org/wiki/Wilhelm_R%C3%B6ntgen

Do you need electricity to make X-rays to make pretty photographs? It's complicated... (February 1896)



Antoine Henri Becquerel (1852-1908)
https://en.wikipedia.org/wiki/Henri_Becquerel

About the radiations emitted through phosphorescence
Note by Mr HENRI BECQUEREL
Comptes Rendus. 122: 420–421.

(translated Oscar Naviliat-Cuncic)

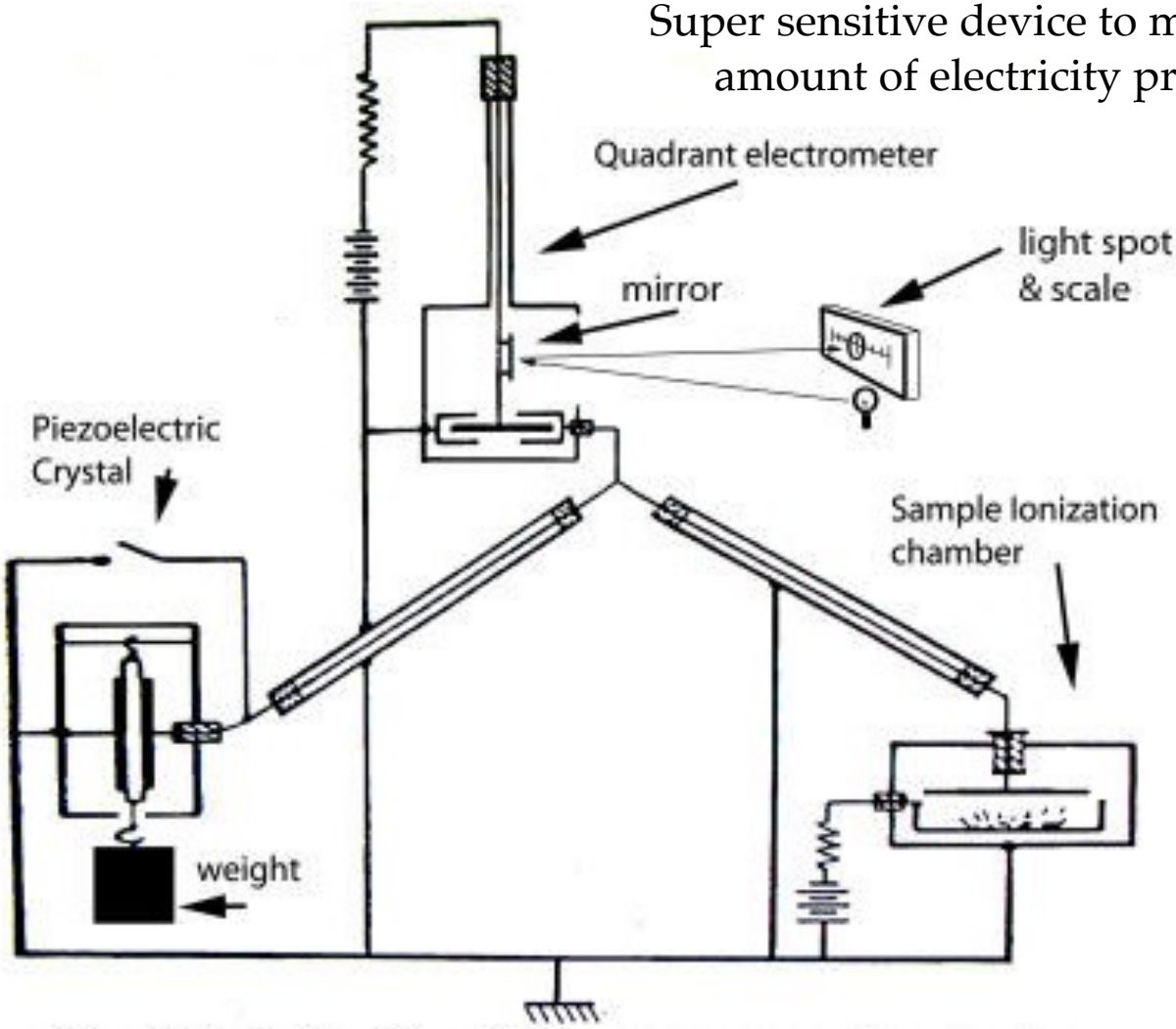
In a previous session, Mr Ch. Henry announced that when phosphorescent zinc sulphide was interposed on the trajectory of rays coming out from a Crookes tube, the intensity of radiations traversing aluminum increased. On the other hand, Mr Niewenglowski recognized that commercial phosphorescent calcium sulfate emits radiations which traverse opaque bodies. This fact extends to several phosphorescent bodies and, in particular, to urane salts for which the phosphorescence has a short life-time. With double uranium and potassium sulfates, of which I possess crystals which form a thin and transparent layer,

I was able to perform the following experiment:

One wraps a photographic *Lumière* plate – based on **silver** bormide and gelatin – with two very thick and black paper foils such that the plate is not revealed when exposed to the Sun during one day. On the paper foil, from the outside, one poses a plate of the phosphorescent substance and one exposes everything to the Sun during several hours. When one develops then the photographic plate, one recognizes that the contour of the phosphorescent substance appears in black on the image. If one interposes a coin between the phosphorescent substance and the paper, or a metallic screen pierced with a drawing, one sees the images of these objects to appear on the picture. One can repeat the same experiments by interposing a thin glass slide between the phosphorescent substance and the paper, what excludes the possibility of a chemical action due to vapors that could emanate from the substance heated by the Sun rays. One has to conclude from these experiments that the phosphorescent substance in question emits radiations which cross the black paper which is opaque to light, and reduce the **silver** salts.

Radioactivity produces electricity.

Super sensitive device to measure the amount of electricity produced



Super sensitive scale to measure how much sample is left

Radioactive sample

https://carnotcycle.wordpress.com/wp-content/uploads/2017/06/mir05.jpg

Radioactivity comes from only certain chemicals, but the production of radioactivity is not due to chemistry.

SCAN ME

https://lamethodecurie.fr/en/article15.html#&gid=1&pid=3

There are different kinds of radioactivity. We know because of magnets!

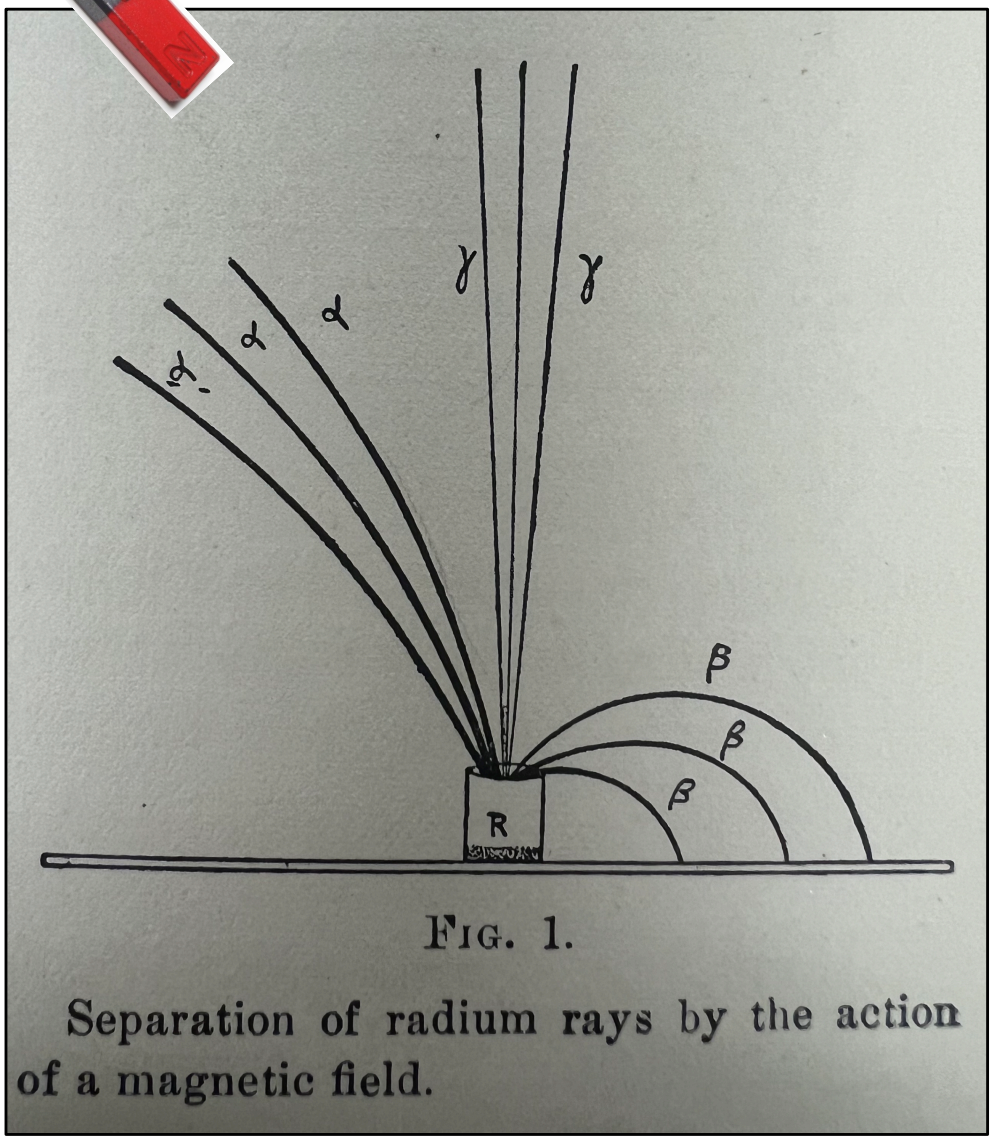
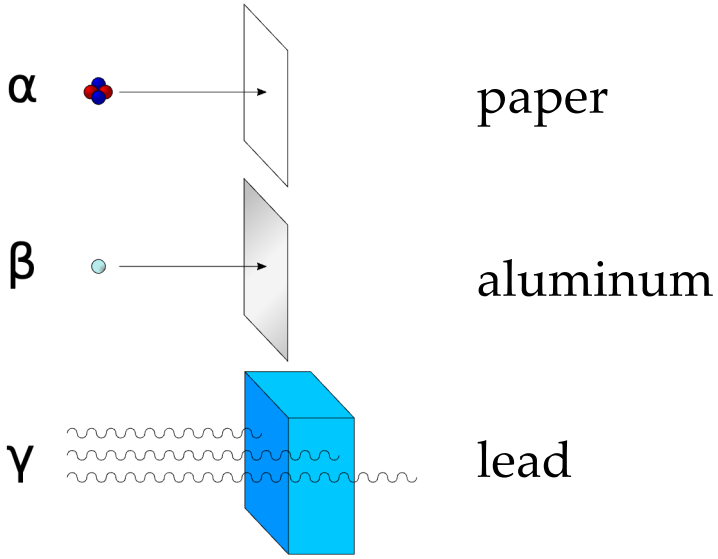


FIG. 1.

Separation of radium rays by the action of a magnetic field.

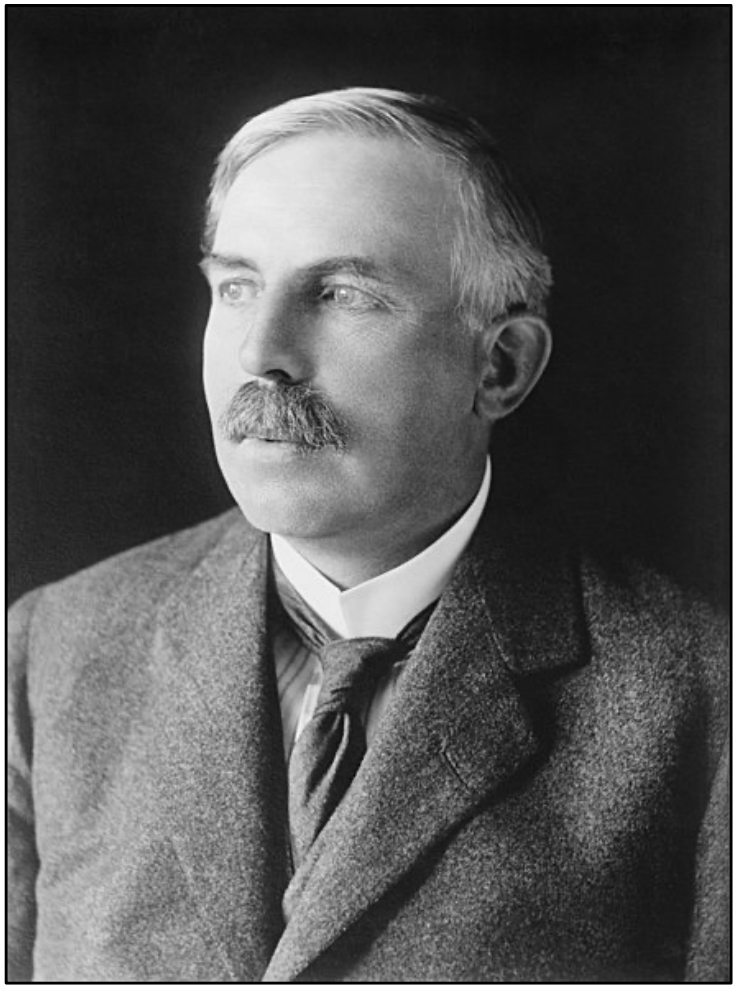
	MASS	VELOCITY	ENERGY
α	○	−	⊗
β	·	——	⊙

Radioactive Transformations, Rutherford (1906)



https://simple.wikipedia.org/wiki/Magnet
https://en.wikipedia.org/wiki/Radioactive_decay

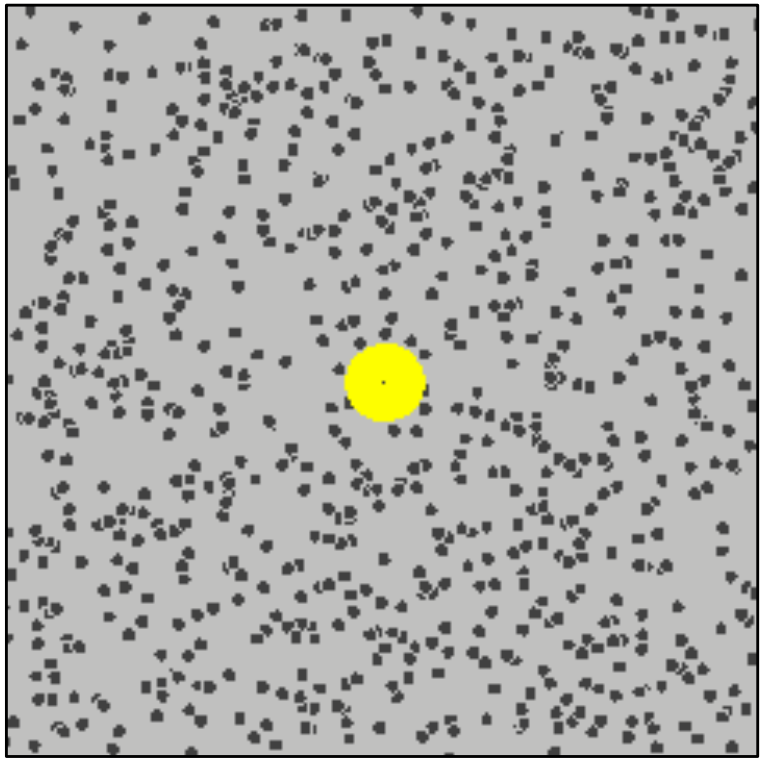
Radium is more radioactive than Uranium, but both produce Helium and Radon gas.

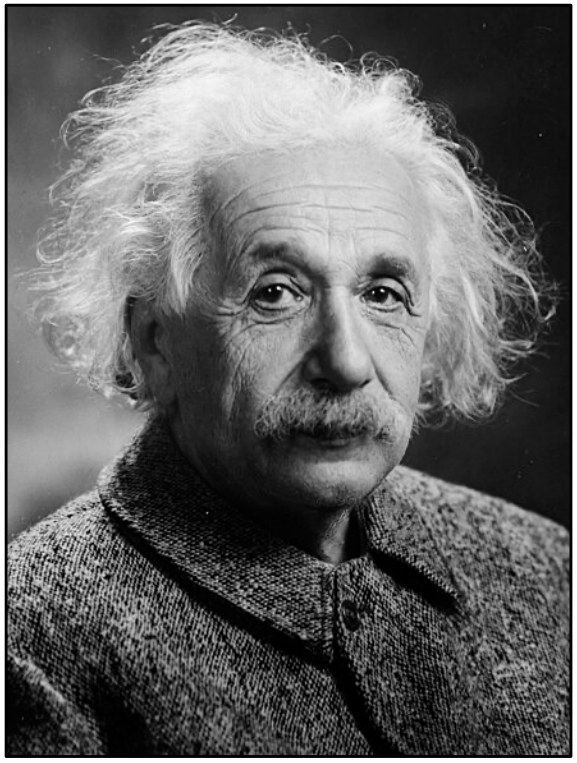


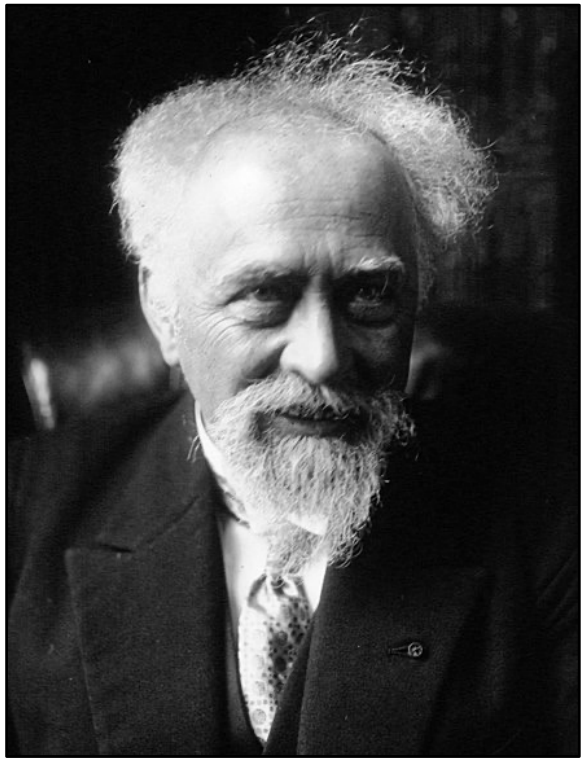
Ernest Rutherford (1871-1937)
https://en.wikipedia.org/wiki/Ernest_Rutherford

Harriet Brooks (1876-1933)
https://en.wikipedia.org/wiki/Harriet_Brooks

Atoms are real and contain electricity inside of them in the form of electrons. (1905-1908)





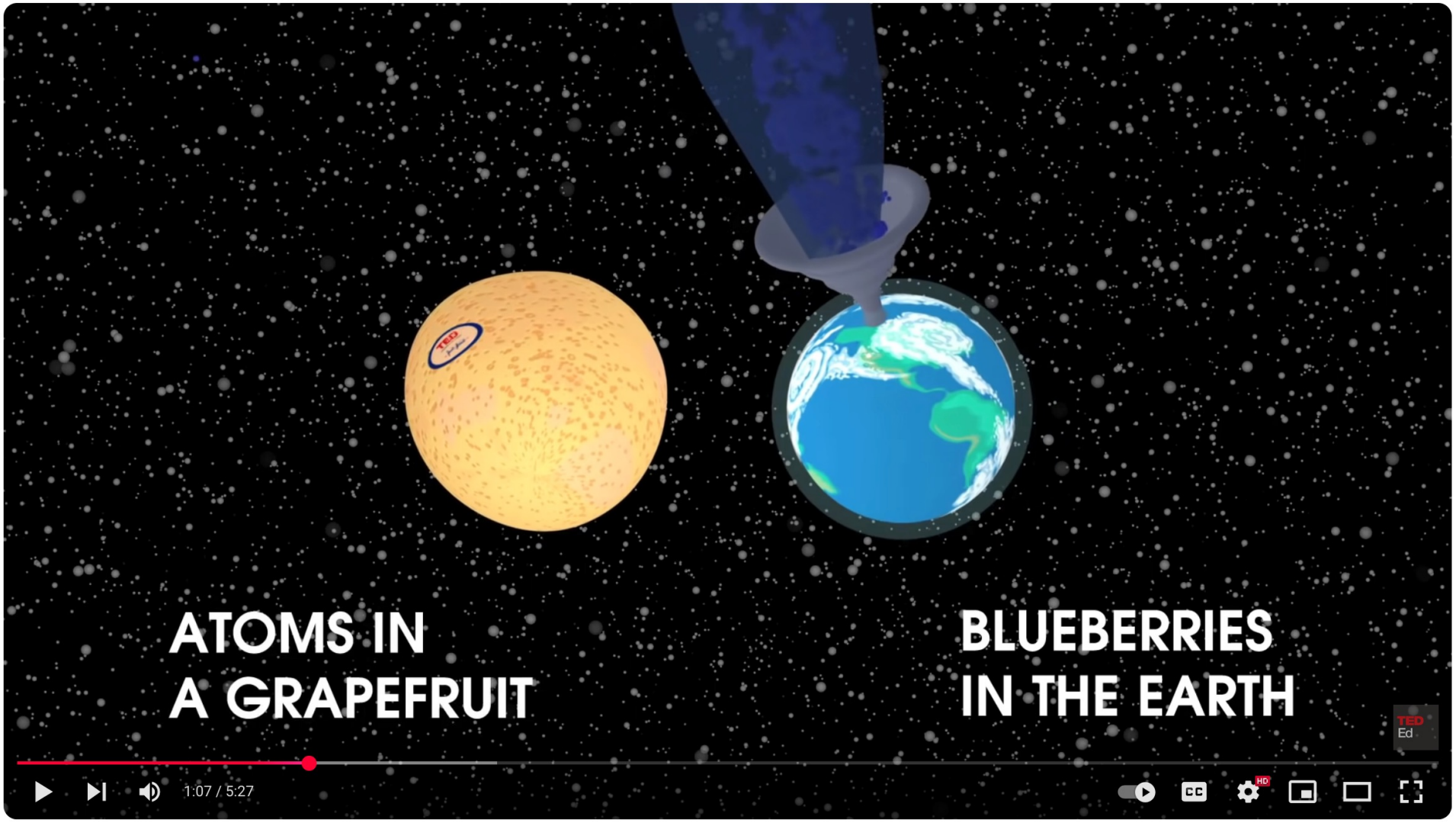


https://en.wikipedia.org/wiki/Brownian_motion

Albert Einstein (1879-1955)
https://en.wikipedia.org/wiki/Albert_Einstein

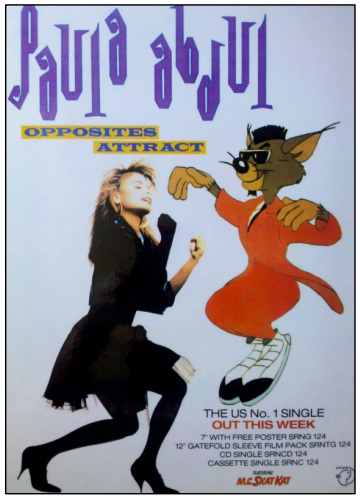
Jean Baptiste Perrin (1870-1942)
https://en.wikipedia.org/wiki/Jean_Baptiste_Perrin

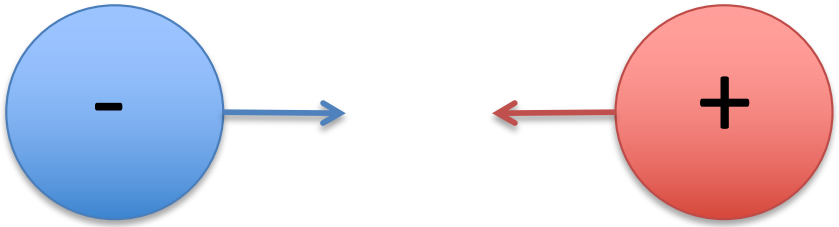
How big is an atom?



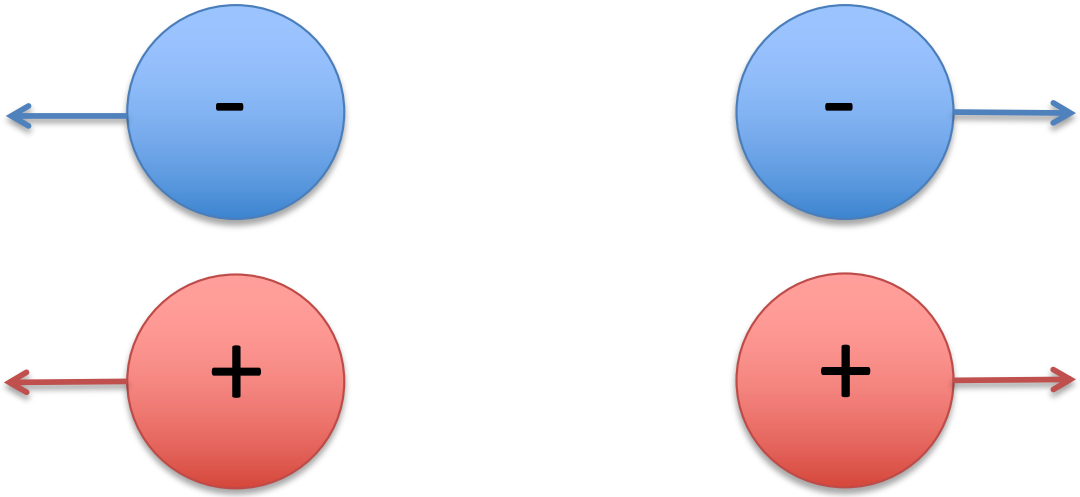
https://www.youtube.com/watch?v=yQP4UJhNn0I&t=36s

Everything that you need to know about electricity: opposites attract while the same charges repel.

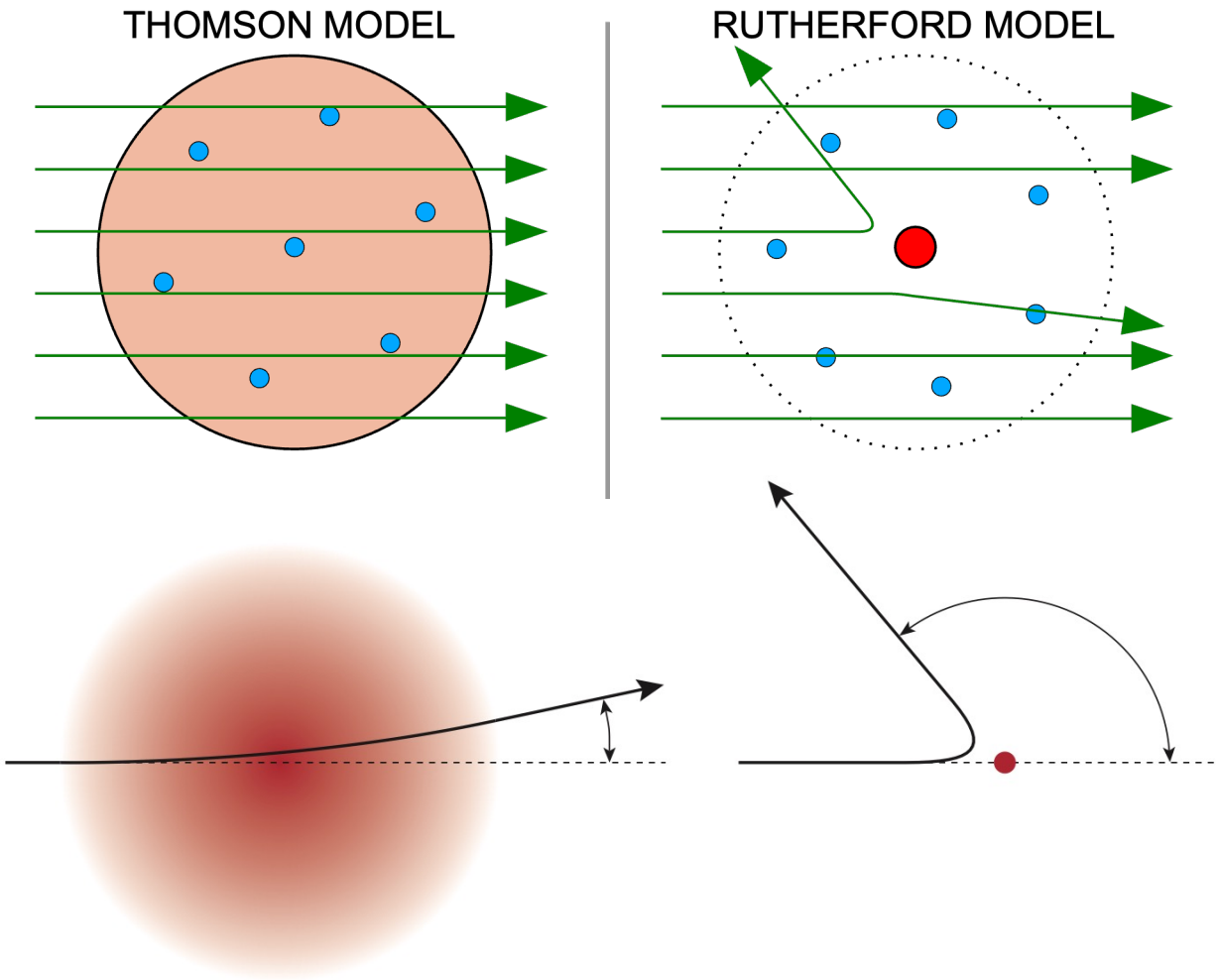




https://www.facebook.com/PaulaAbdul/posts/35-years-ago-today-opposites-attract-hit-1-it-became-my-fourth-1-from-my-debut-a/1160209945473906/



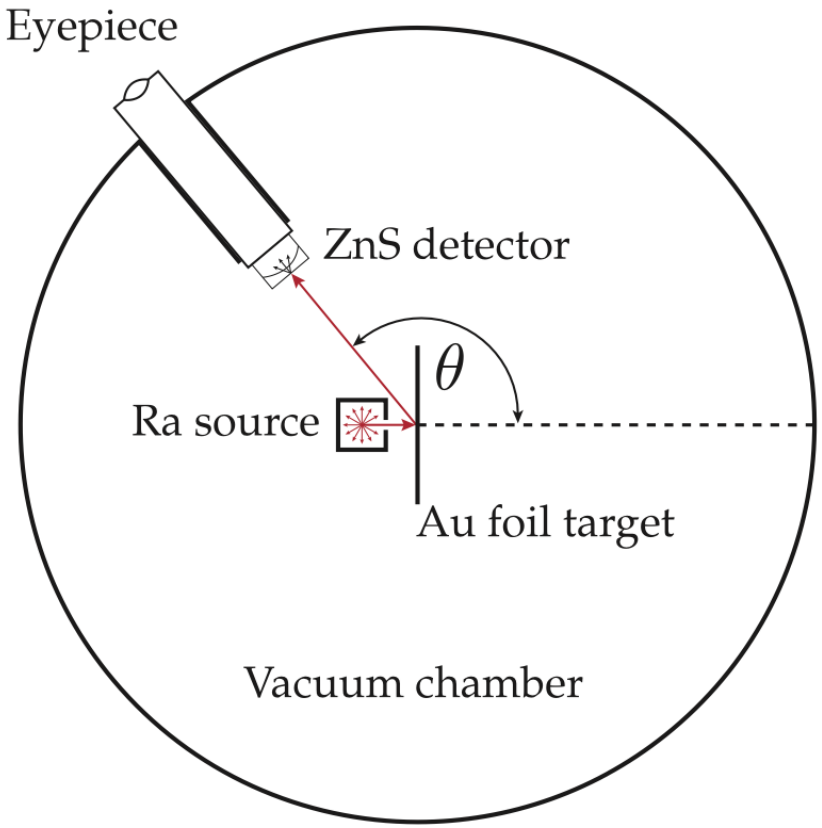
Is the positive stuff holding atoms together everywhere inside an atom or just all in one place?

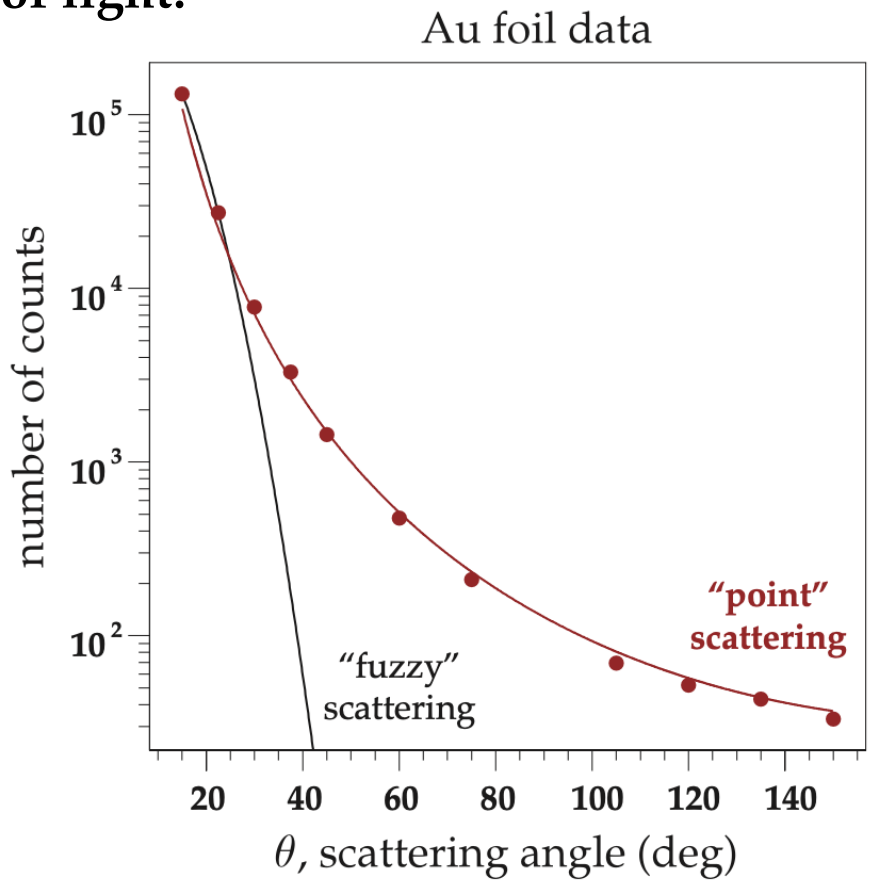


https://en.wikipedia.org/wiki/History_of_atomic_theory

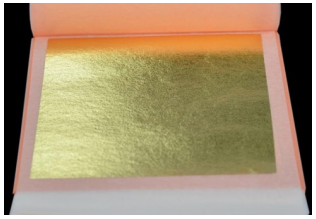
What did physics graduate students do in 1909?

100,000 flashes of light!





JTS PhD UVa 2010



Au = Gold
3 inches

https://barnabasgold.com/product/22kt-genuine-gold-leaf-sheets-80mm-transfer/

How big is an atomic nucleus?

atom =

https://msuspartans.com/sports/2018/7/20/facilities-spartan-stadium-html

nucleus =

https://en.wikipedia.org/wiki/Marble_(toy)

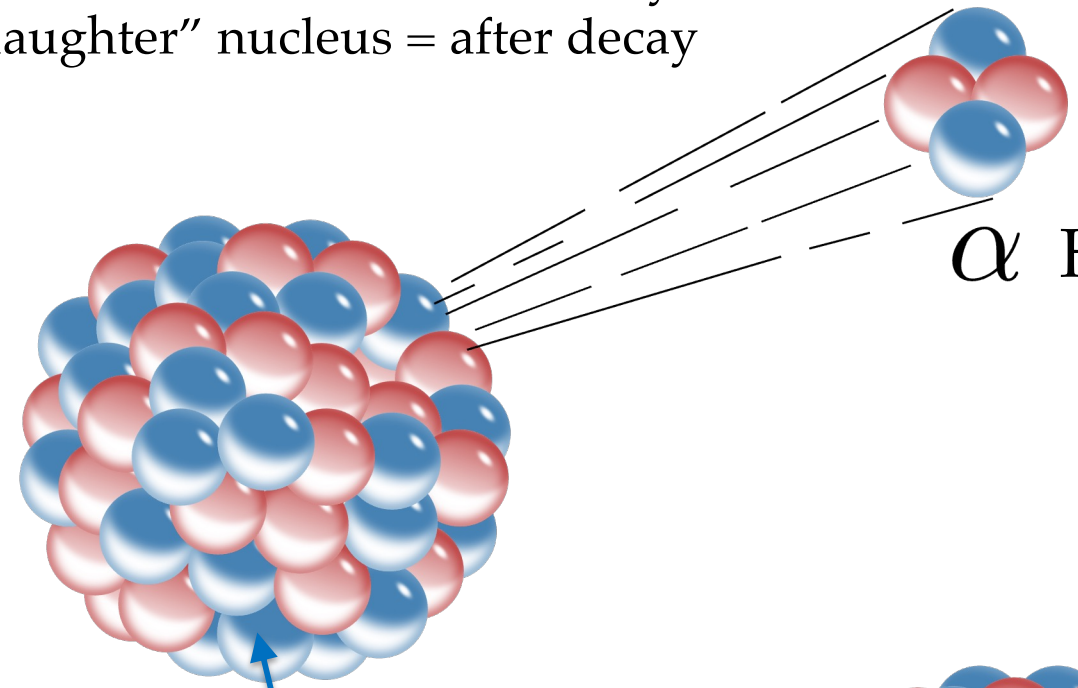
What shapes can an atomic nucleus have?

baseball (sphere) | pill (aspirin) | football (American) | pear (avocado)

photo: Alex Brown

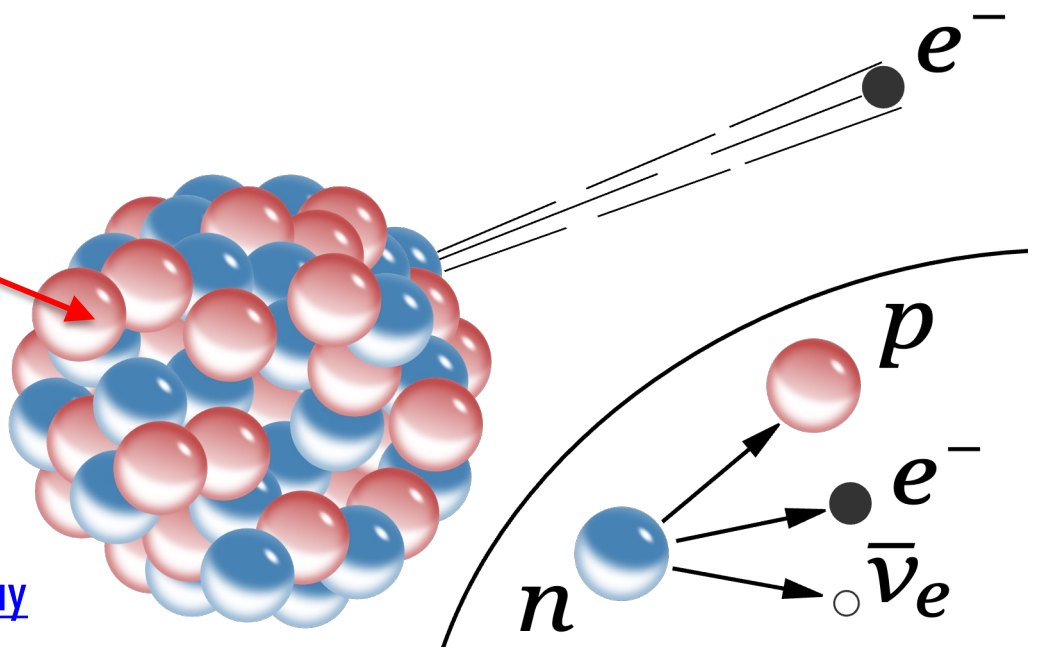
How is radioactivity related to atomic nuclei?

"parent" nucleus = before decay
"daughter" nucleus = after decay



α Helium

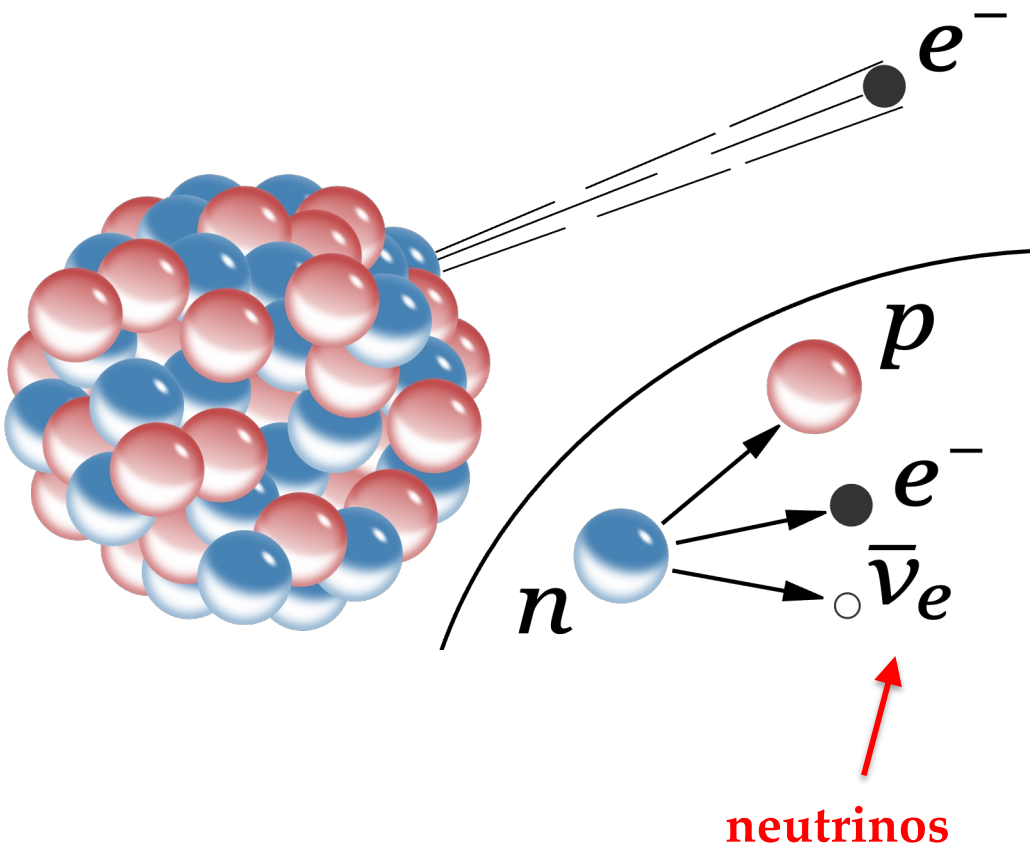
electron = - e^- = β^-



proton = +
neutron = 0

https://en.wikipedia.org/wiki/Beta_decay
https://en.wikipedia.org/wiki/Radioactive_decay

What else is produced when an atomic nucleus breaks apart?



$10^{0.5}$ feet

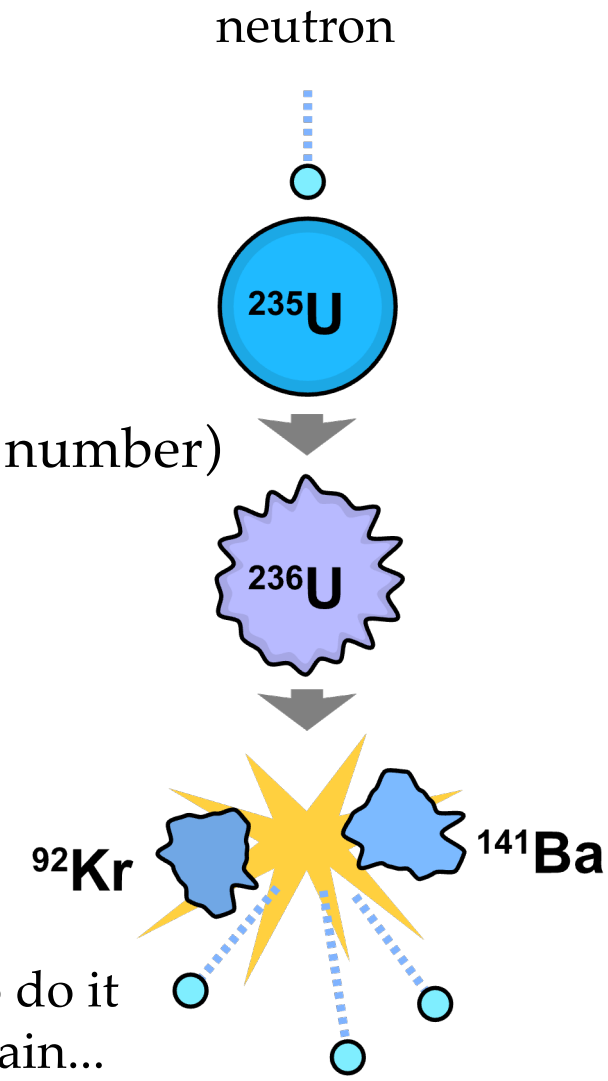
https://en.wikipedia.org/wiki/Beta_decay

"Electricity" = "Magnets" times (Cats)^2

Lise Meitner: Nuclear Fission and Nuclear Energy

Lise Meitner (1878-1968)
https://en.wikipedia.org/wiki/Lise_Meitner

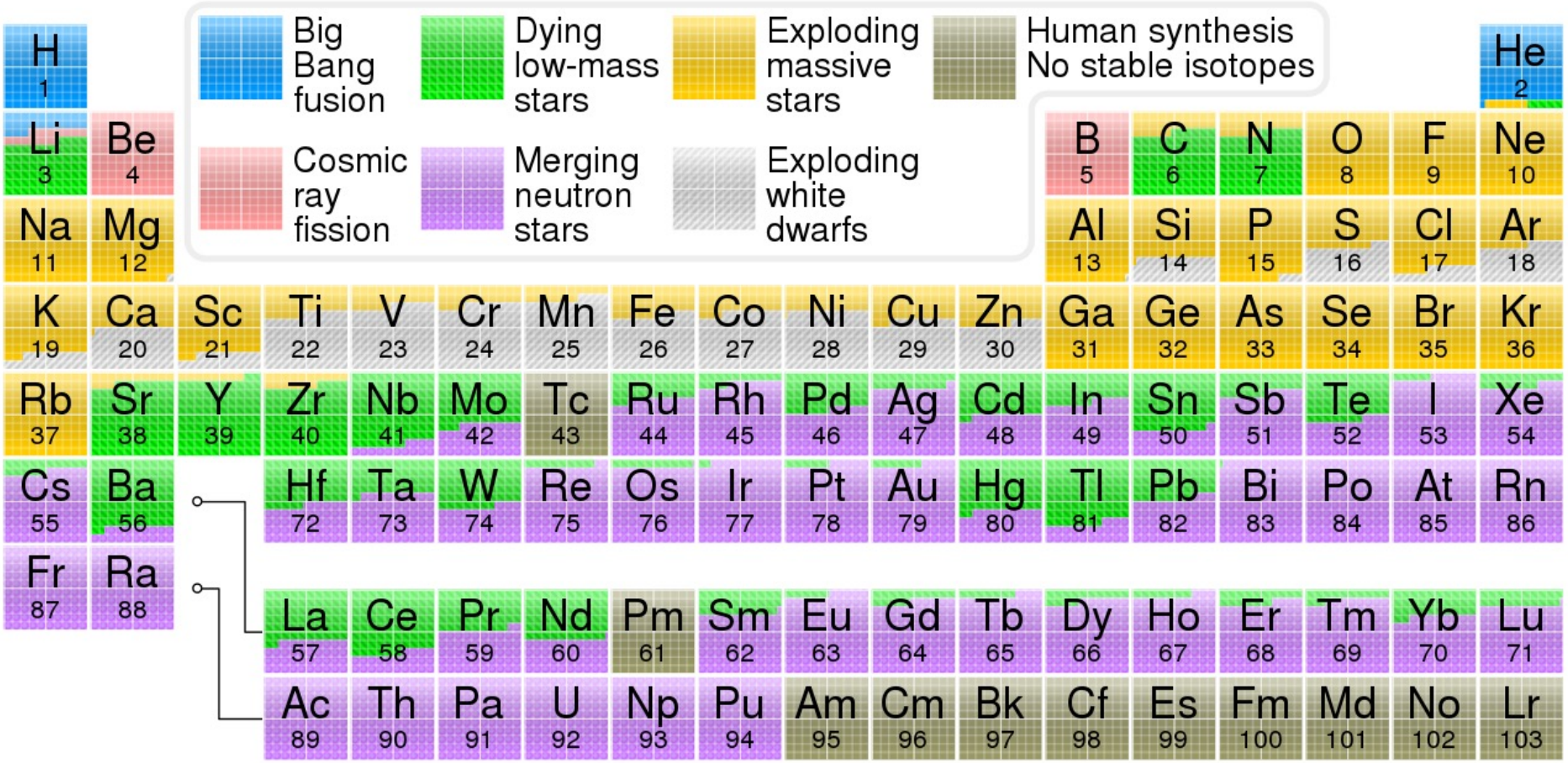
$E = mc^2$
lots of energy =
(tiny change in mass)
times (really really big number)



more neutrons to do it
over and over again...

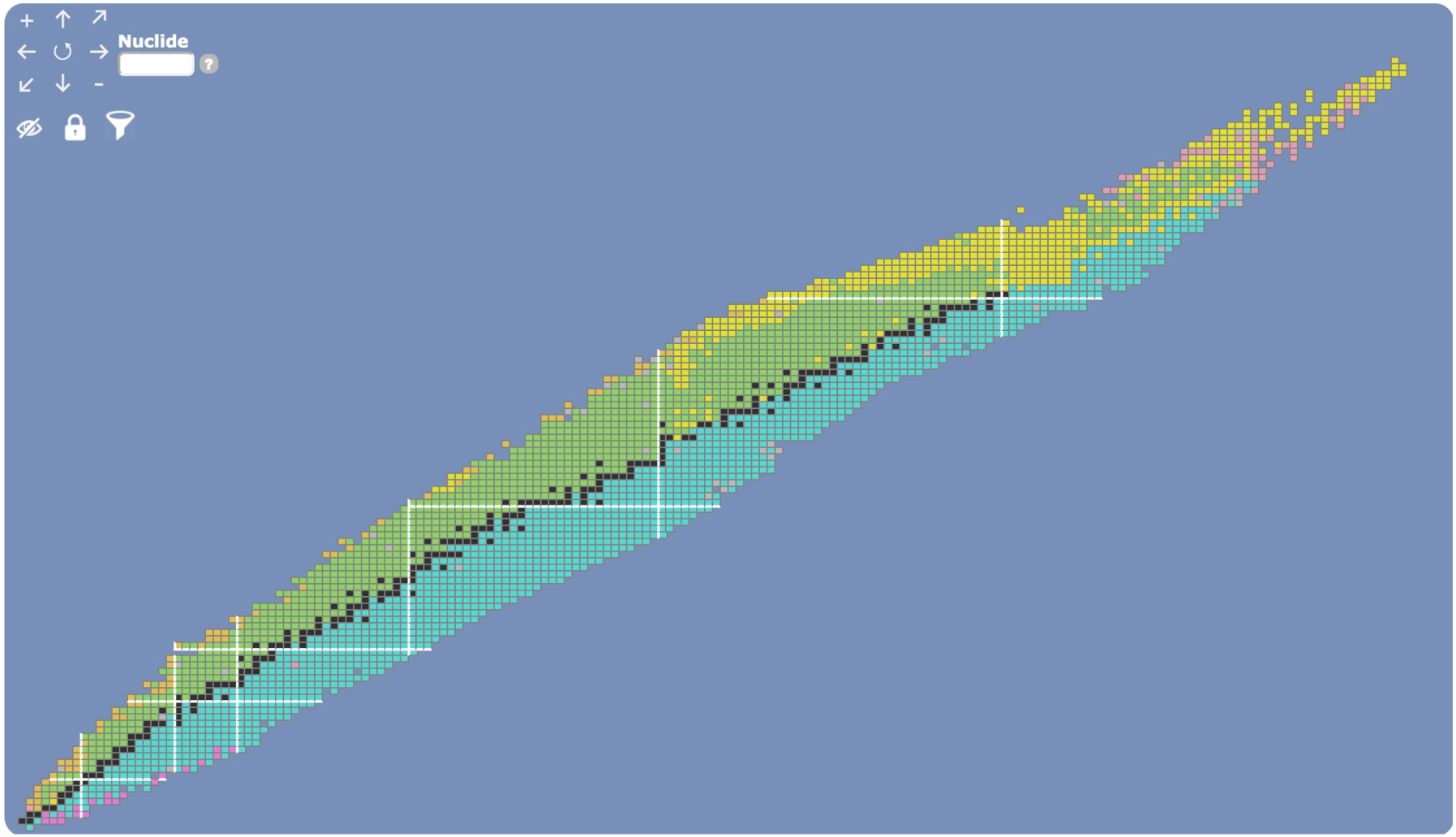
https://en.wikipedia.org/wiki/Nuclear_fission

Different chemical elements have different numbers of protons.



File:Nucleosynthesis periodic table.svg. (2020, March 7). Wikimedia Commons, the free media repository. Retrieved 16:41, May 24, 2020 from https://commons.wikimedia.org/w/index.php?title=File:Nucleosynthesis_periodic_table.svg&oldid=402170545.

The same chemical element can weigh differently because it has some extra or fewer neutrons.



https://www-nds.iaea.org/relnsd/vcharthtml/VChartHTML.html

How many bananas are too many bananas?

Potassium-40 = 0.01%
beta decay "half-life"
1 billion years

Dental x-ray (5 μSv)

50 bananas!

Background dose received by an average person over one normal day (10 μSv)

Eating one banana (0.1 μSv)

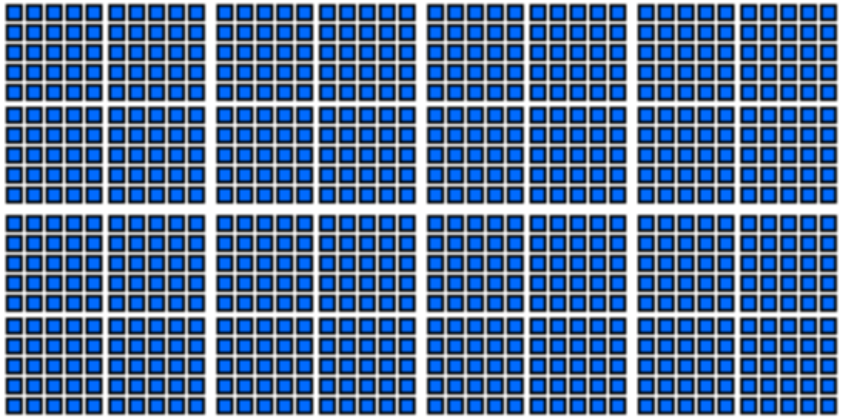
Living within 50 miles of a coal power plant for a year (0.3 μSv)

Arm x-ray (1 μSv)

Using a CRT monitor for a year (1 μSv)

Extra dose from spending one day in an area with higher-than-average natural background radiation, such as the Colorado plateau (1.2 μSv)

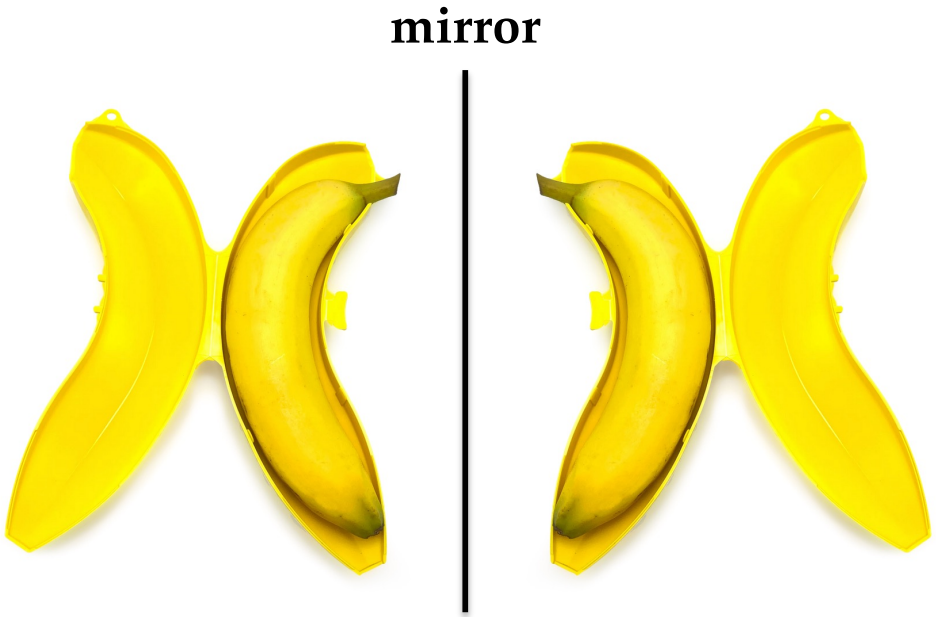
Airplane flight from New York to LA (40 μSv)



400 bananas!

https://en.wikipedia.org/wiki/Banana_equivalent_dose

P1: Are bananas left-handed or right-handed? (1957)



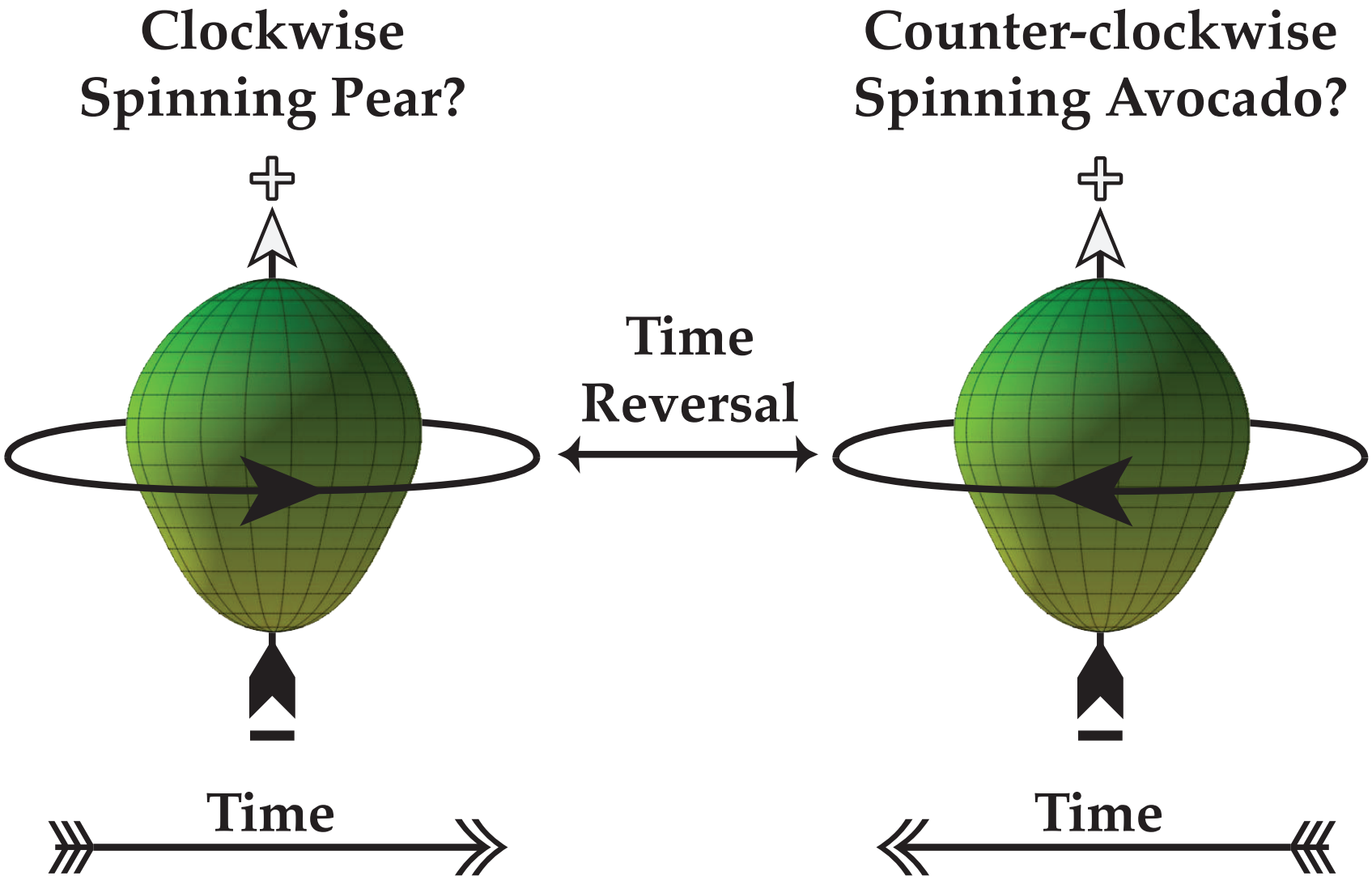
https://www.pocampo.com/products/protective-banana-case

SCAN ME

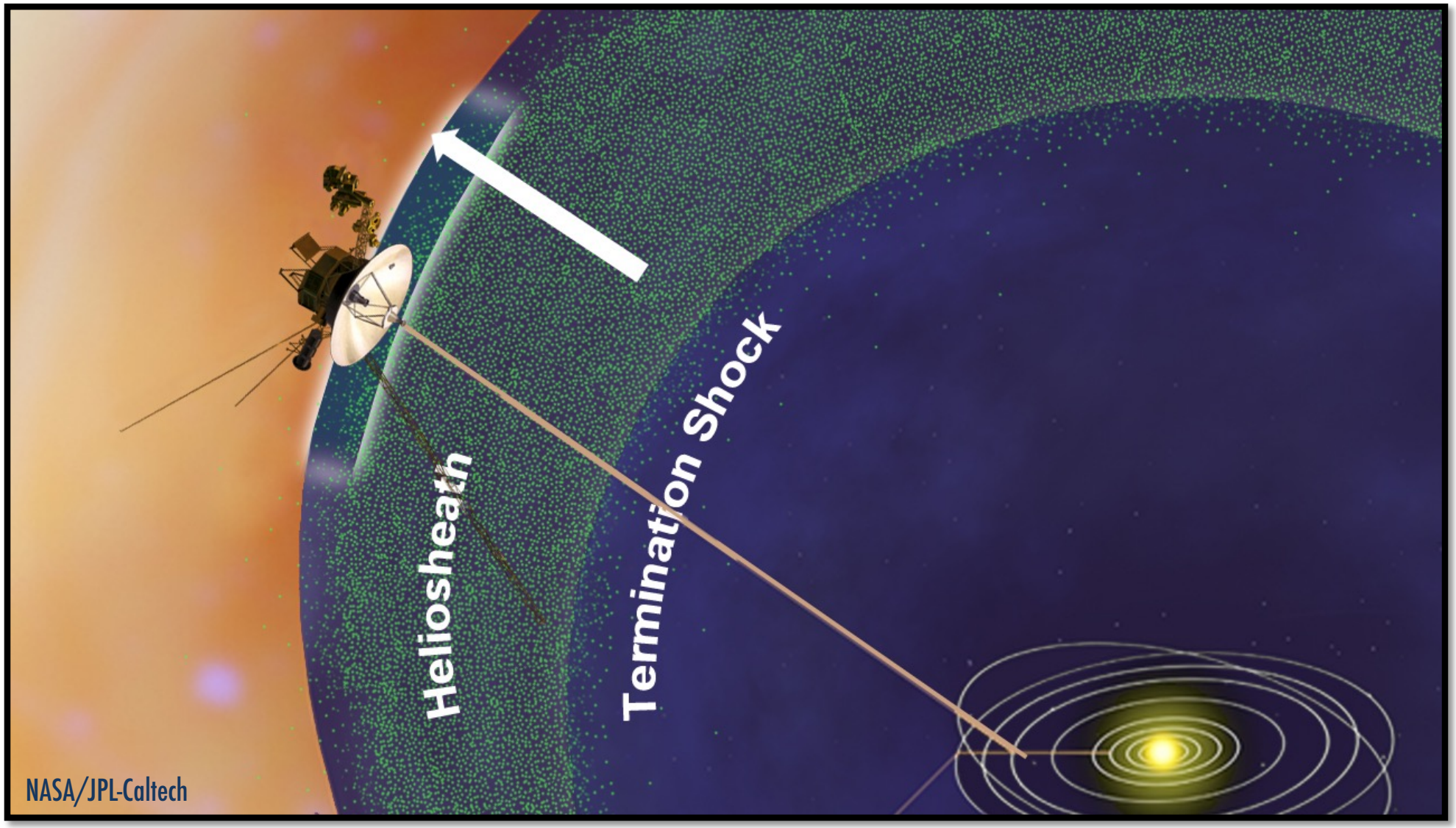
C.S. Wu: My All-Time Favorite Science Super-Hero!

http://en.wikipedia.org/wiki/File:Wu_experiment.jpg

P2: Do pears (or avocados) spin faster clockwise? (Today)

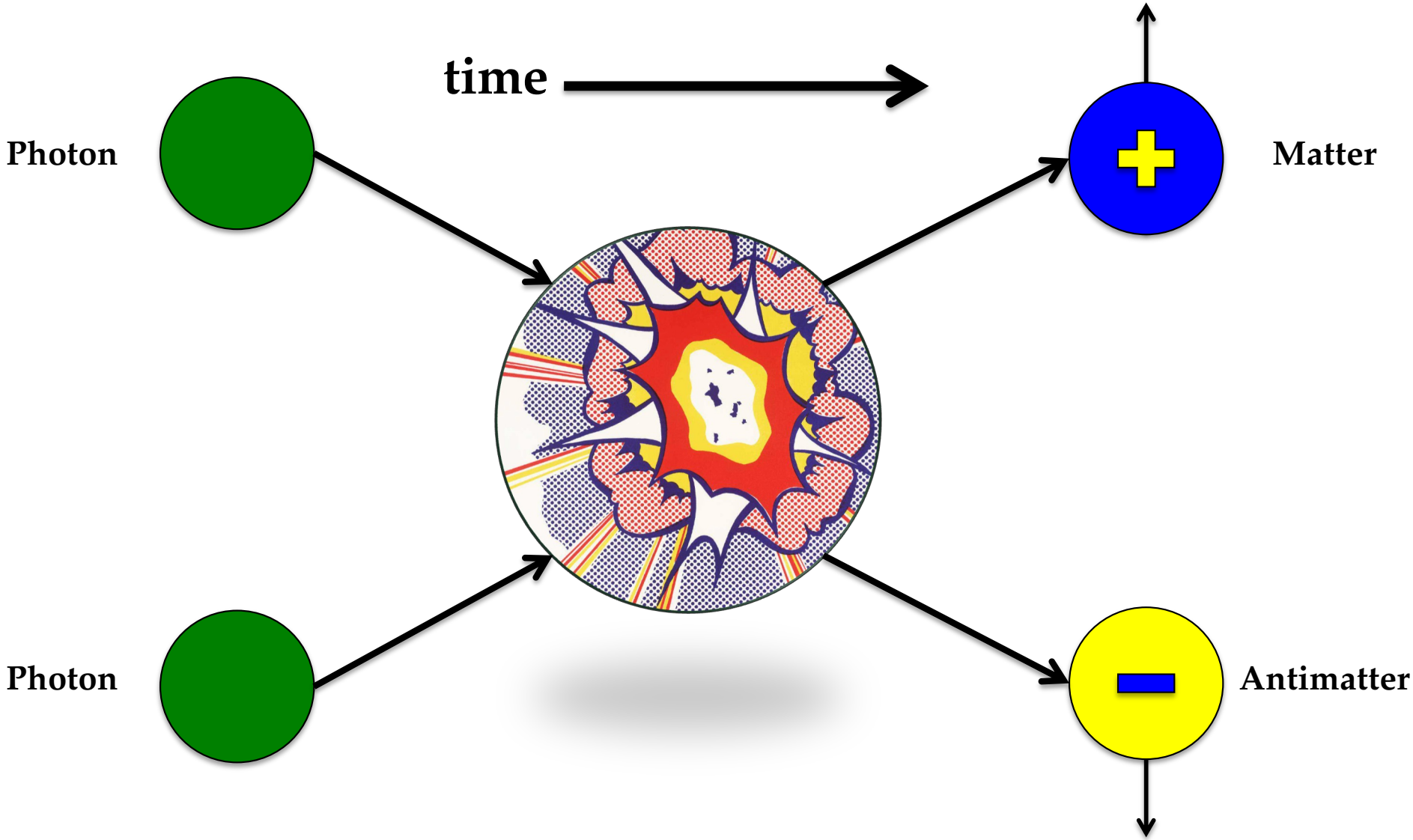


D: Why hasn't Voyager blown up…yet!



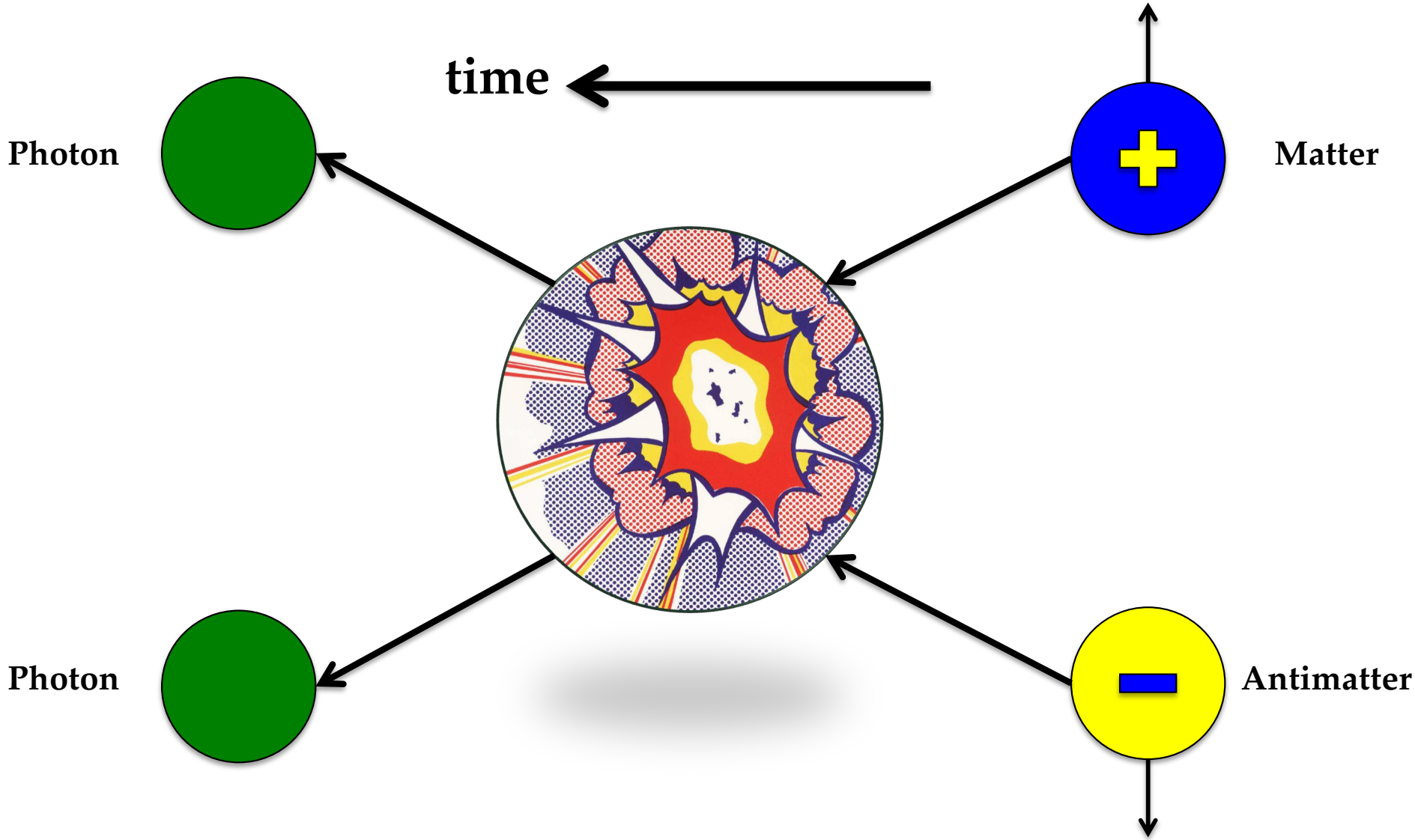
D: Everything that you can *see* is made of Matter.

Light (Energy) can be converted into Matter and Antimatter.



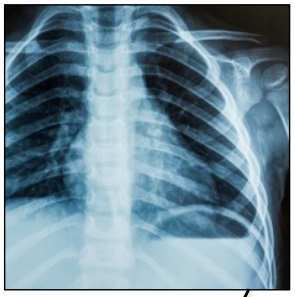
https://www.tate.org.uk/kids/explore/who-is/who-roy-lichtenstein

Matter and Antimatter annihilates into Light (Energy).



https://www.tate.org.uk/kids/explore/who-is/who-roy-lichtenstein

The Color of Light corresponds to the Photon Energy.

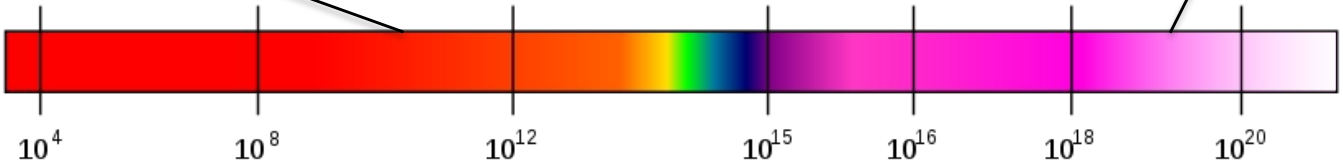


Infrared Invisible

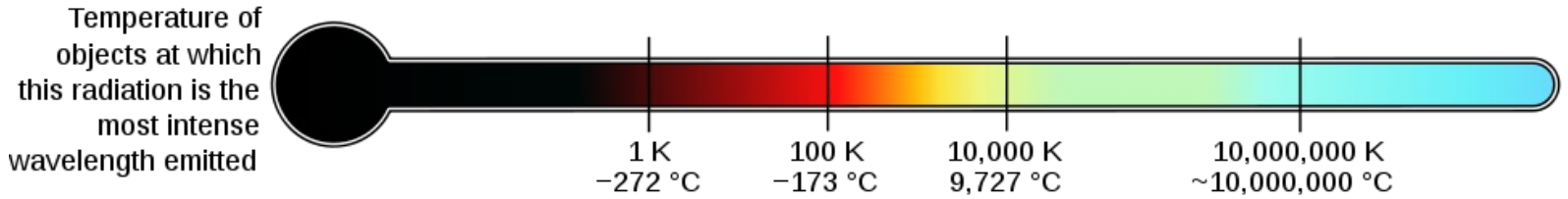
ROY G BIV Visible

Ultraviolet Invisible

Color



Energy and Temperature



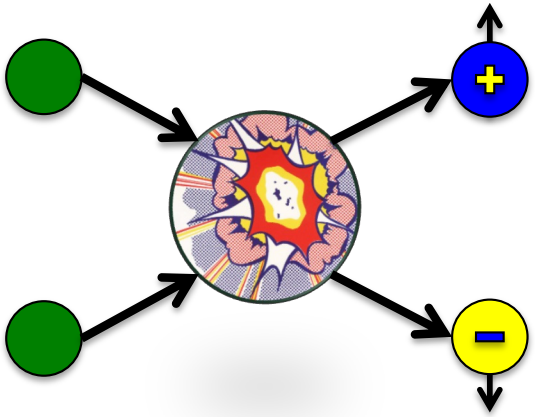
low energy
cold

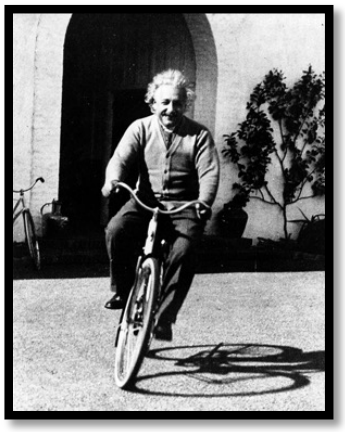
HIGH ENERGY
HOT

https://en.wikipedia.org/wiki/Rainbow
https://en.wikipedia.org/wiki/Microwave_oven
https://medlineplus.gov/xrays.html
http://earthsky.org/space/what-is-the-electromagnetic-spectrum

The Light must have enough Energy to create the mass of the Matter & Antimatter ($E=mc^2$).

Incoming Light Energy is greater than the outgoing mass.

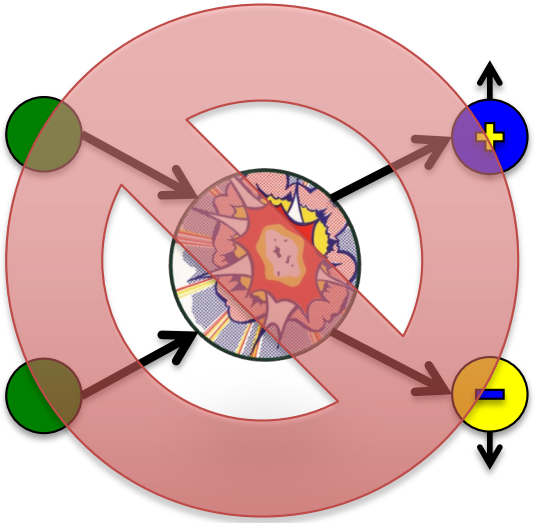


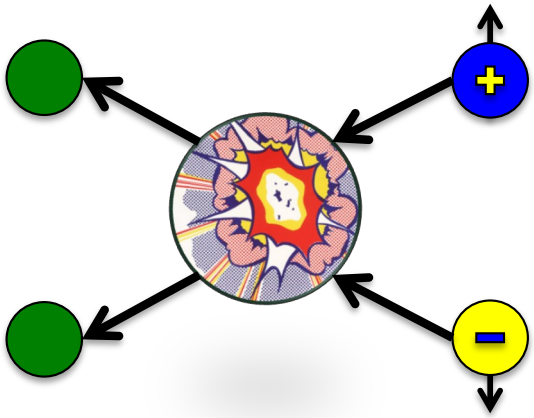


NASA

The incoming Mass is converted into Light Energy with the corresponding color.

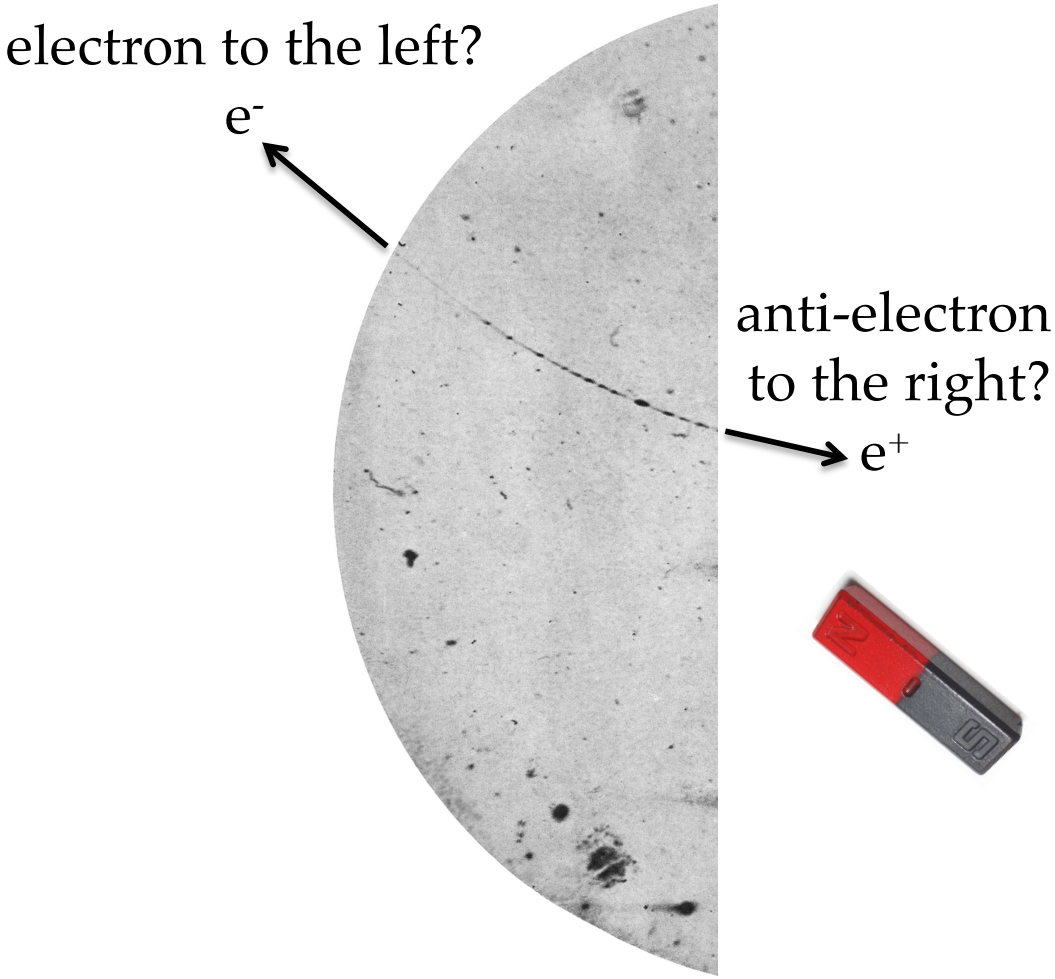
Incoming Light Energy is less than the outgoing mass.





https://www.tate.org.uk/kids/explore/who-is/who-roy-lichtenstein

Does Antimatter even exist?



A magnetic field points into the page.

An electron (negative charge) moving to the left bends up.

An anti-electron (positron, positive charge) moving to the right bends down.

http://dx.doi.org/10.1103/PhysRev.43.491
https://simple.wikipedia.org/wiki/Magnet

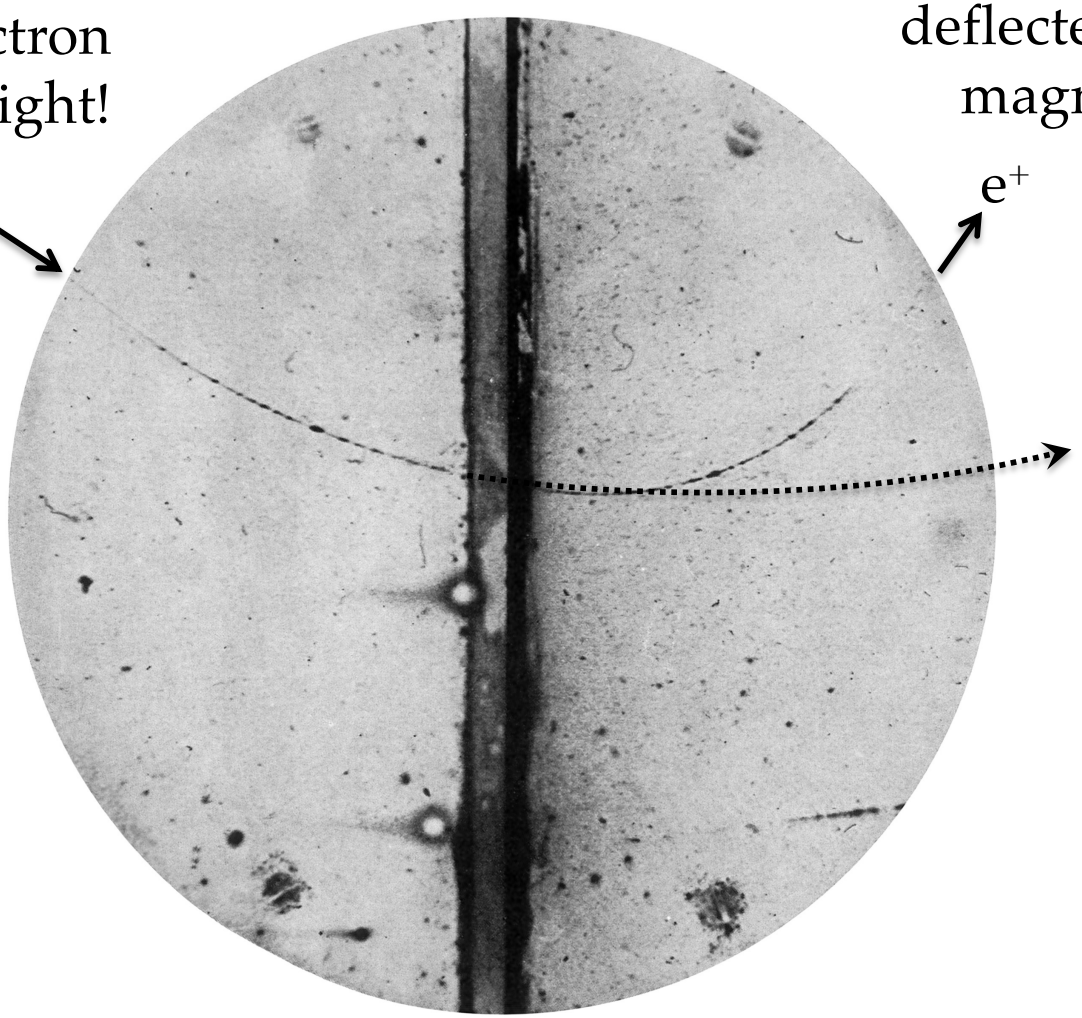
Yes, Antimatter exists! The "first" picture:

anti-electron
to the right!

e^+

A slower particle is deflected more by a magnetic field.

e^+

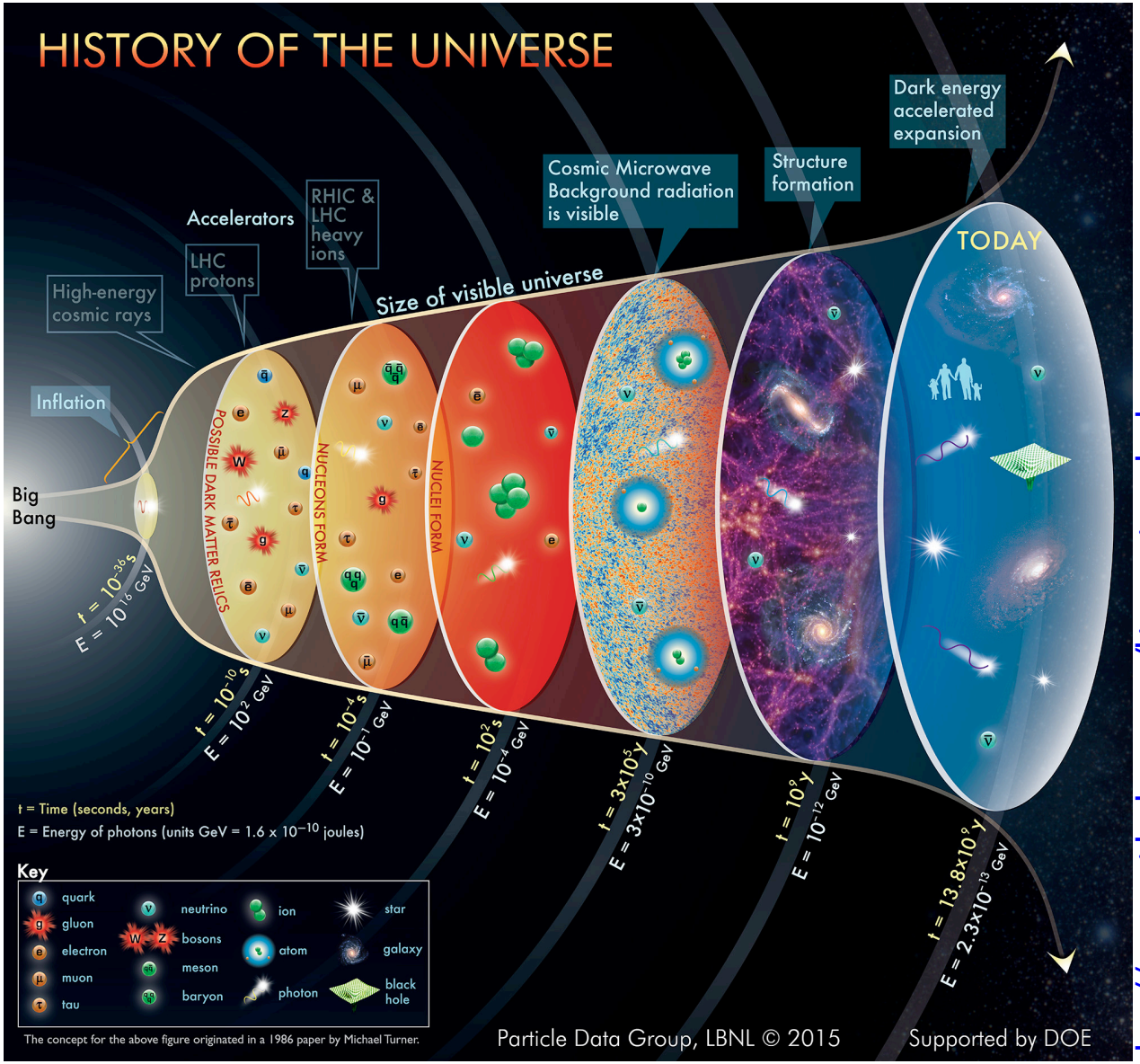


http://dx.doi.org/10.1103/PhysRev.43.491

Lead plate slows down the particle.

Big Bang…expanding Universe

HOT & DENSE



cold & dilute

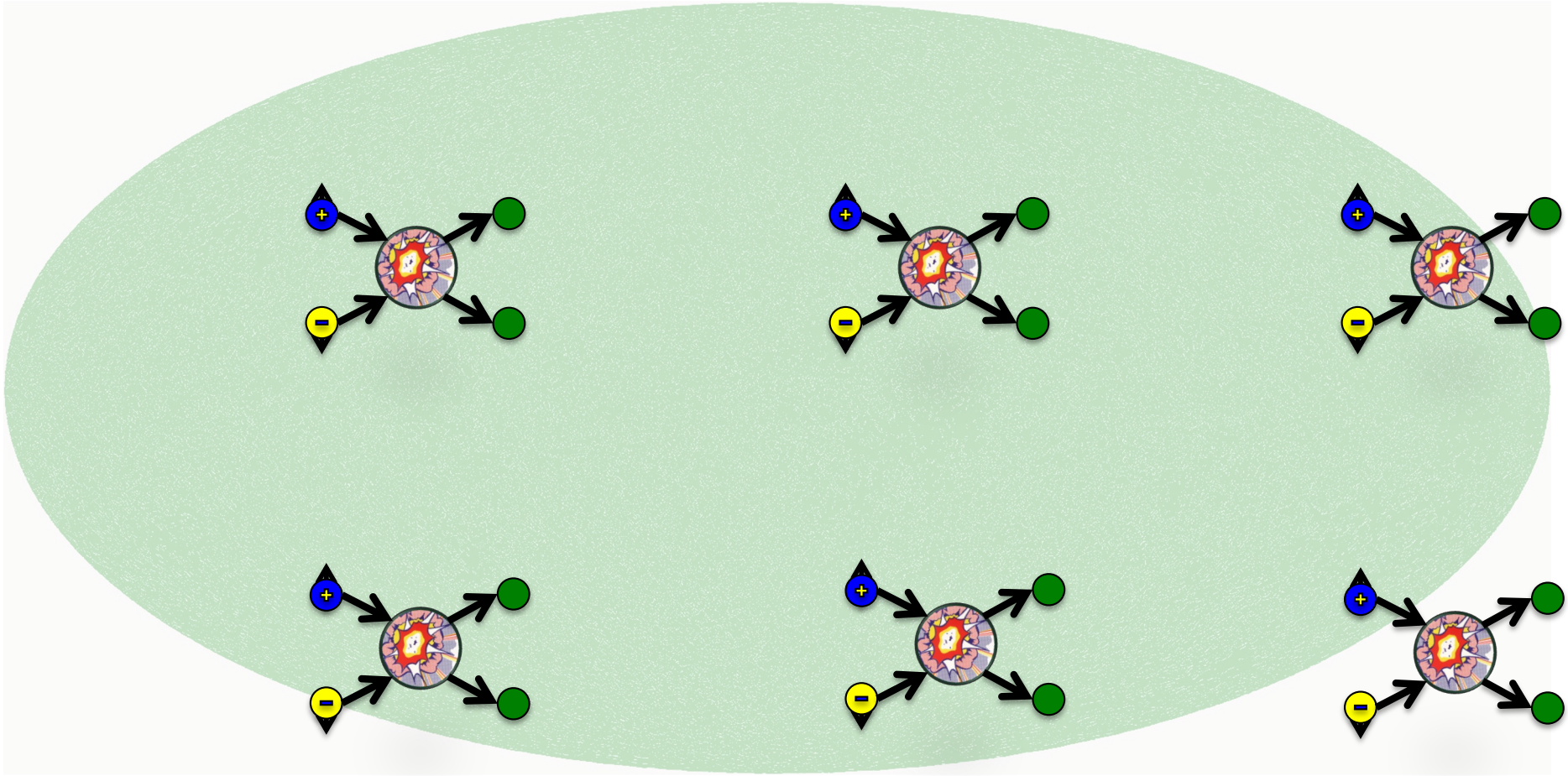
http://www.particleadventure.org/history-universe.html

Everything Everywhere All At Once!

https://www.bbc.com/news/entertainment-arts-64938320

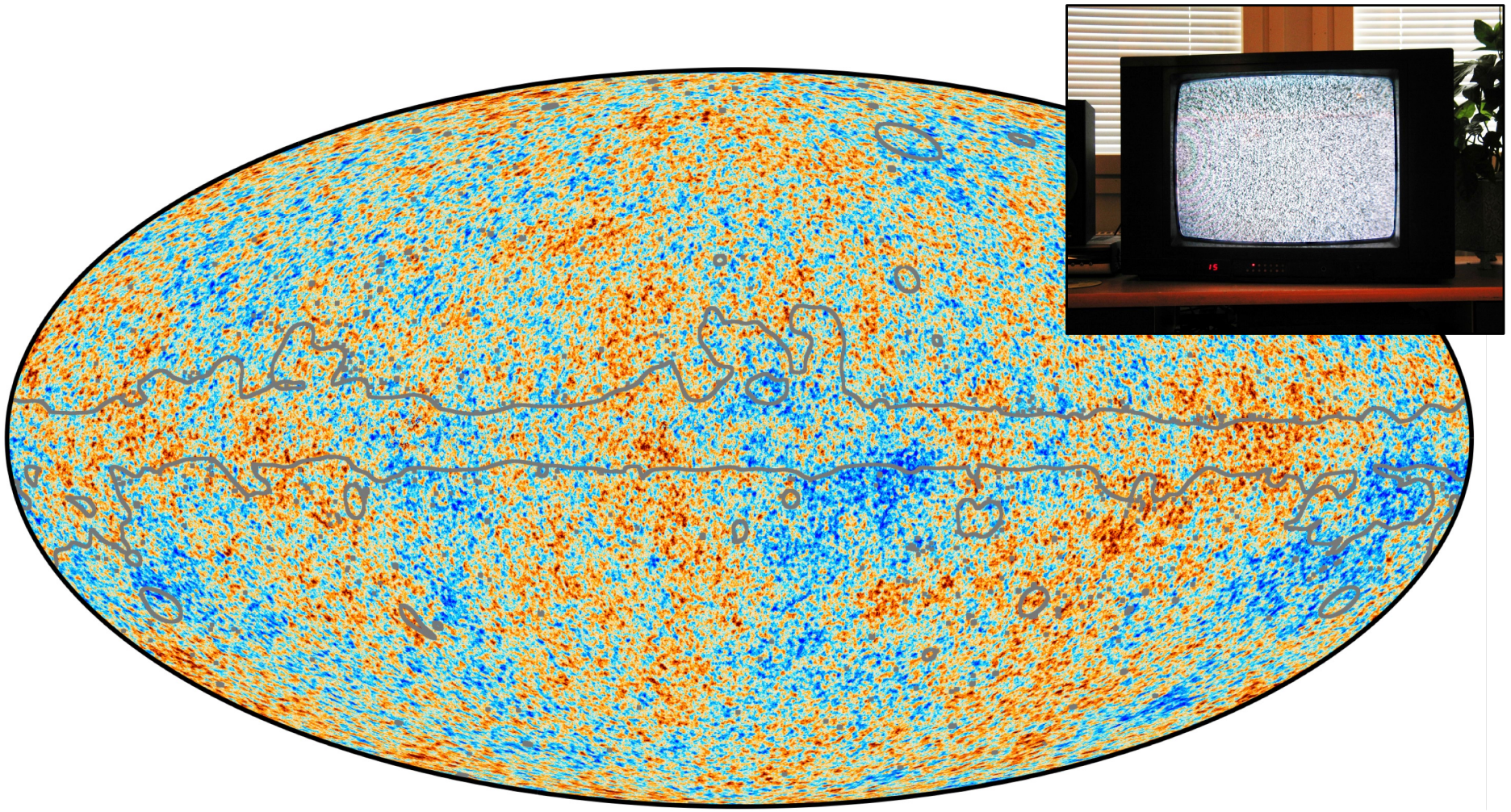
https://www.tate.org.uk/kids/explore/who-is/who-roy-lichtenstein

Expansion implies cooling:
Light can't turn back into matter+antimatter
Temperature = -455 ºF (Everywhere)



https://www.tate.org.uk/kids/explore/who-is/who-roy-lichtenstein

D: "Baby Picture" of the Universe



https://www.cosmos.esa.int/web/planck/picture-gallery
Planck 2018
https://en.wikipedia.org/wiki/Noise_(video)

Temperature of red "spots" = -454.95 °F
Temperature of blue "spots" = -455.05 °F

How much matter, antimatter, and light is there?

Average size of "spots"

↓ *Einstein's Theory of General Relativity*

$$\frac{\text{[amount of MATTER]} - \text{[amount of antimatter]}}{\text{[amount of Light]}}$$

↓

If > 0, then more MATTER than antimatter
If < 0, then more antimatter than MATTER

If > 1, then more MATTER/antimatter than Light
If < 1, then more Light than MATTER/antimatter

How much matter, antimatter, and light is there?

Average size of "spots"

↓ *Einstein's Theory of General Relativity*

$$\frac{\text{[amount of MATTER]} - \text{[amount of antimatter]}}{\text{[amount of Light]}}$$

↓

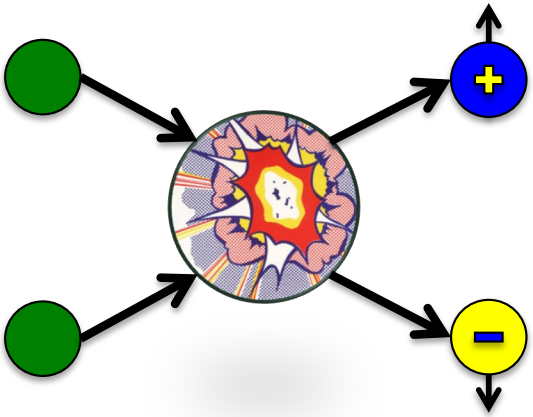
+0.00000000061

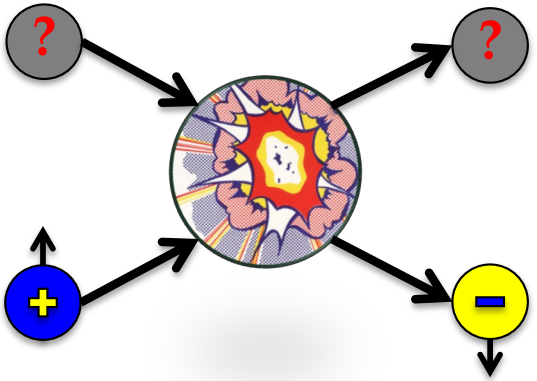
more MATTER than antimatter

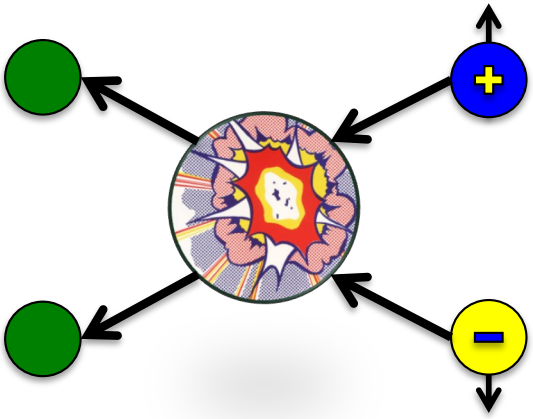
more Light than MATTER by a factor of 1 billion!

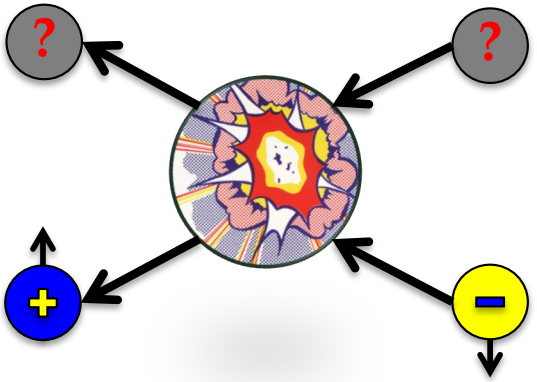
Think about how small this number is…

Why? "Time-Reversal Symmetry Violation"



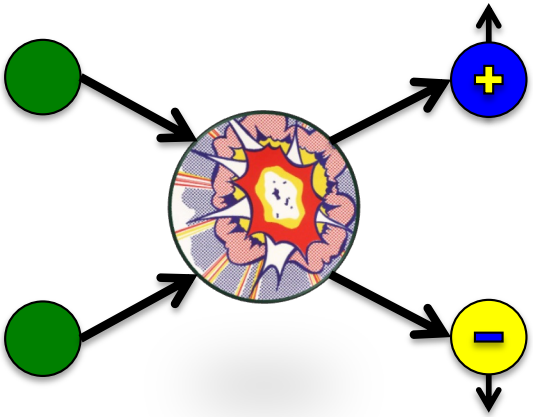


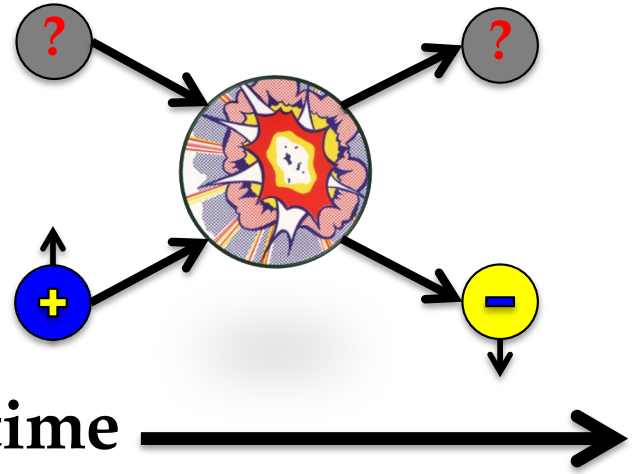


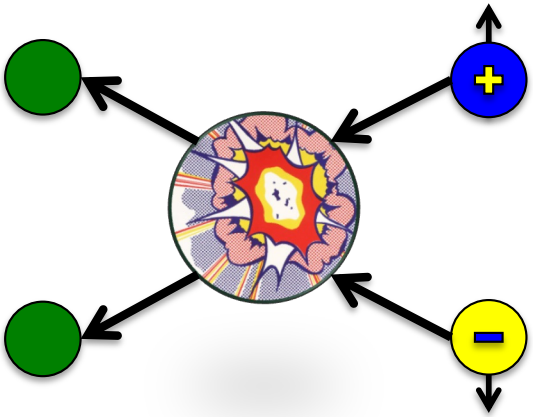


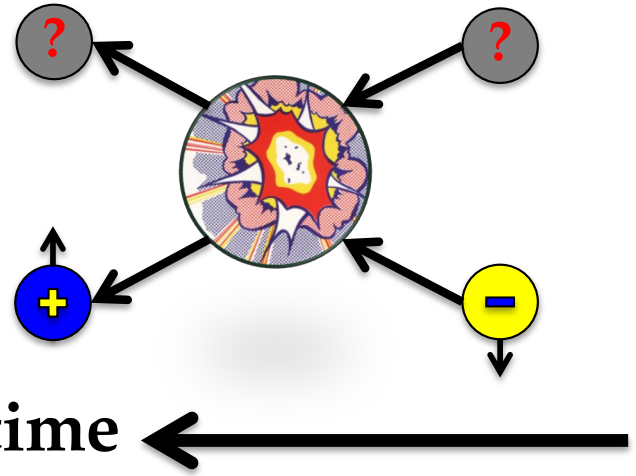
https://www.tate.org.uk/kids/explore/who-is/who-roy-lichtenstein

Forces Between Subatomic Particles That Are Not The Same When The Arrow of Time is Reversed



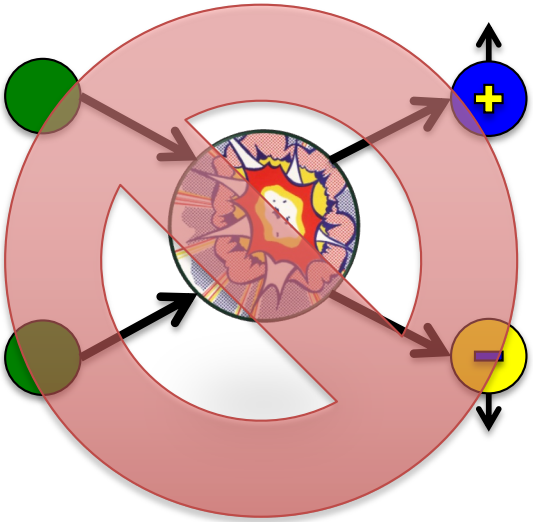




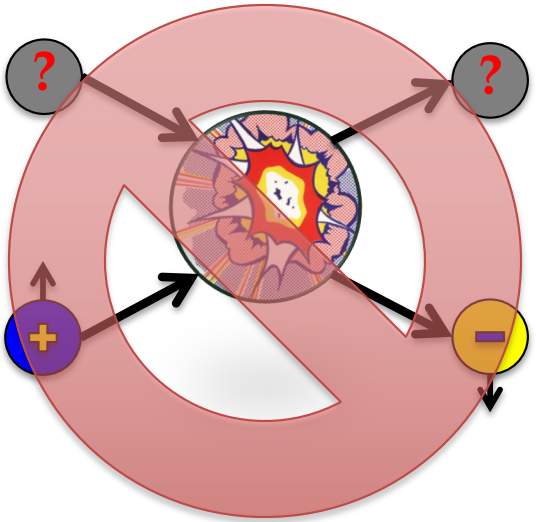


https://www.tate.org.uk/kids/explore/who-is/who-roy-lichtenstein

P2: You're left with only Light and Matter.

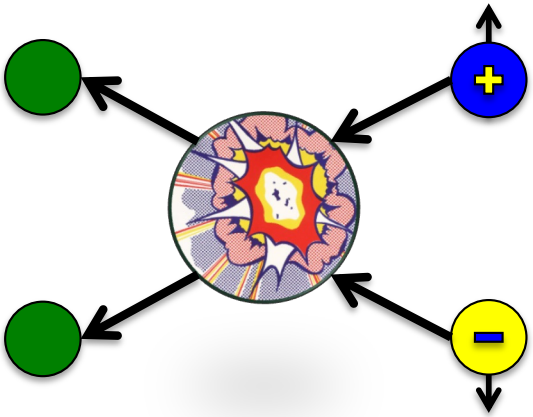


expanding/cooling Universe

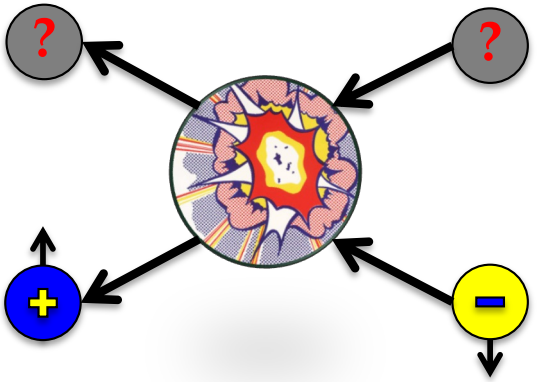


T-violation!

Light



Matter



https://www.tate.org.uk/kids/explore/who-is/who-roy-lichtenstein

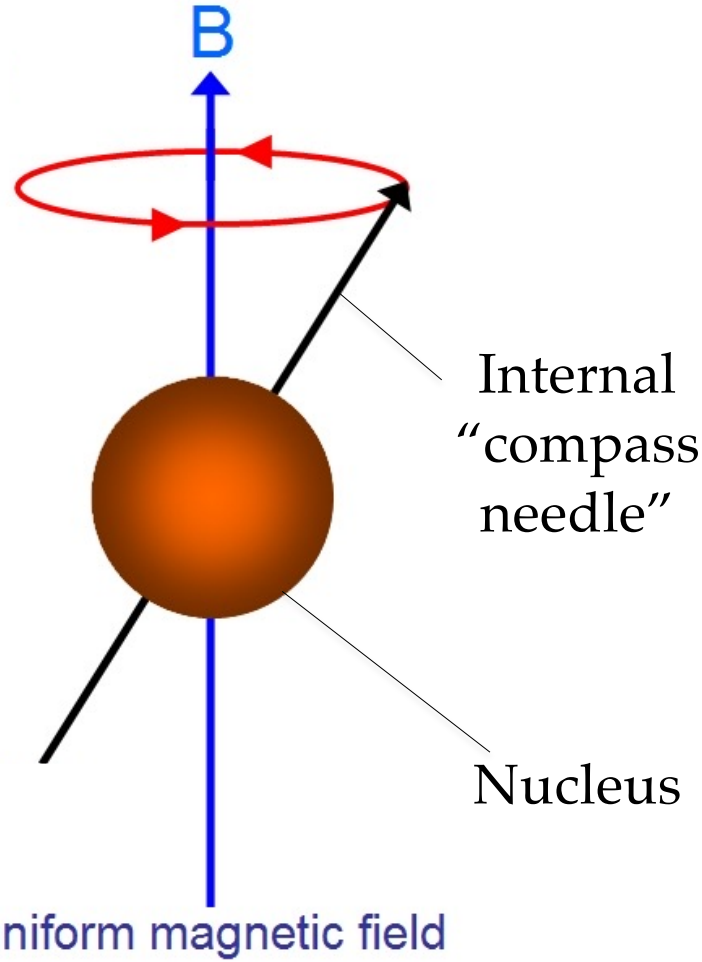
P3: How do we search for Time-Reversal Symmetry Violation (*T*-violation)?

Measure the clock rate clockwise.

Measure the clock rate counterclockwise.

Are they different?

What kind of clocks? Nuclear Clocks!

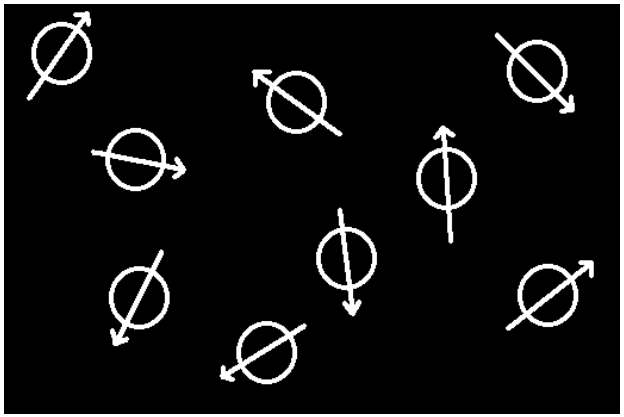


Compass needle aligns to the magnetic field. (Friction is added on purpose to stop the needle.)

No friction! Needle "precesses" around the magnetic (B) field.

http://cronodon.com/Atomic/quantum_angular_momentum.html

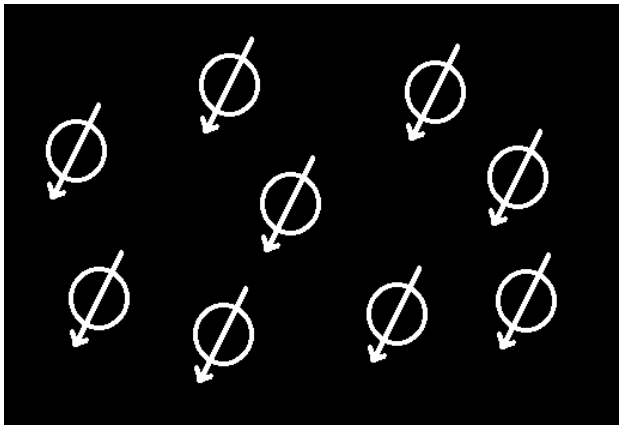
Nuclei have to be magnetized first!
How? Using lasers...



Unmagnetized nuclei

Random directions

Clocks are unsynchronized



Magnetized nuclei

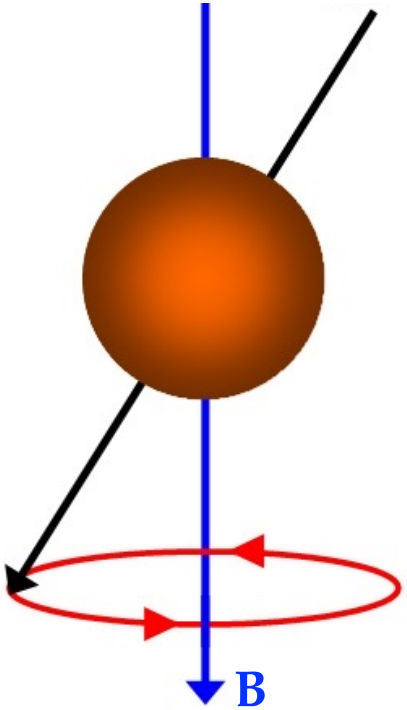
Aligned directions

Clocks are synchronized

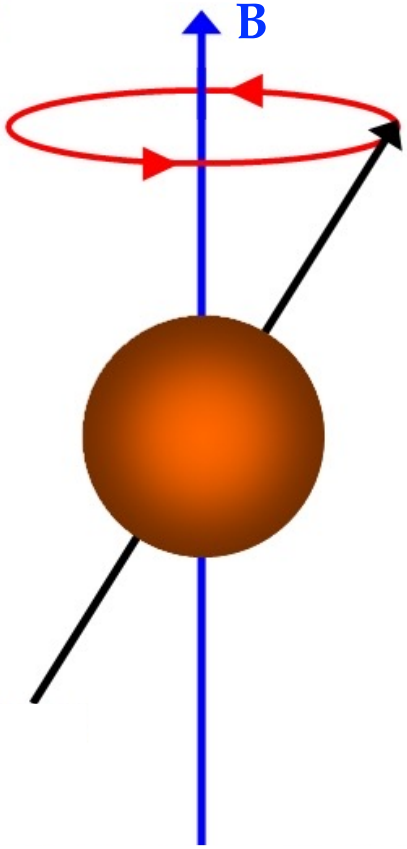
http://uhavax.hartford.edu/chemistry/pdb/nmr/theory1.htm

Nuclear clock rate & direction depends on the magnetic field!

Need a very stable (in time) and uniform (in space) magnetic field!



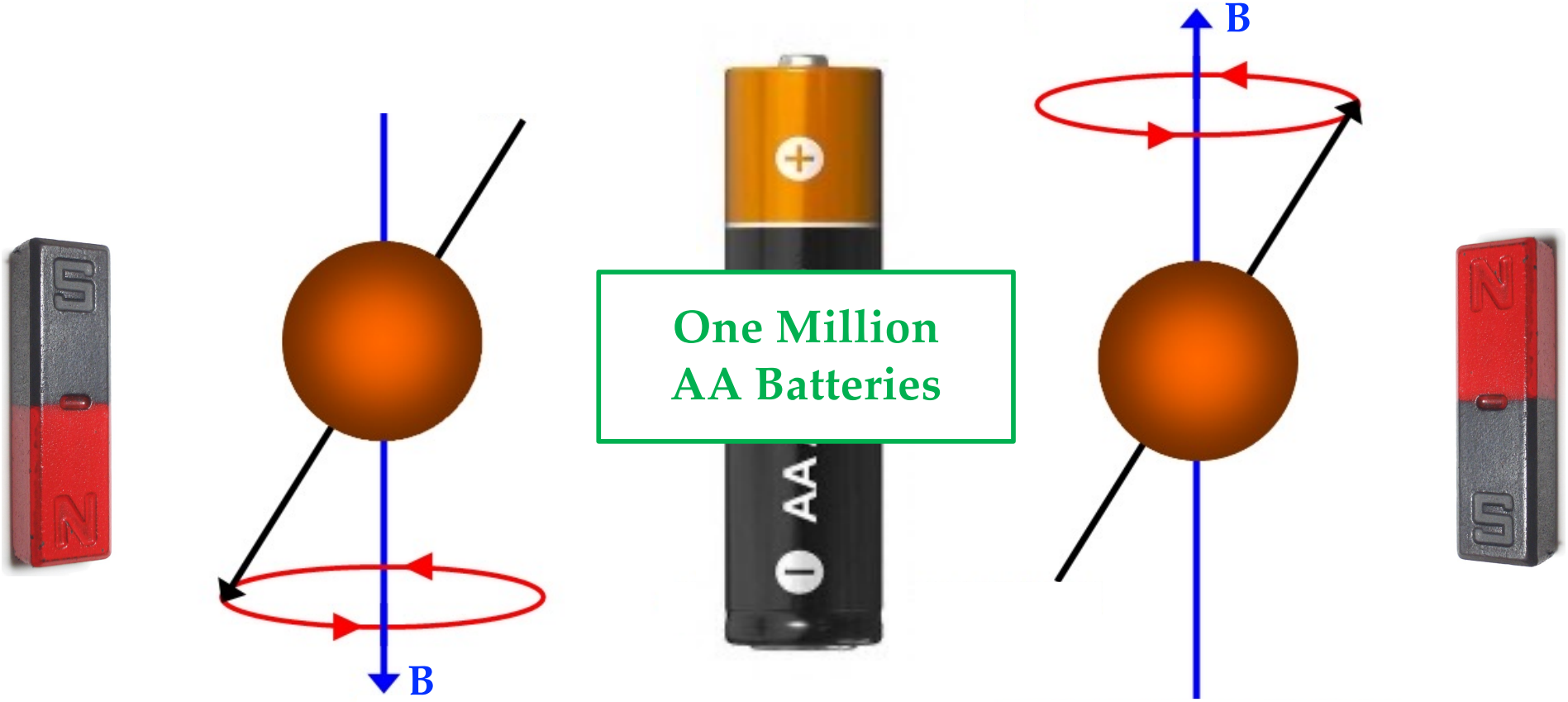
Magnetic (B) field down
Clockwise



Magnetic (B) field up
Counterclockwise

Measure the two nuclear clock rates in the presence of a Battery.

Need a lot of batteries!



Magnetic (B) field down
Clockwise

Magnetic (B) field up
Counterclockwise

Magnetic field sizes

Object	Strength of Magnetic Field
MRI Machine	60000
Computer hard drive	40000
Loudspeaker	20000
Sun spots	3000
Refrigerator magnet	100
Earth's magnetic field	1
Cassette tape	0.4
Magnetic shielded room	0.00002
Human Brain	0.0000002
"SQUID" magnetometer	0.00000000002

“Magic room” in Munich, Germany

Lots of Magnetized Helium/Xenon Gas for MRI

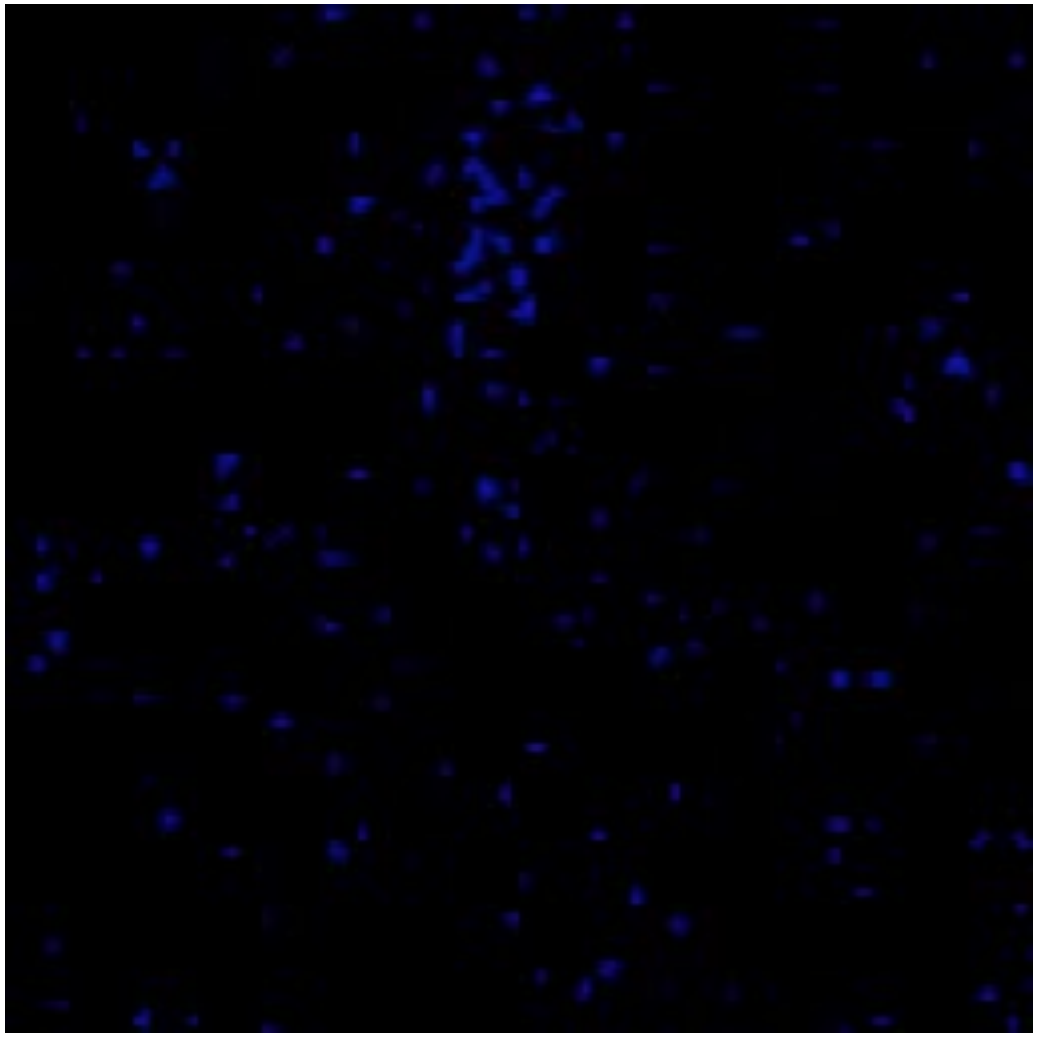
M.A. Bouchiat

0.000001 liters of gas

M.A. Bouchiat et al.
Phys. Rev. Lett. 5, 373 (1960)

2 Liters of gas

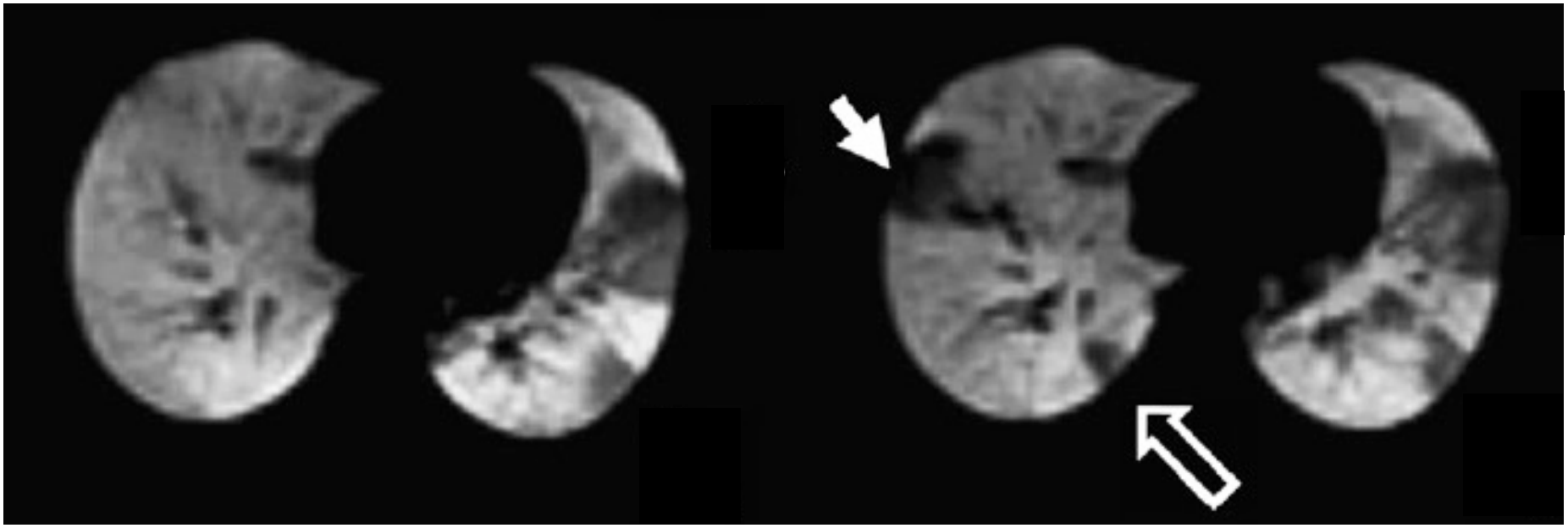
JTS et al.
Phys. Rev. C 91, 055205 (2015)



University of Virginia Radiology

Asthma and Lungs: How Sensitive Is the Subject?

Mild-intermittent asthmatic:



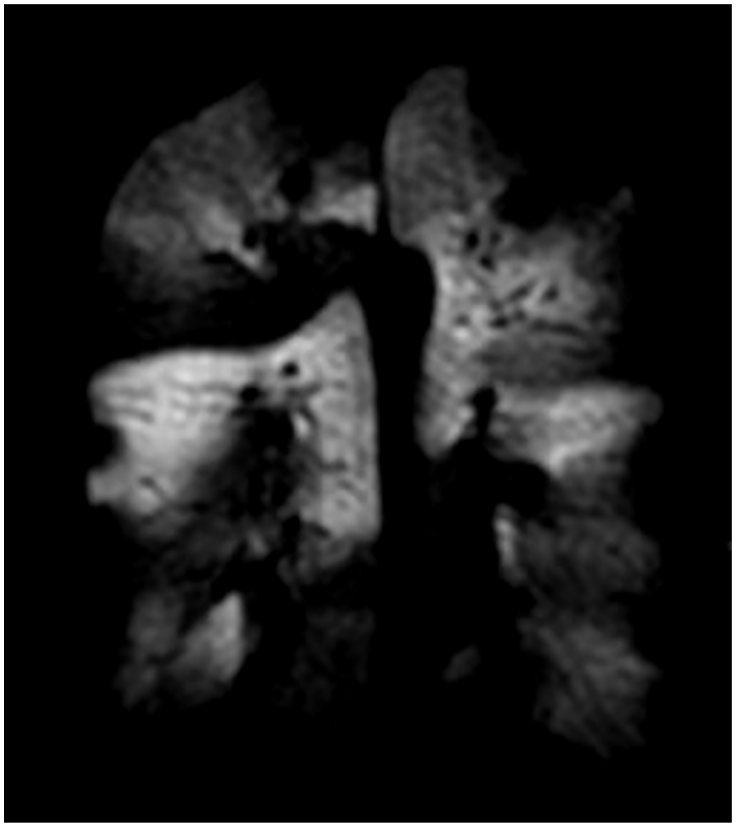
Pre Methacholine

Post Methacholine

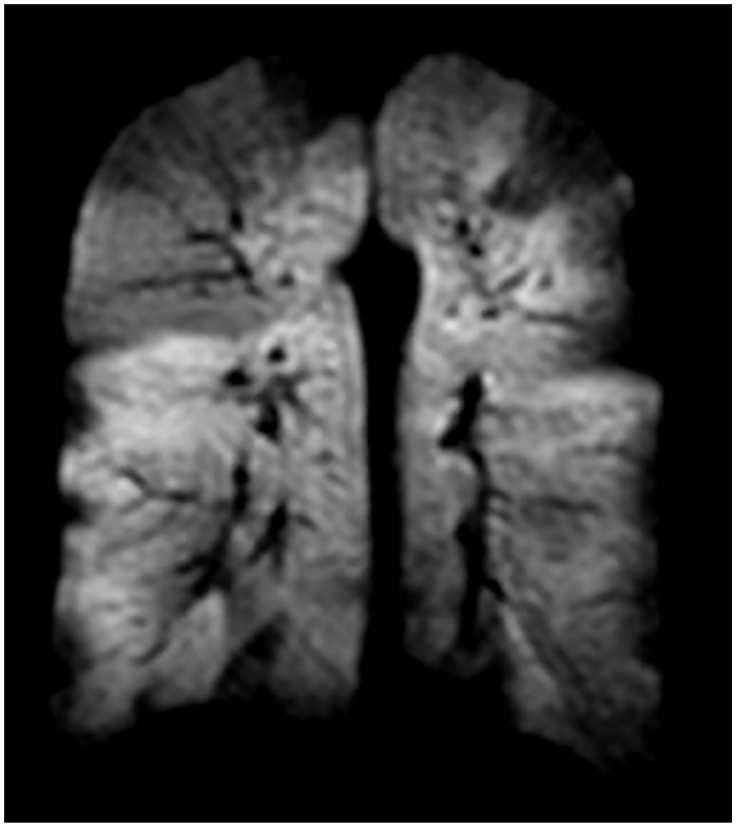
EE de Lange et al. J. Allergy Clin Immunol 119:1072-1078 (2007).

Asthma & Lungs: How Effective is the Treatment?

Severe-persistent asthmatic:



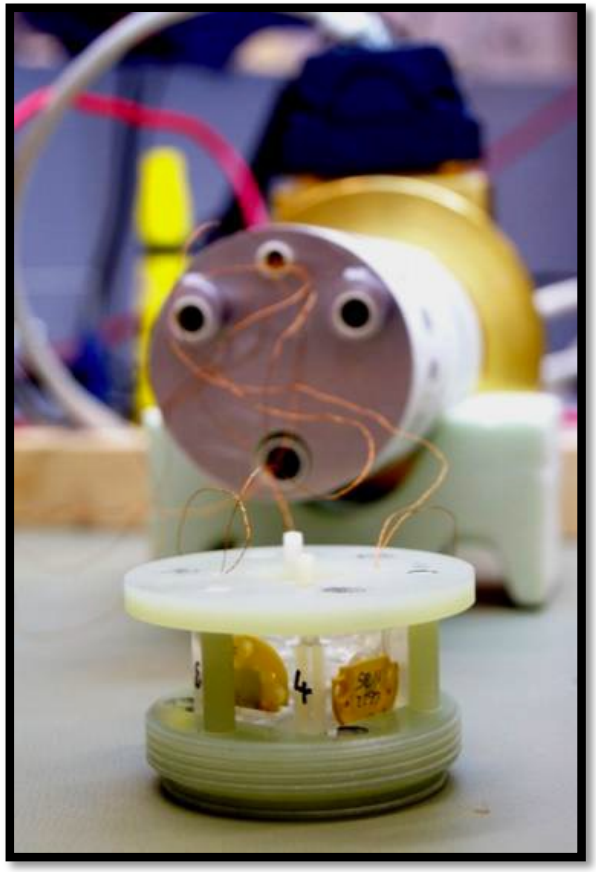
Pre Albuterol



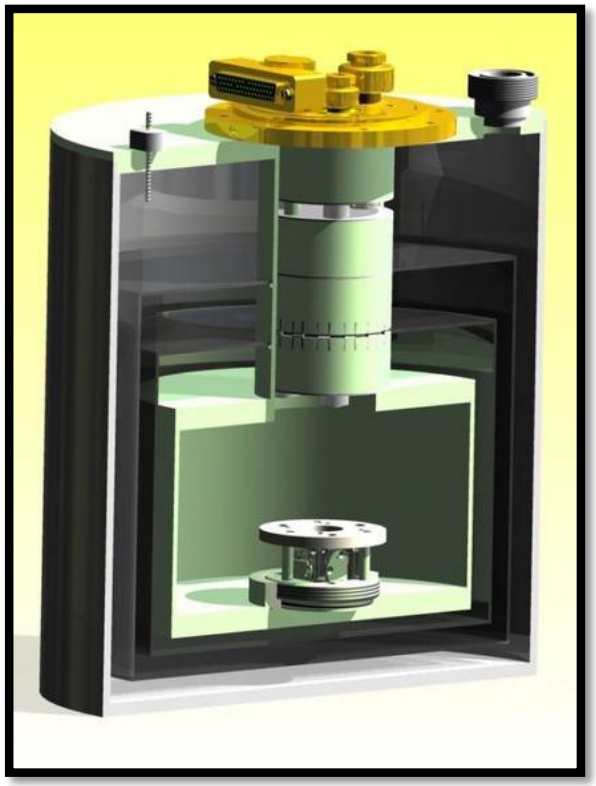
Post Albuterol

TA Altes et al. JMRI 2001;13:378-84

Cold Magnetic Sensors: "SQUID" (2019)



Sensors

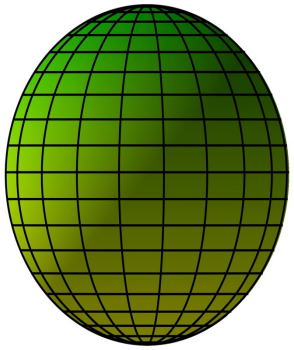


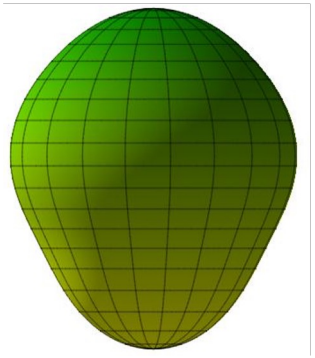
Operate at -452 °F

Nonmagnetic
wooden components

Clock rate difference: Smaller than one second per day
How do we do better? Use a faster clock!

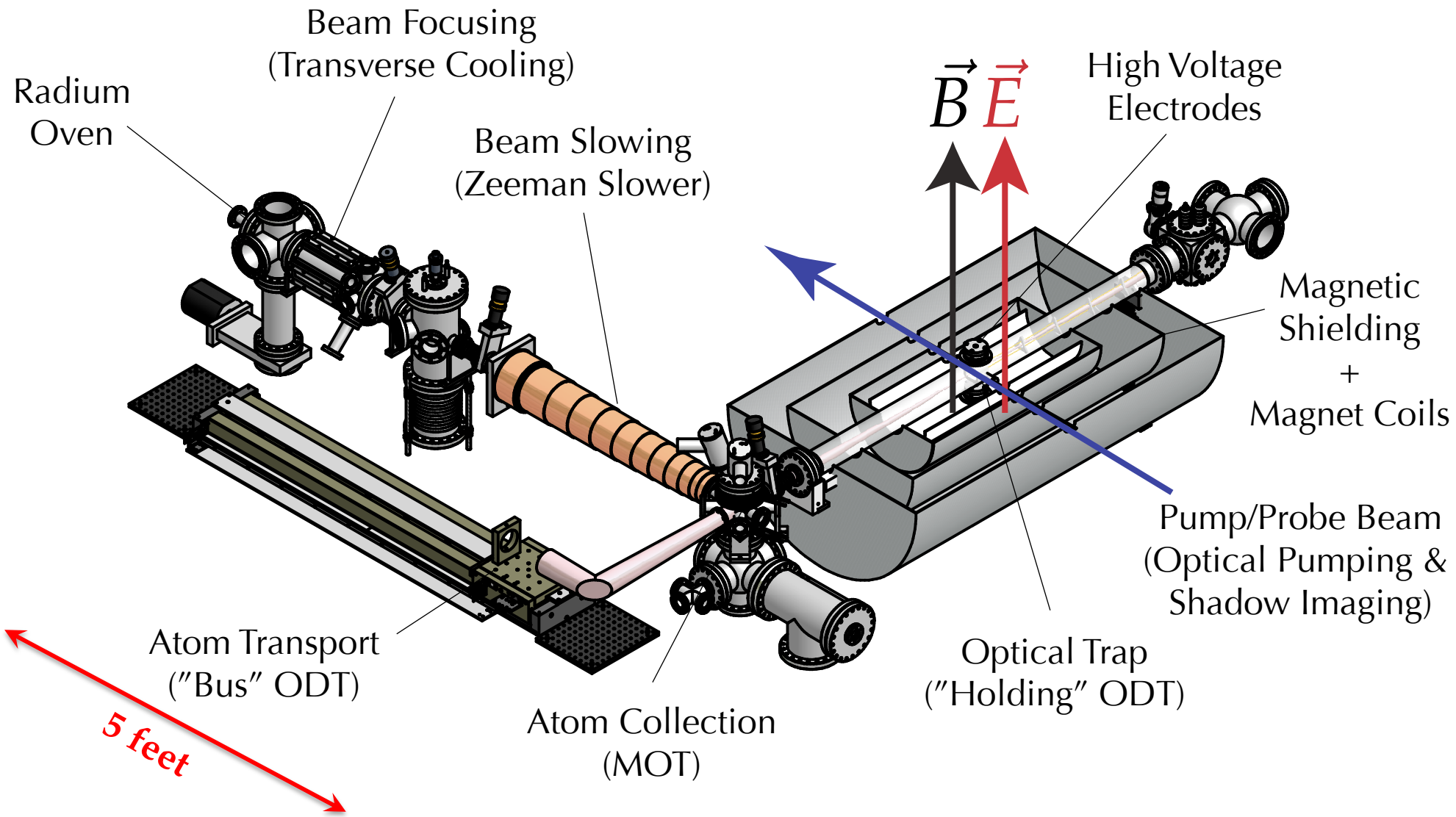
Pear-shaped atomic nuclei amplify the clock rate difference by 1000x or more!



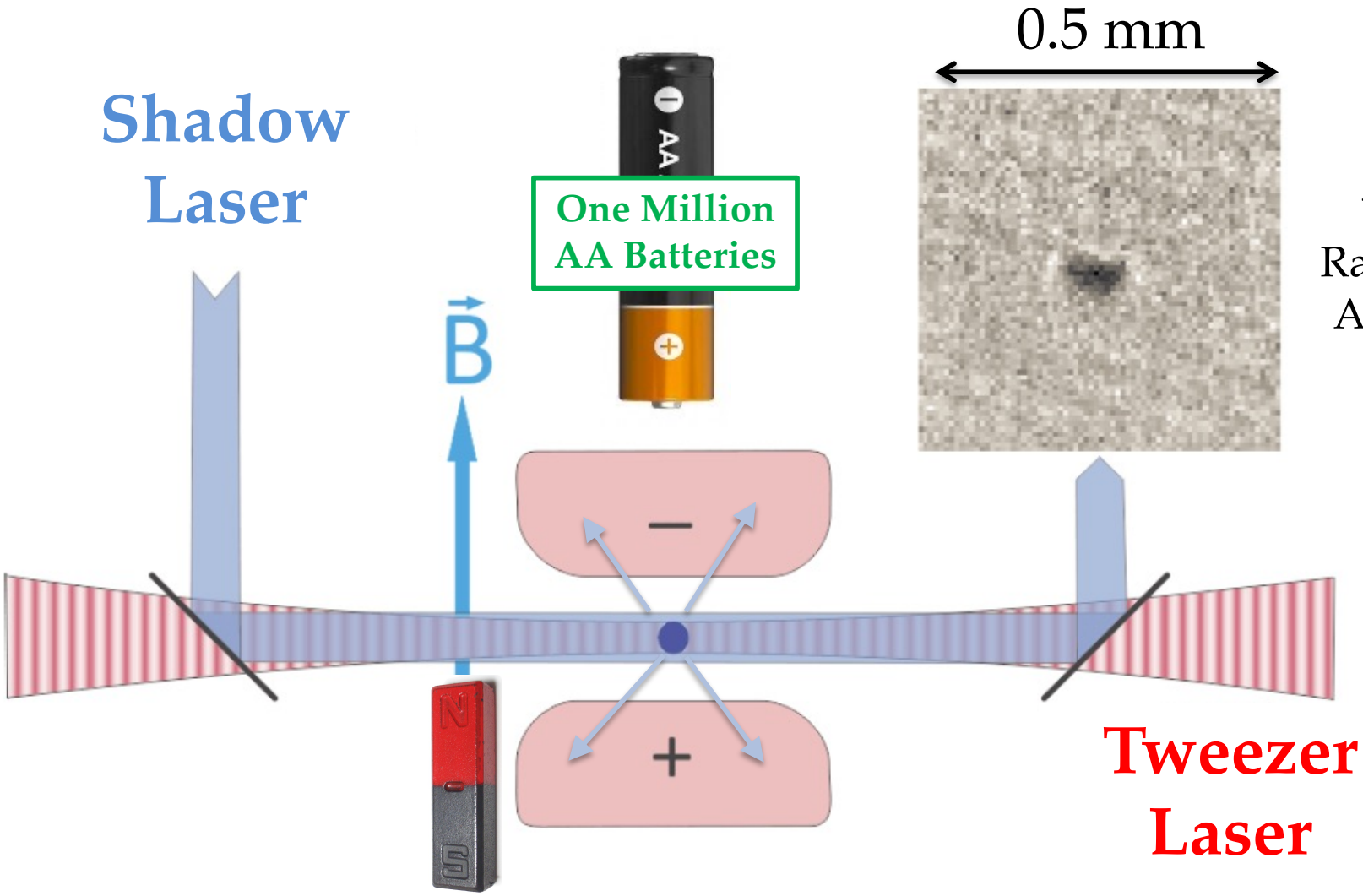


property	Not pear shaped	Pear shaped
example	Xenon/Helium	Radium/Protactinium
cost	basically free	super expensive
source	the air we breathe	nuclear physics lab
radioactive?	no	yes
size of signal	1	1000x or higher
expected clock rate difference per day	1 second	half an hour or longer

The Laser Tweezer Radium Experiment



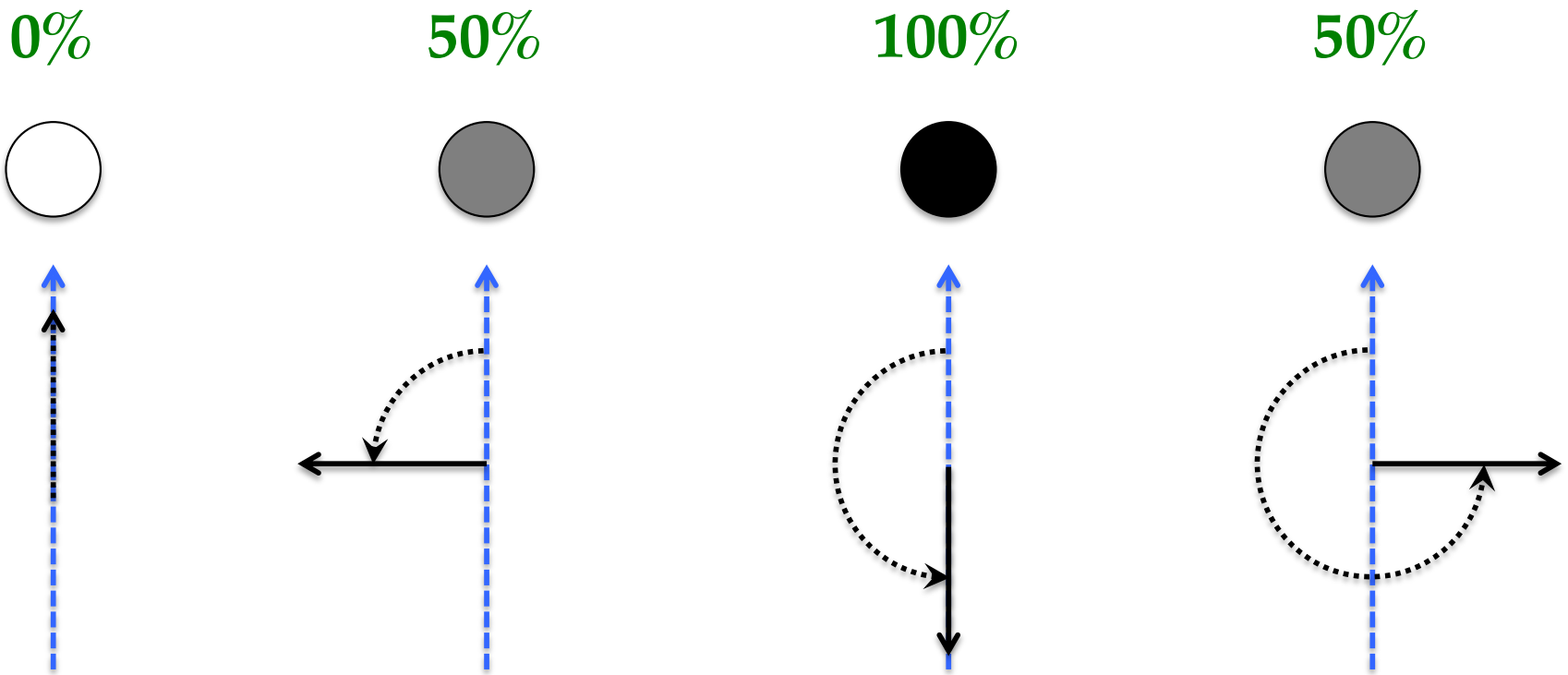
Radium atoms create a shadow.



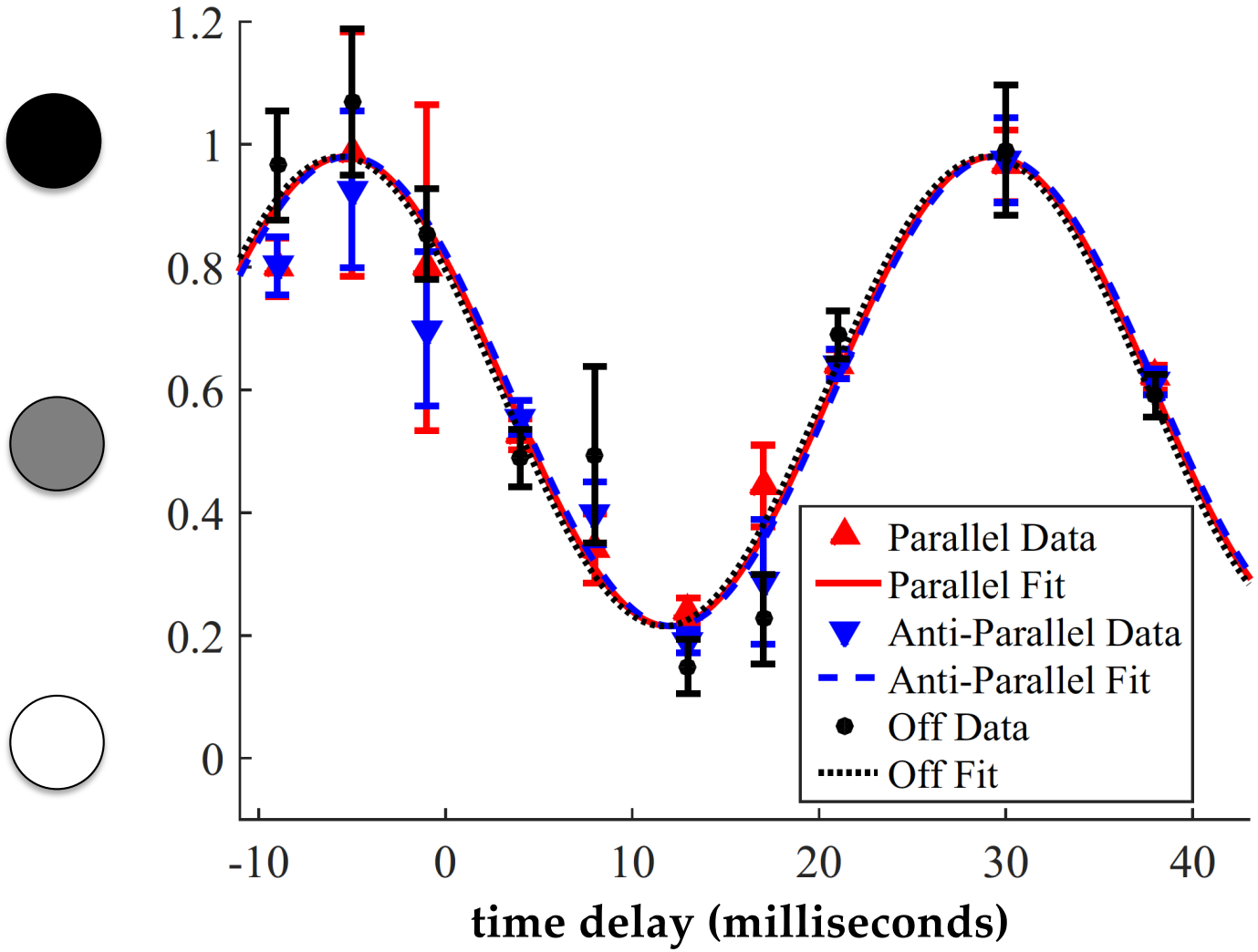
Parker et al. Phys. Rev. Lett. 114, 233002 (2015)

The transparency of the atoms oscillate in time.

probability of absorbing laser light and creating a shadow:



Measure the darkness of the shadow at different times!



red data

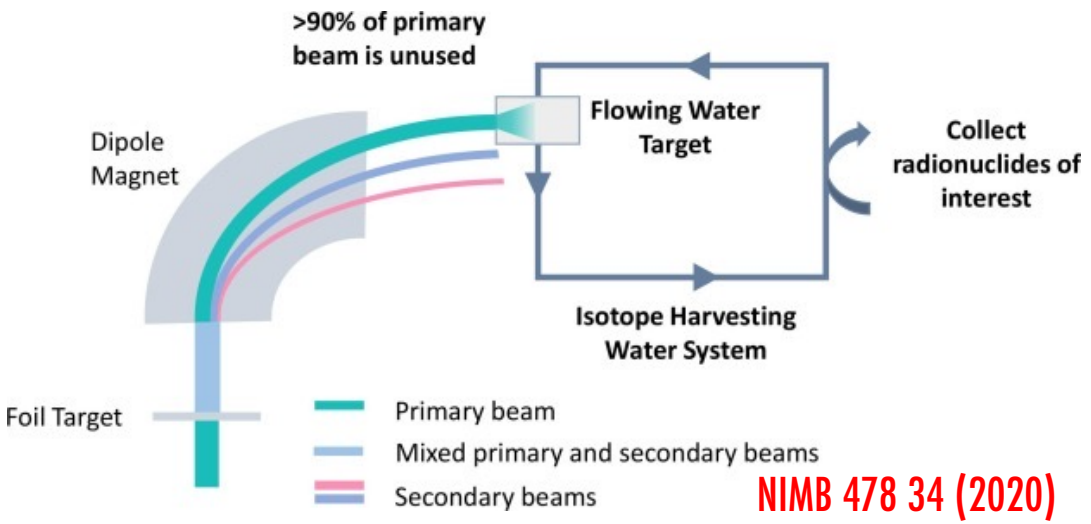
blue data

Clock rate difference: Smaller than half an hour per day

How do we do better? Need more clocks (atoms)

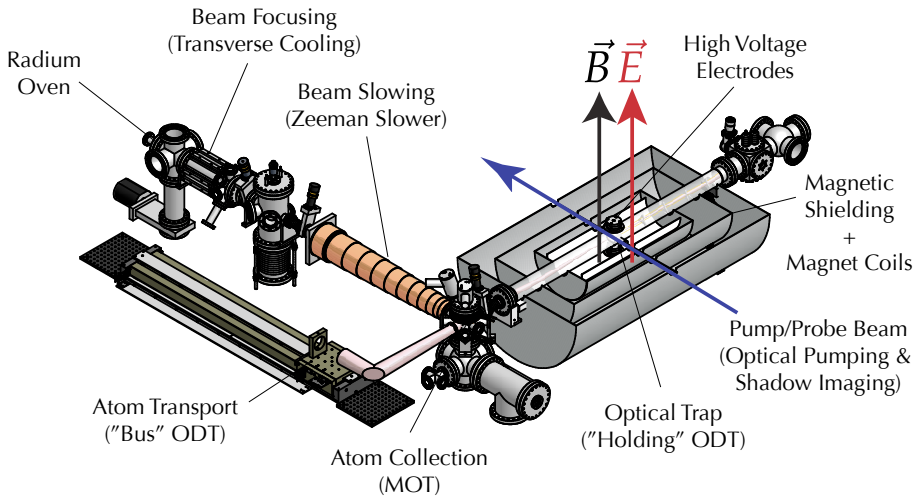
Facility for Rare Isotope Beams @ MSU

FRIB will make lots of pear-shaped nuclei!

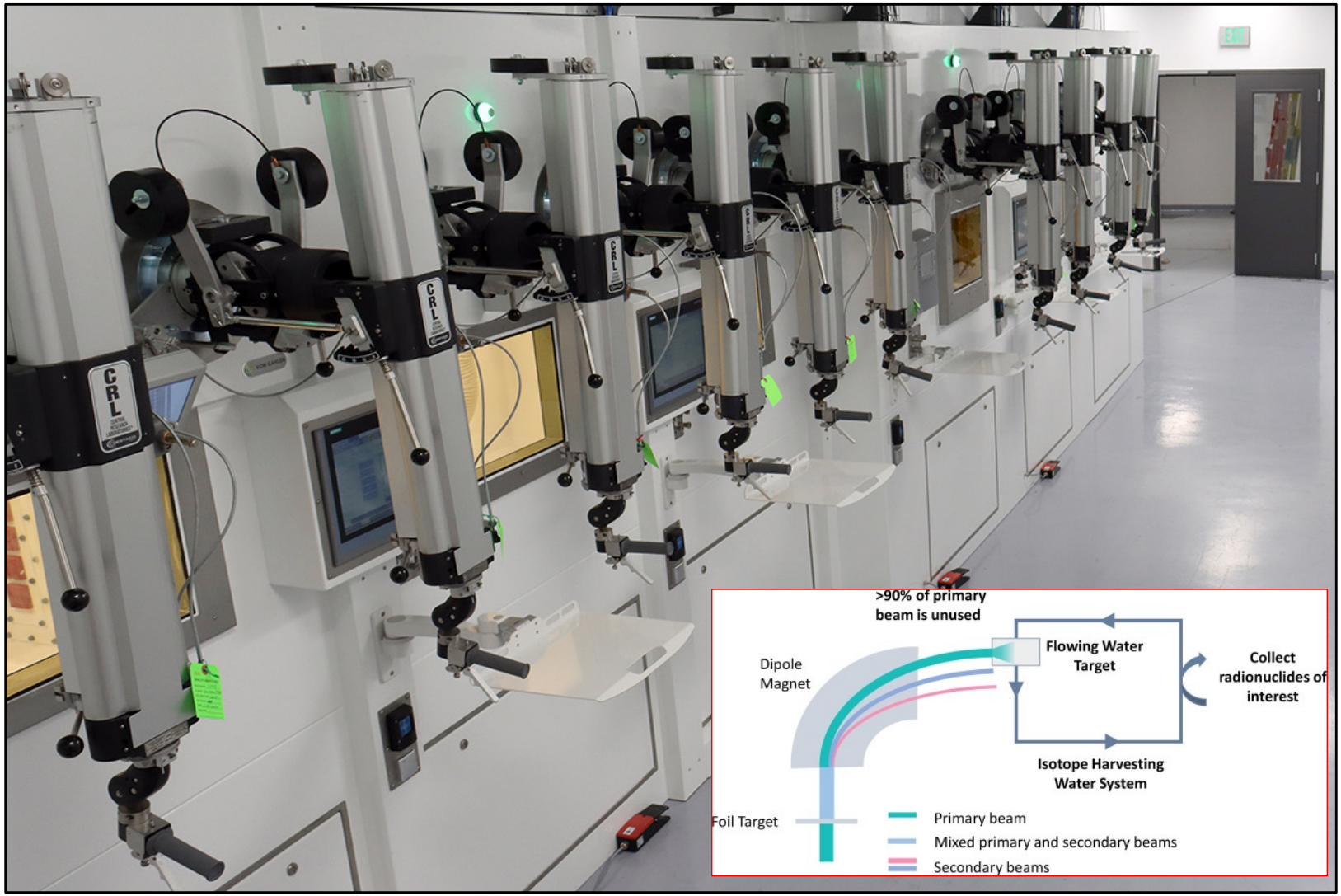


NIMB 478 34 (2020)

Uranium beam collides with a Graphite target and makes all the things.
Most of the things get dumped into water which can be "harvested."



Isotope Harvesting Vault Is Installed (2025)

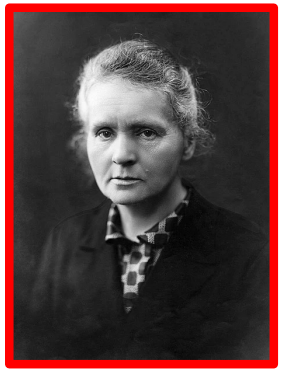


C. Vyas

NIMB 478 34 (2020)

30 feet

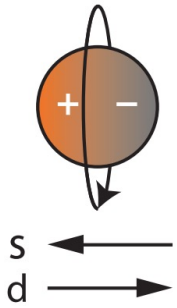
We Are Following In The Footsteps Of Giants Towards A Transformational Discovery Within Our Student's Lifetime!

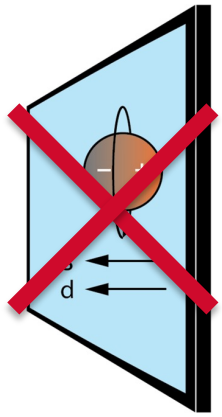


88 $^1S_0$
Ra
Radium
(226)
$[Rn]7s^2$
5.2784

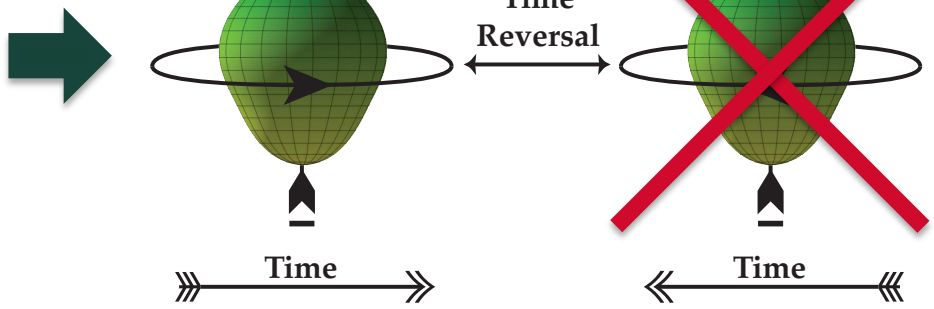
C.S. Wu

M.A. Bouchiat





91 $^4K_{11/2}$
Pa
Protactinium
231.04
$[Rn]5f^2 6d 7s^2$
5.89

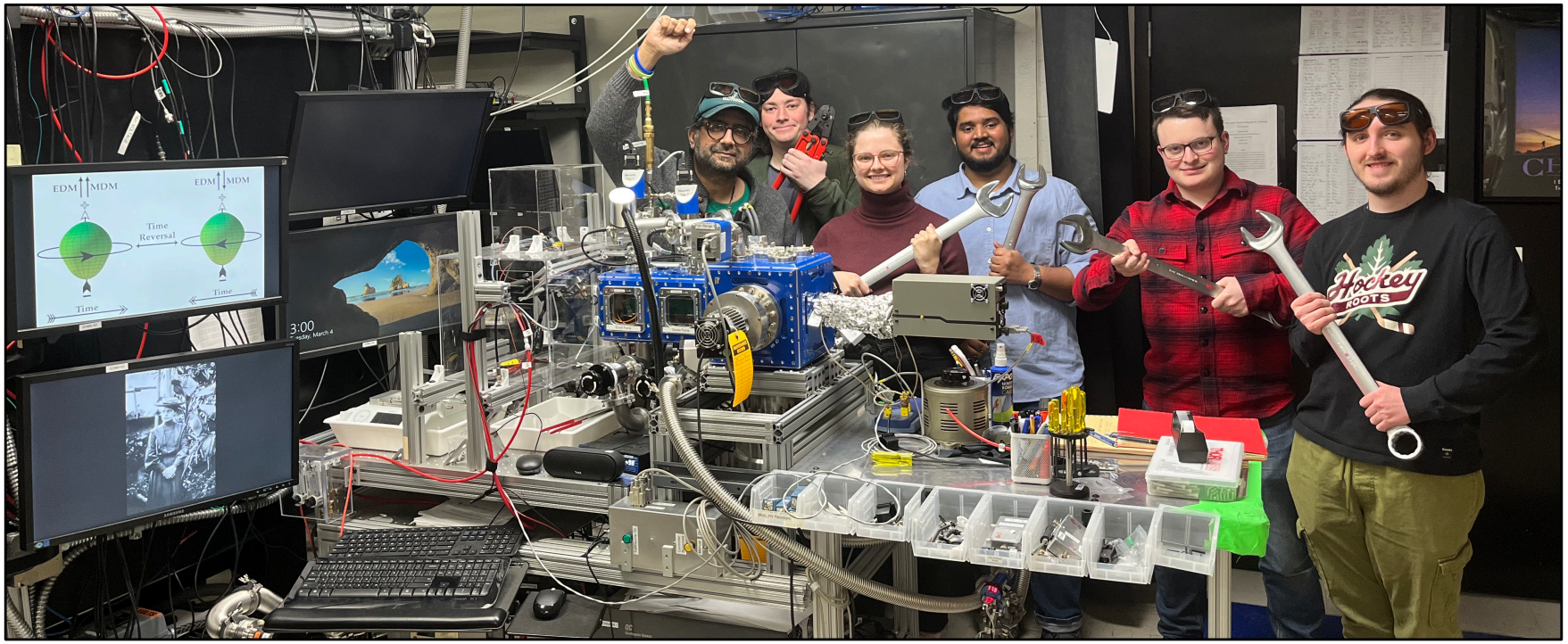


87 $^2S_{1/2}$
Fr
Francium
(223)
[Rn]7s
4.0727

M. Curie (2/5), L. Meitner (0/49), & M. Perey (0/5)

Wikipedia, NIST, AIP Emilio Segre Visual Archives, M. Zolotrev

Thanks For Your Attention! More Questions?



U.S. DEPARTMENT of ENERGY

DE-SC0019015 (ECA-EDM3)
DE-SC0019455 (Ra EDM)
DE-NA0003996 (Pa-229/SAM)
DE-SC0025679 (Ra EDM+EDM3)

NSF

#1654610
(CAREER-SAM)
#2412951 (SAM)

GORDON AND BETTY MOORE FOUNDATION

ALFRED P. SLOAN FOUNDATION 1934

E. A. Hessels
@ York (Canada):
GBMF8863
G-2019-12503