Radiation / Radioactivity / Radioactive Decay

Radioactive Particles / Common Isotopes

Counting

History – Discovery of X-rays / Radioactivity / Nuclear atom

Radioactive Decay – particles, half-life and equations

Radioactivity – the Nuclear atom / trip to the "Particle Zoo"

Counting: Film / Geiger Counter / LSC / PI

Common Radio isotopes / C Isotopes – C-12 / C-13 / C-14

C-14 and radiocarbon dating

Nuclear Energy - fission and fusion

Terms: Radioactivity / Exposure / Dose

Hackert – CH370

The Nobel Prize in Physics 1901

"in recognition of the extraordinary services he has rendered by the discovery of the remarkable rays subsequently named after him"

Wilhelm Conrad Röntgen

Germany

Munich University
Munich, Germany

b. 1845
d. 1923

Sept. 1895 - Marconi (radio waves / wireless)

Nov. 8, 1895 - Rontgen (discovery of X-rays)

Feb. 24, 1896 – Becquerel (U luminesce”)

(Feb. 26, 27 - cloudy days)

(Mar. 1 - “radioactivity”)

1897 - JJ Thomson (discovery of electrons)

1898 – Pierre & Marie Curie (Po, Ra)

1898 – Rutherford (α and β radiation)

1902 – Rutherford (disintegration of elements)

1911 – Rutherford (Au foil exp. / nuclear atom)

1912 – von Laue (X-rays as waves)

1913 Braggs – 1st crystal structure

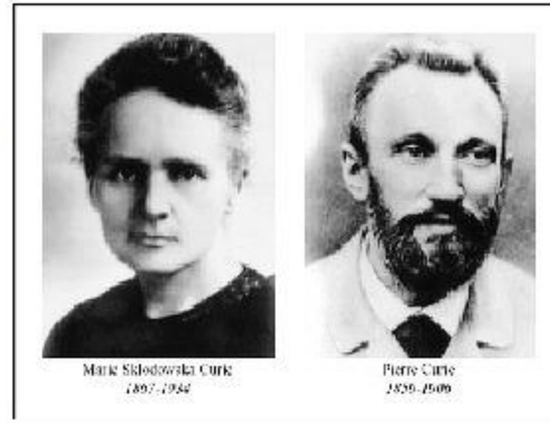
1920 – Rutherford (predicts neutron)

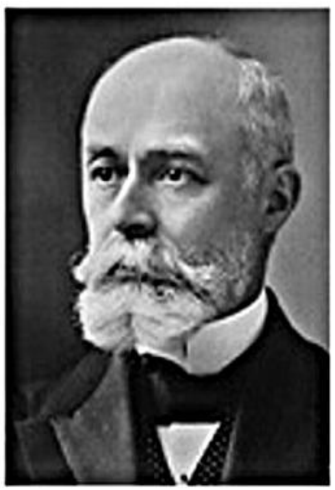
The Nobel Prize in Physics 1903

"in recognition of the extraordinary services he has rendered by his discovery of spontaneous radioactivity"

"in recognition of the extraordinary services they have rendered by their joint researches on the radiation phenomena discovered by Professor Henri Becquerel"

Marie and Pierre Curie





Antoine Henri Becquerel

1/2 of the prize

France

Pierre Curie

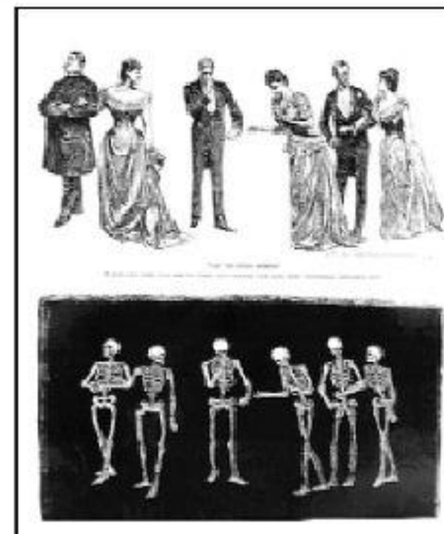
1/4 of the prize

France

Marie Curie, née Sklodowska

1/4 of the prize

France



See "Women in Chemistry" in our S 2000 "Chemical Compositions" newsletter, p.4)

The Nobel Prize in Physics 1906

"in recognition of the great merits of his theoretical and experimental investigations on the conduction of electricity by gases"

Joseph John Thomson

United Kingdom

University of Cambridge
Cambridge, United Kingdom

b. 1856
d. 1940

Sept. 1895 - Marconi (radio waves / wireless)

Nov. 8, 1895 - Rontgen (discovery of X-rays)

Feb. 24, 1896 – Becquerel (U luminesce")

(Feb. 26, 27 - cloudy days)

(Mar. 1 - "radioactivity")

1897 - JJ Thomson (discovery of electrons)

1898 – Pierre & Marie Curie (Po, Ra)

1898 – Rutherford (α and β radiation)

1902 – Rutherford (disintegration of elements)

1911 – Rutherford (Au foil exp. / nuclear atom)

1912 – von Laue (X-rays as waves)

1913 Braggs – 1st crystal structure

1920 – Rutherford (predicts neutron)

The Nobel Prize in Chemistry 1908

"for his investigations into the disintegration of the elements, and the chemistry of radioactive substances"

Ernest Rutherford

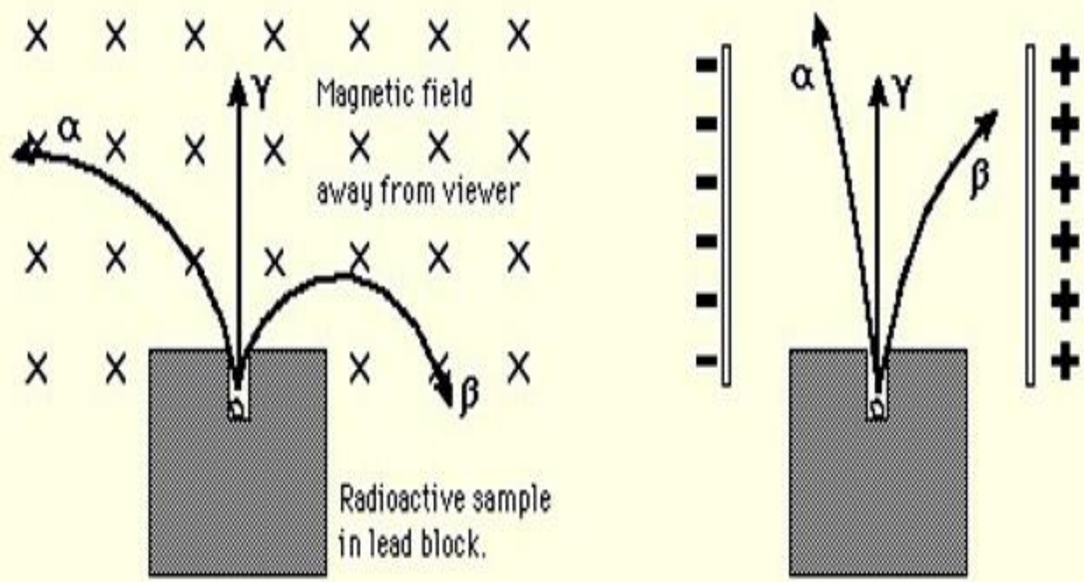
United Kingdom and New Zealand

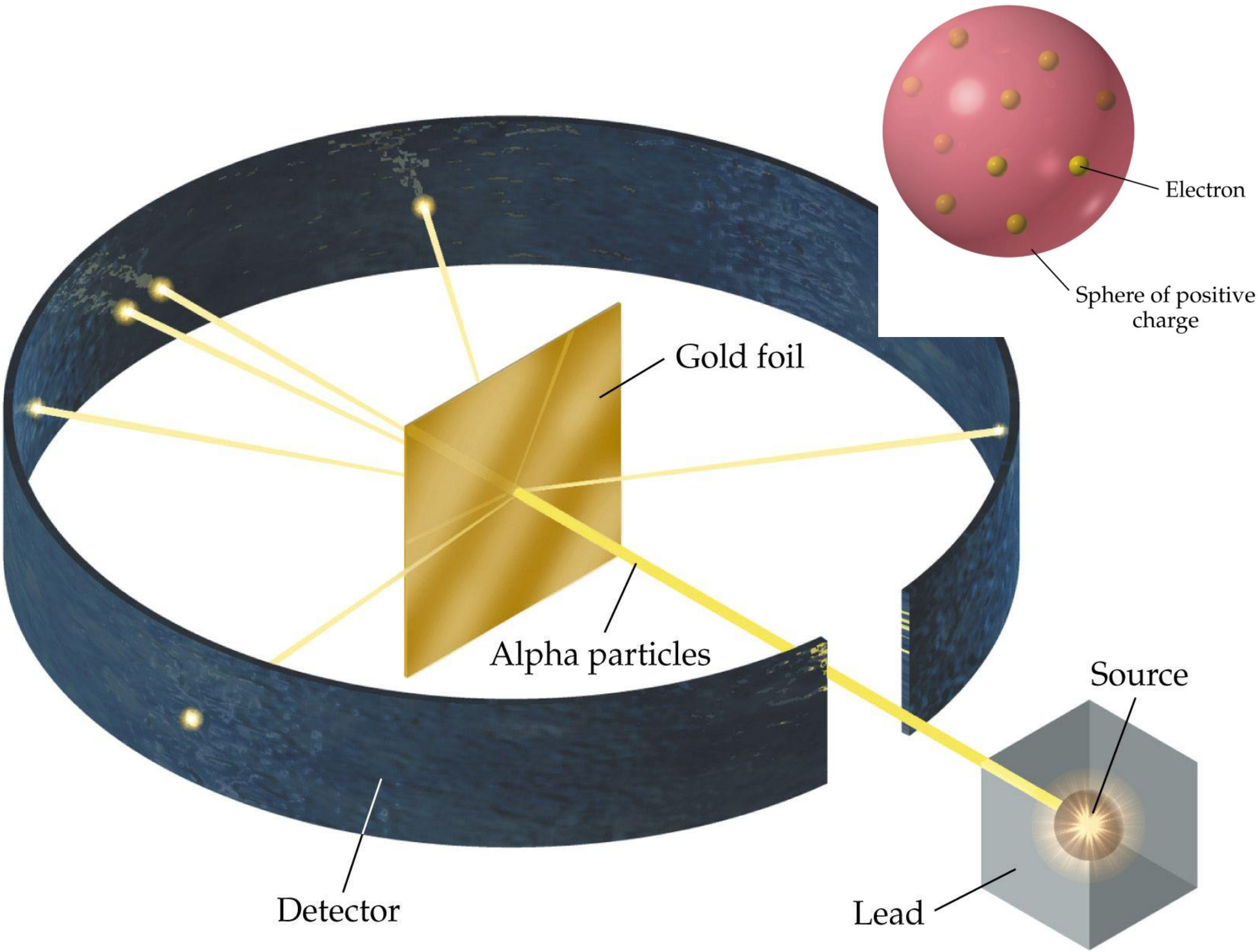
Victoria University
Manchester, United Kingdom

b. 1871
(in Nelson, New Zealand)
d. 1937

Alpha, Beta, and Gamma

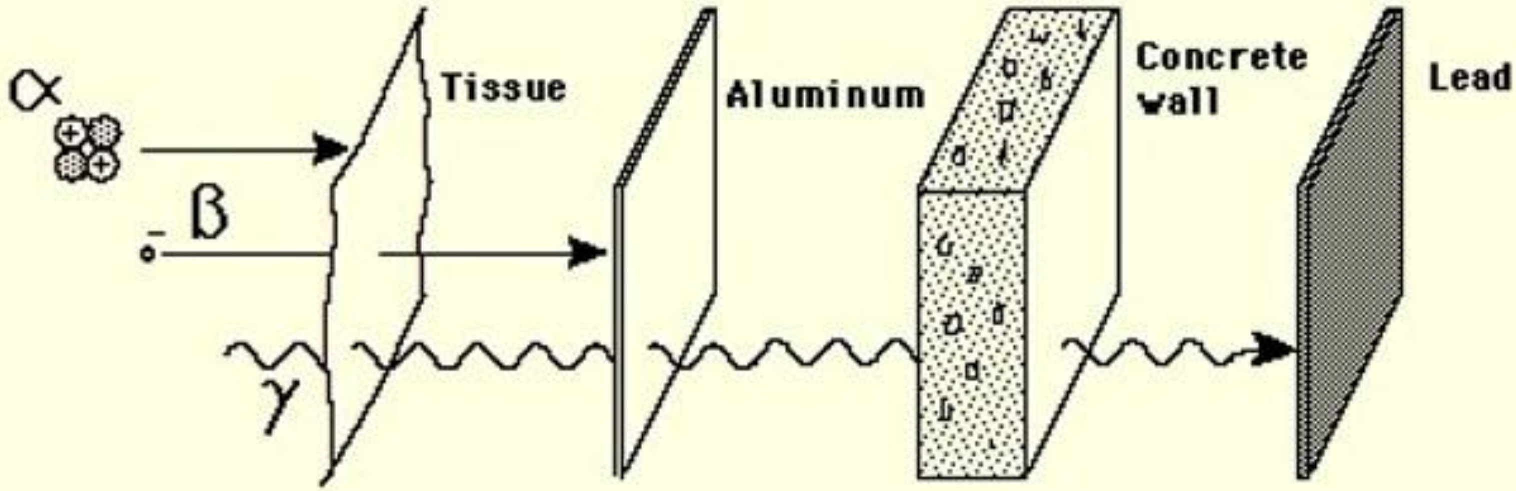
Historically, the products of radioactivity were called alpha, beta, and gamma when it was found that they could be analyzed into three distinct species by either a magnetic field or an electric field.




Electron
Sphere of positive charge
Gold foil
Alpha particles
Source
Detector
Lead

Penetration of Matter

Though the most massive and most energetic of radioactive emissions, the alpha particle is the shortest in range because of its strong interaction with matter. The electromagnetic gamma ray is extremely penetrating, even penetrating considerable thicknesses of concrete. The electron of beta radioactivity strongly interacts with matter and has a short range.



$$I = I_o \, e^{-\lambda t}$$

Rutherford – quantitative measurements

Mass Number = #p + #n

Atomic Number = # protons

$^{238}_{92}U$

Radioactive Decay

Remember that the lower number is the atomic number and the upper number is the mass number.

Alpha Decay

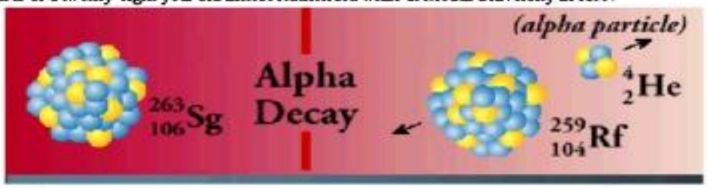
In 1899, Ernest Rutherford wrote the following words:

"These experiments show that the uranium radiation is complex and that there are present at least two distinct types of radiation - one that is very readily absorbed, which will be termed for convenience the alpha-radiation, and the other of more penetrative character which will be termed the beta-radiation."

The image to the right is of a twenty-eight year old Ernest Rutherford while at McGill University in 1899.

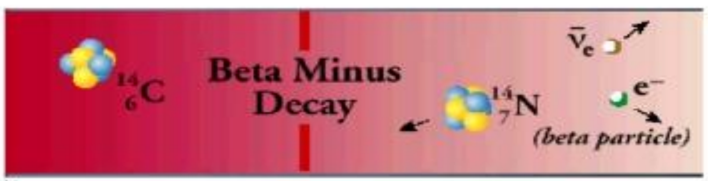
Ernest Rutherford
1899

Alpha



$$^{222}_{88}Ra \longrightarrow \, ^{4}_{2}He + \, ^{218}_{86}Rn$$

Beta -



$$^{14}_{6}C \longrightarrow \, ^{14}_{7}N + \, ^{0}_{-1}e + \, ^{0}_{0}\bar{\nu}$$

b)

Beta +
(positron)

$$^{50}_{25}Mn \longrightarrow \, ^{50}_{24}Cr + \, ^{0}_{+1}e + \, ^{0}_{0}\nu$$

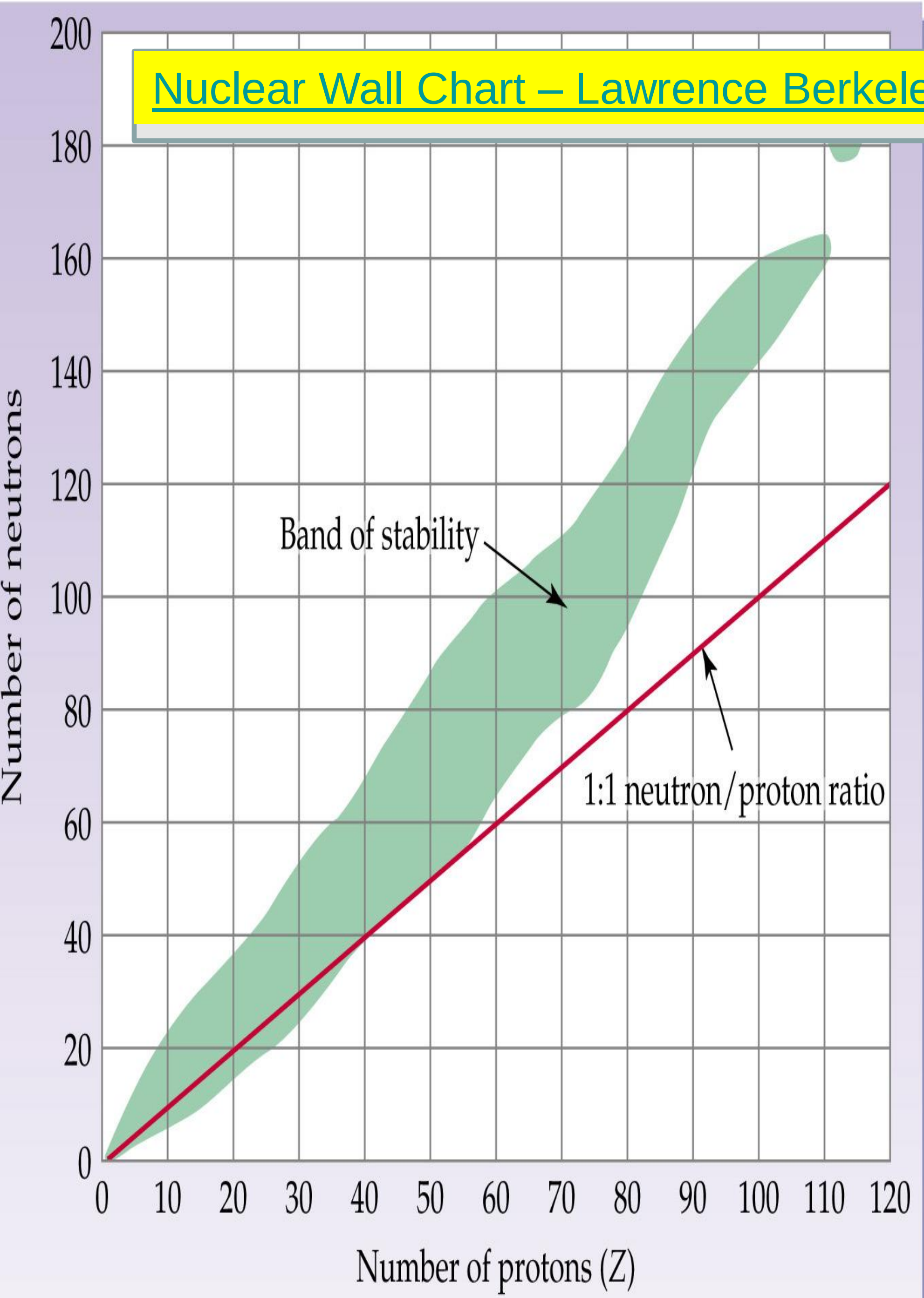
Gamma Emission

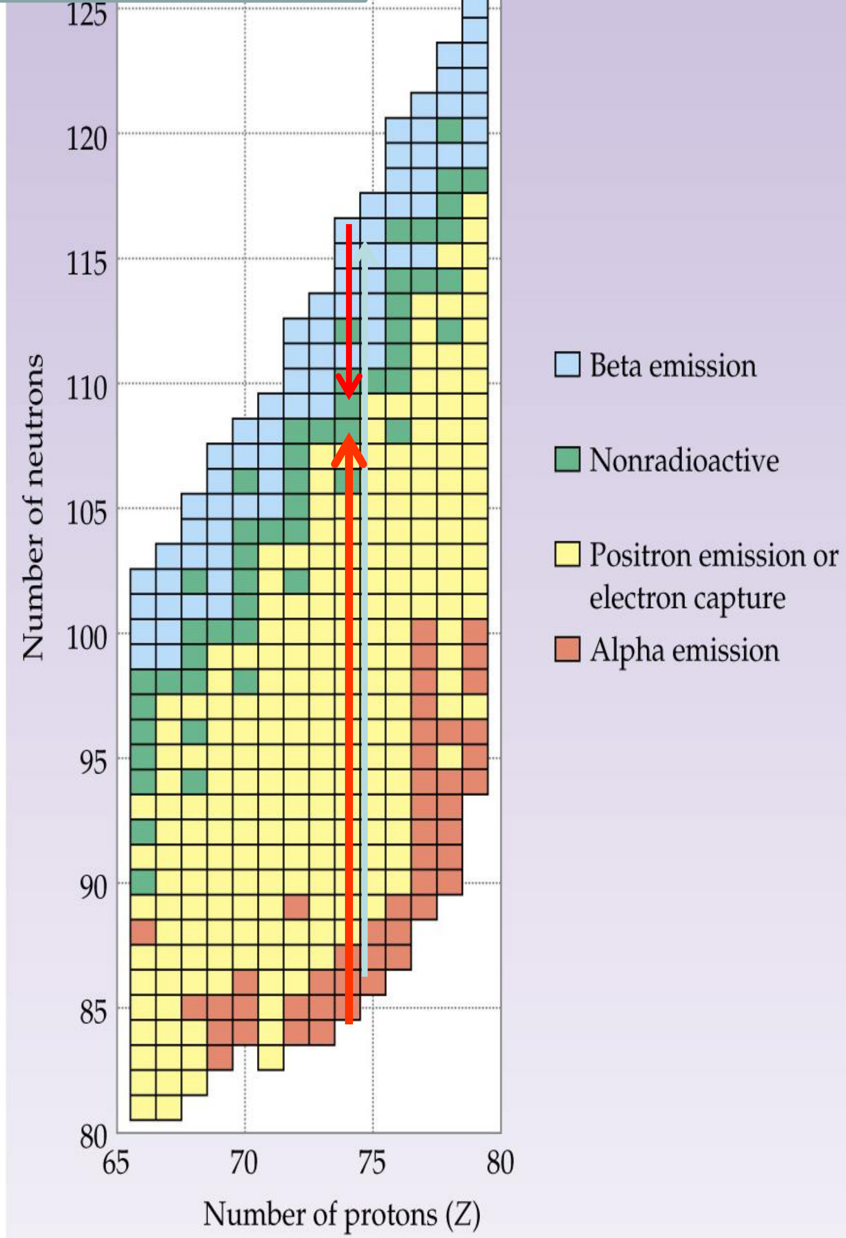
Electron Capture

$$^{81}_{36}Kr + \, ^{0}_{-1}e \longrightarrow \, ^{81}_{35}Br + \, ^{0}_{0}\nu$$

Nuclear Wall Chart - Lawrence Berkeley National Laboratory
Contemporary Physics Education Project (CPEP)

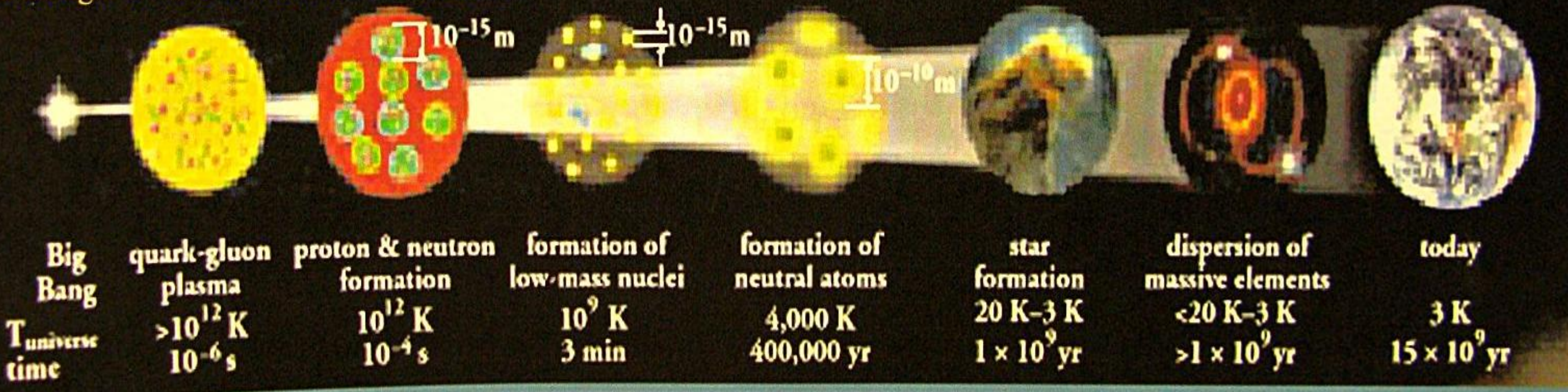
[Nuclear Wall Chart – Lawrence Berkeley Natl. Laboratory]





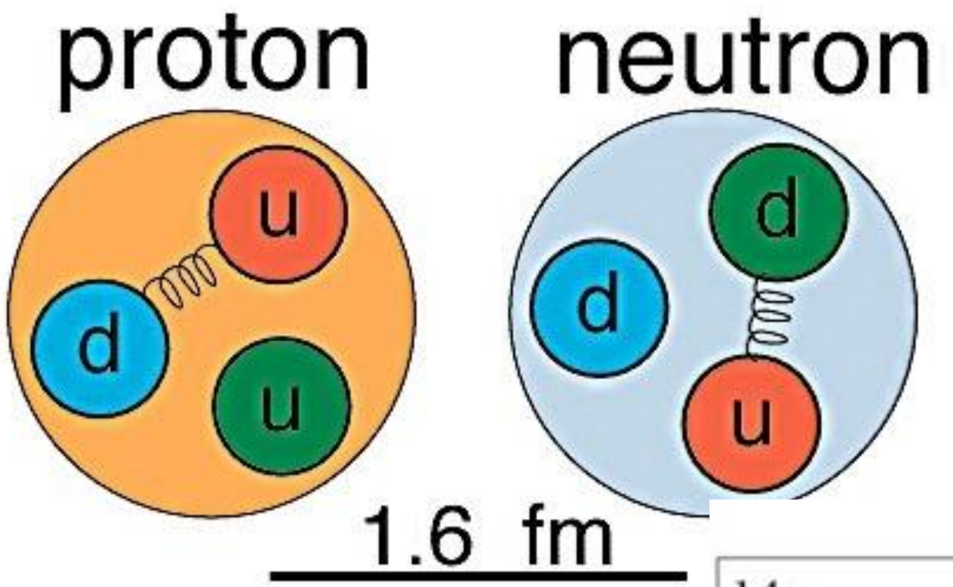
Expansion of the Universe

After the BIG BANG, the universe expanded and cooled. After about 10-6 sec and temperatures over 10+12K, the universe consisted of a soup of quarks, gluons, electrons, and neutrinos. After about 10-4 sec and about 10+12K, this soup coalesced into protons, neutrons, and electrons. After about 3 min and cooling to 10+9K, some of the protons and neutrons formed light nuclei like deuterium, helium and lithium. Further cooling and at about 400,000 years, electrons combined with the light nuclei to form small, neutral atoms. With further cooling and gravity clouds of atoms contracted to form stars where H and He fused to form heavier elements. Exploding stars (supernovae) form even more massive elements and disperse them across space. Earth is thought to have formed from such debris.



Nuclear Wall Chart - Lawrence Berkeley National Laboratory
Contemporary Physics Education Project (CPEP)

Protons and Neutrons (Hadrons) are both made up of Quarks. In the Quark Model the only difference between a Proton and a Neutron is that an "up" Quark has been replaced by a "down" Quark.



$$^{14}_{6}C \longrightarrow ^{14}_{7}N + ^{0}_{-1}e + ^{0}_{0}\bar{\nu}$$

The little spring in the drawing is used
to indicate that the quarks inside a nucleon
are held together by a force we call gluon exchange.

Size of Nucleons

Nuclear Wall Chart - Lawrence Berkeley National Laboratory
Contemporary Physics Education Project (CPEP)

The Standard Model

In the Standard Model of particles and forces, everything in the Universe is made from **twelve basic building blocks** called **fundamental particles**, governed by **four fundamental forces**.

Matter particles

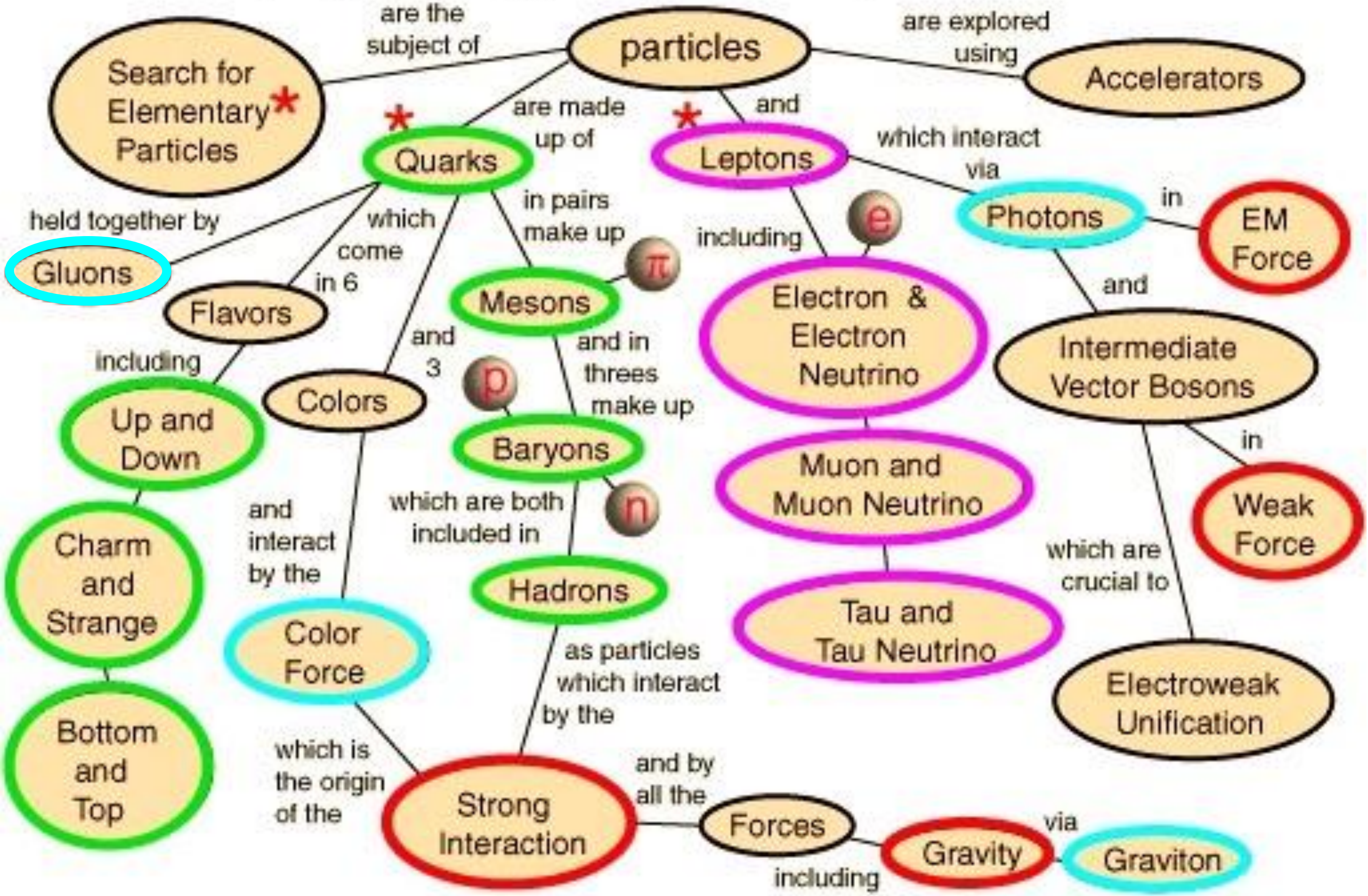
Everything around us is made of matter particles in two basic types called **quarks** and **leptons**. All stable matter in the Universe is made from first generation particles; the 'up quark‘, 'down quark‘, electron, e-neutrino. Neutrinos are electrically neutral with very little mass.

Forces and carrier particles

There are four fundamental forces at work in the Universe: the strong force, the weak force, the electromagnetic force, and the gravitational force. They work over different ranges and have different strengths. Gravity is the weakest but it has an infinite range. The weak and strong forces are effective only over a very short range and dominate only at the level of subatomic particles.

Particle Concepts Roadmap

http://hyperphysics.phy-astr.gsu.edu/Hbase/particles/parcon.html

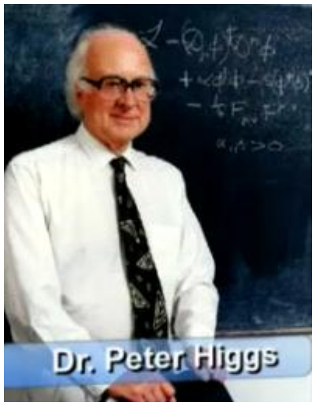


CERN

European Organization for Nuclear Research

Higgs Boson Particle -

July 4, 2012 – Announcement of experimental evidence for the Higgs Particle!



What exactly is the Higgs field?
A theoretical, invisible energy field that stretches throughout the universe. It clings to fundamental particles wherever they are, dragging on them and making them heavy.

http://bcove.me/v34o1pf6
http://www.squidoo.com/higgs-boson-for-dummies
http://vimeo.com/41038445

The Large Hadron Collider

Our understanding of the Universe is about to change...

The Large Hadron Collider (LHC) is a gigantic scientific instrument near Geneva, where it spans the border between Switzerland and France about 100m underground. It is a particle accelerator used by physicists to study the smallest known particles – the fundamental building blocks of all things. It will revolutionise our understanding, from the minuscule world deep within atoms to the vastness of the Universe.

Two beams of subatomic particles called "hadrons" – either protons or lead ions – travel in opposite directions inside the circular accelerator, gaining energy with every lap. Physicists use the LHC to recreate the conditions just after the Big Bang, by colliding the two beams head-on at very high energy. Teams of physicists from around the world then analyse the particles created in the collisions using special detectors in a number of experiments dedicated to the LHC.

There are many theories as to what will result from these collisions. For decades, the Standard Model of particle physics has served physicists well as a means of understanding the fundamental laws of Nature, but it does not tell the whole story. Only experimental data using the high energies reached by the LHC can push knowledge forward, challenging those who seek confirmation of established knowledge, and those who dare to dream beyond the paradigm.

The Nobel Prize in Physics 2013

Photo: A. Mahmoud

François Englert

Prize share: 1/2

Photo: A. Mahmoud

Peter W. Higgs

Prize share: 1/2

The Nobel Prize in Physics 2013 was awarded jointly to François Englert and Peter W. Higgs *"for the theoretical discovery of a mechanism that contributes to our understanding of the origin of mass of subatomic particles, and which recently was confirmed through the discovery of the predicted fundamental particle, by the ATLAS and CMS experiments at CERN's Large Hadron Collider"*

The neutrino and its friends

Neutrinos are one of the fundamental particles which make up the universe. They are also one of the least understood.

Neutrinos are similar to the more familiar electron, with one crucial difference: neutrinos do not carry electric charge. Because neutrinos are electrically neutral, they are not affected by the electromagnetic forces which act on electrons. Neutrinos are affected only by a "weak" sub-atomic force of much shorter range than electromagnetism, and are therefore able to pass through great distances in matter without being affected by it. If neutrinos have mass, they also interact gravitationally with other massive particles, but gravity is by far the weakest of the four known forces.

Three types of neutrinos are known; there is strong evidence that no additional neutrinos exist, unless their properties are unexpectedly very different from the known types. Each type or "flavor" of neutrino is related to a charged particle (which gives the corresponding neutrino its name). Hence, the "electron neutrino" is associated with the electron, and two other neutrinos are associated with heavier versions of the electron called the muon and the tau (elementary particles are frequently labelled with Greek letters, to confuse the layman). The table below lists the known types of neutrinos (and their electrically charged partners).

Neutrino	ν_e	ν_μ	ν_τ
Charged Partner	electron (e)	muon (μ)	tau (τ)

The electron neutrino (a lepton) was postulated in 1930 by Fermi to avoid a violation of conservation of energy and momentum during beta decay. It was not experimentally observed until 1953. It is thought that neutrinos left over from the Big Bang are the most abundant particles in the universe. Solar neutrino flux is estimated at 5,000,000 /cm^2/s. With no charge and almost no mass, the mean free path of a neutrino in matter is about 22 light years in lead!!!! ***"Solar neutrinos shine down on us during the day, and shine up on us during the night."*** **Can neutrinos travel faster than the speed of light (2011) ?**

What is a “half-life”?

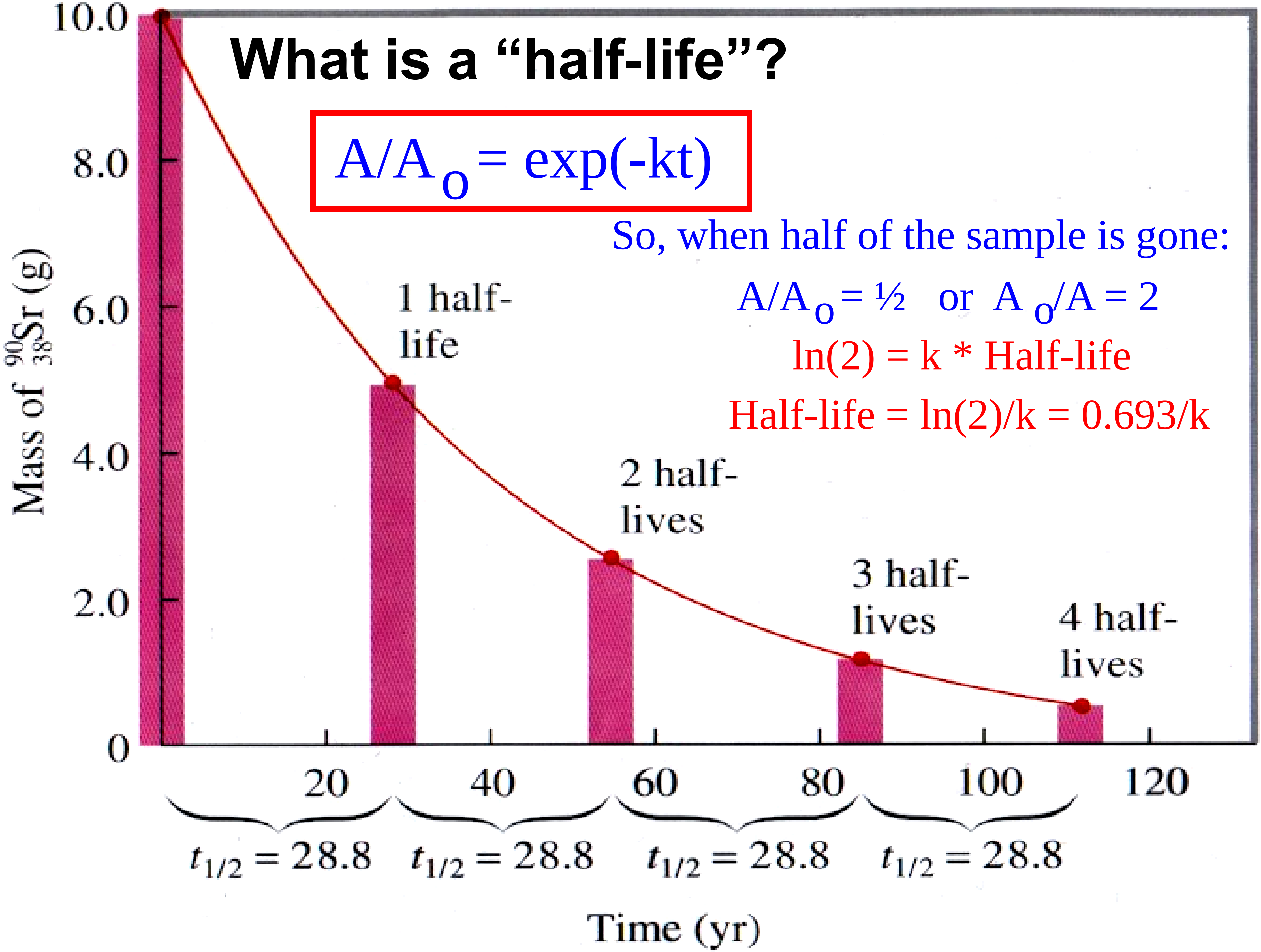
$$A/A_o = \exp(-kt)$$

So, when half of the sample is gone:

$A/A_o = ½$ or $A_o/A = 2$

$\ln(2) = k * \text{Half-life}$

$\text{Half-life} = \ln(2)/k = 0.693/k$



Characteristics of Biologically Significant Isotopes

TABLE 6-1. Half-life, decay constant, type of radiation, and maximum energy of radioisotopes important in biochemistry

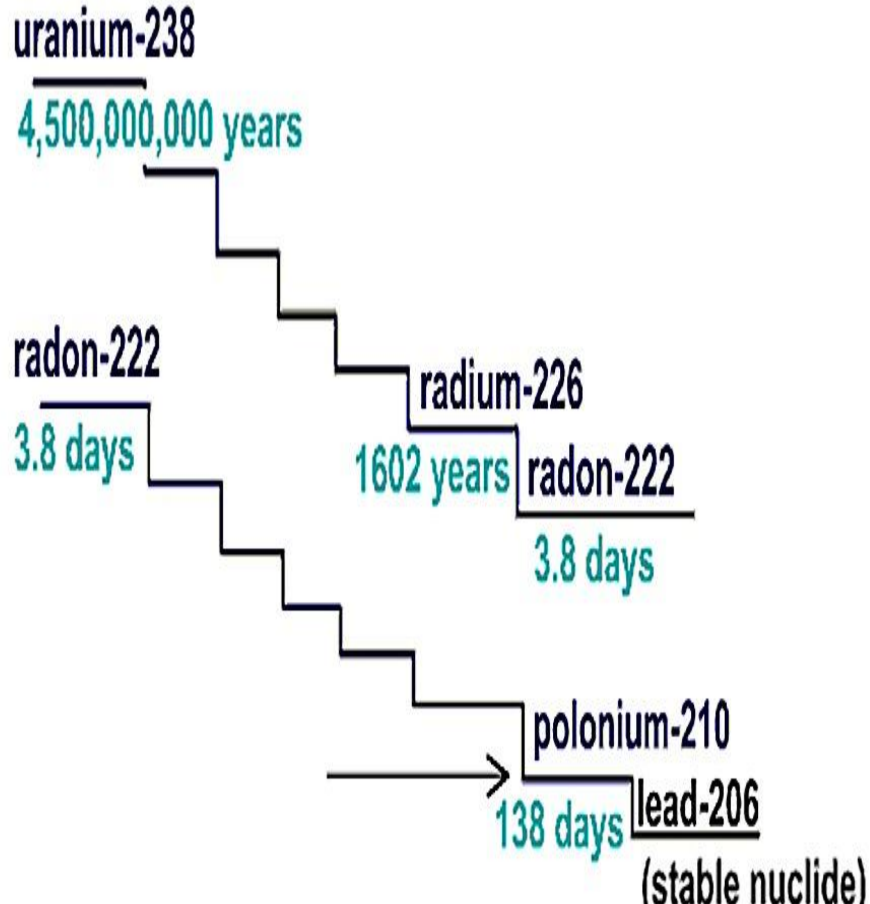
Isotope	Half-life	Decay constant (λ)	Type of radiation	Maximum energy (MeV)
^{3}H	12.26 yrs	1.55×10^{-4}/day	β^-	0.018
^{14}C	5730 yrs	1.21×10^{-4}/year	β^-	0.156
^{22}Na	2.62 yrs	7.24×10^{-4}/day	$\beta^+ + \gamma$	0.55 (1.28)[a]
^{32}P	14.3 days	4.85×10^{-2}/day	β^-	1.71
^{33}P	25 days	2.77×10^{-2}/day	β^-	0.25
^{35}S	87 days	7.97×10^{-3}/day	β^-	0.167
^{36}Cl	3×10^{5} yrs	2.31×10^{-6}/year	β^-	0.71
^{40}K	1.3×10^{9} yrs	5.33×10^{-10}/year	$\beta^- + \gamma$	1.4 (1.5)
^{45}Ca	165 days	4.2×10^{-3}/day	$\beta^- + \gamma$	0.26 (0.013)
^{59}Fe	45 days	1.54×10^{-2}/day	$\beta^- + \gamma$	0.46 (1.1)
^{60}Co	5.3 yrs	3.58×10^{-4}/day	$\beta^- + \gamma$	0.318 (1.33)
^{65}Zn	245 days	2.83×10^{-3}/day	$\beta^+ + \gamma$	0.33 (1.14)
^{90}Sr	29 yrs	6.54×10^{-5}/day	β^-	0.54
^{125}I	60 days	1.16×10^{-2}/day	γ	0.036
^{131}I	8.06 days	8.60×10^{-2}/day	$\beta^- + \gamma$	0.61 (0.36)
^{137}Cs	30.2 yrs	6.28×10^{-5}/day	$\beta^- + \gamma$	0.51 (0.66)
^{226}Ra	1620 yrs	4.28×10^{-4}/year	$\alpha + \gamma$	4.78 (0.19)

[a] Where two types of radiation occur, the number in parentheses is the maximum energy for the second type of radiation.

$$t_{1/2} = \frac{0.693}{\lambda}$$

$$I = I_o e^{-\lambda t}$$

Uranium-238 Decay Chain



URANIUM 238 (U238) RADIOACTIVE DECAY

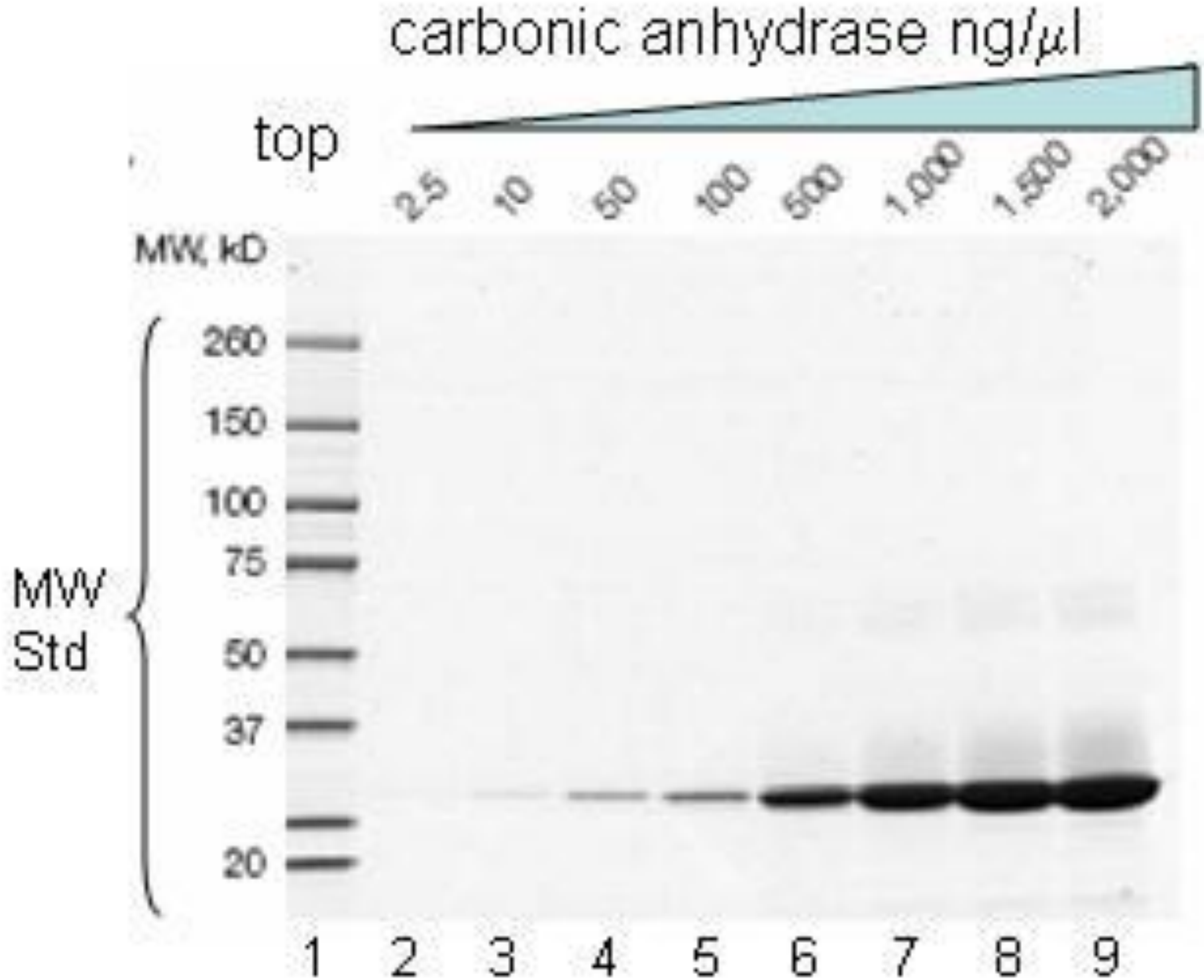
type of radiation	nuclide	half-life
	uranium—238	4.5×10^9 years
α	thorium—234	24.5 days
β	protactinium—234	1.14 minutes
β	uranium—234	2.33×10^5 years
α	thorium—230	8.3×10^4 years
α	radium—226	1590 years
α	radon—222	3.825 days
α	polonium—218	3.05 minutes
α	lead—214	26.8 minutes
β	bismuth—214	19.7 minutes
β	polonium—214	1.5×10^{-4} seconds
α	lead—210	22 years
β	bismuth—210	5 days
β	polonium—210	140 days
α	lead—206	stable

Counting Radioactivity

1) Film
2) Geiger Counter
3) Liquid Scintillation Counters
4) PhosphorImager

Efficiency of counting: It is relatively easy to detect gamma rays emitted from isotopes such as 125I with LSC, so efficiencies are usually over 90%. With 3H, the efficiency of counting is much lower, often about 40%.

Errors in counting: Poisson distribution



BioRad: tech note 5299

Counting errors and the Poisson distribution

The decay of a population of radioactive atoms is random, and therefore subject to a sampling error. For example, the radioactive atoms in a tube containing 1000 cpm of radioactivity won't give off exactly 1000 counts in every minute. There will be more counts in some minutes and fewer in others, with the distribution of counts following a Poisson distribution. This variability is intrinsic to radioactive decay and cannot be reduced by more careful experimental controls. So long as the number of counts, C, is greater than about 50 you can calculate the confidence interval using this approximate equation:

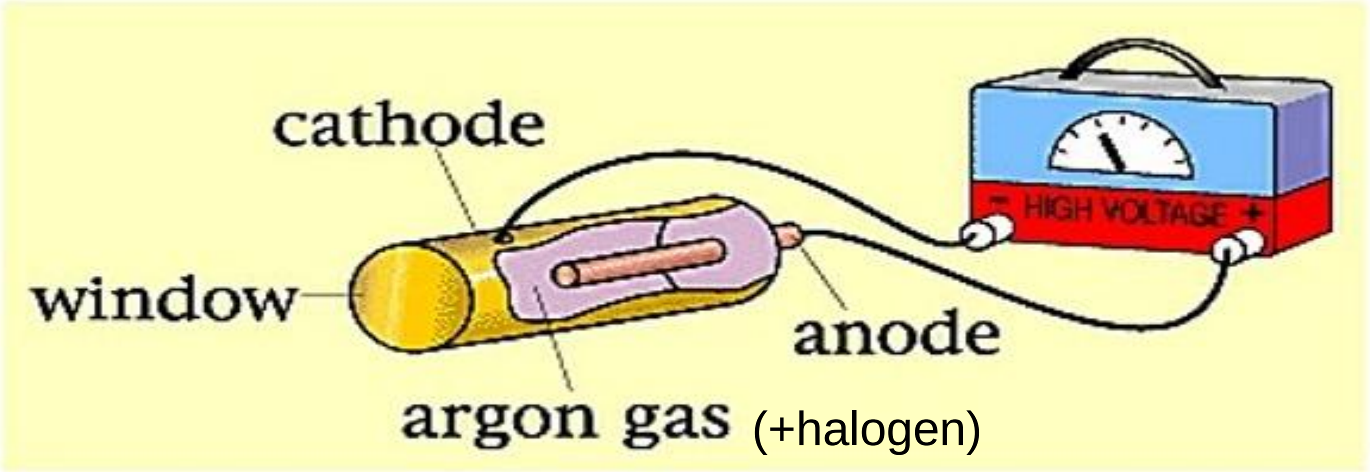
$$\text{95\% Confidence Interval: } \left(C - 1.96\sqrt{C}\right) \text{ to } \left(C + 1.96\sqrt{C}\right)$$

The Poisson distribution explains the advantages of counting your samples for a longer time. For example, the table below shows the confidence interval for 100 cpm counted for various times. When you count for longer times, the confidence interval will be narrower.

	1 minute	10 minutes	100 minutes
Counts per minute (cpm)	100	100	100
Total counts	100	1000	10000
95% CI of counts	81.4 to 121.6	938 to 1062	9804 to 10196
95% CI of cpm	81.4 to 121.6	93.8 to 106.2	98.0 to 102.0

Geiger Counters

This form of detection device is small, portable, and relatively inexpensive. It consists of a metal tube filled with argon or neon and kept at low pressure. Into the center of this tube a wire has been anchored with high voltage set up between the wire and the tube. When ionizing particles enter this tube, it ionizes the entrapped gas and causes an electrical pulse. By adding up the number of pulses, the intesity of radiation can be detected. This type of detector is good for high energy beta particle producers, but not gamma rays or alpha particles.



Hans Geiger worked as a lab tech for Rutherford for 5 years counting subatomic particles in a dark room using a screen and a microscope!

Geiger moved from England to teach in Germany in 1907 and quickly he perfected an automatic way to count these particles (tic tic tic tic ….).

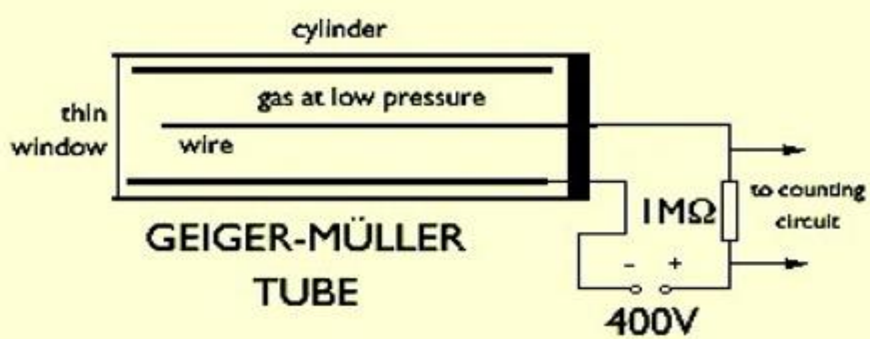

OCDM ITEM NO. CDV-700
MODEL NO. 6A SER. NO.
THE VICTOREEN INSTRUMENT CO.
CLEVELAND, OHIO

A Geiger counter depends on the fact that radiation knocks electrons out of the atoms in a gas and leaves them with an electric charge. These charged atoms (or ions) can then carry an electric current through the gas.

A Geiger-Müller (G-M) tube consists of a metal cylinder with a wire along its axis, sealed inside a glass envelope. At one end there is a very thin mica window, which allows radiation to enter the tube. The tube contains gas at low pressure. There is a high voltage between the wire and the cylinder. This produces a very strong electric field close to the wire. Normally no current can cross the gap. This means that there is no voltage across the 1 megohm resistor.

When an alpha- or beta-particle enters the tube, it produces some ions in the gas. These ions are then accelerated by the strong field close to the wire. They soon gain enough energy to ionise more atoms by bumping into them. There is an avalanche of ions which allows a current to flow through the gas. This current also flows through the resistor and produces a pulse of voltage across it. These pulses are counted by a special electronic circuit. Sometimes they give a click in a loudspeaker.

Geiger counters are best at counting beta-particles and those alpha-particles that have sufficient energy to pass through the window. Gamma-rays and X-rays will also be counted if they produce ions in the tube, but they often just go straight through.



Liquid Scintillation Counting

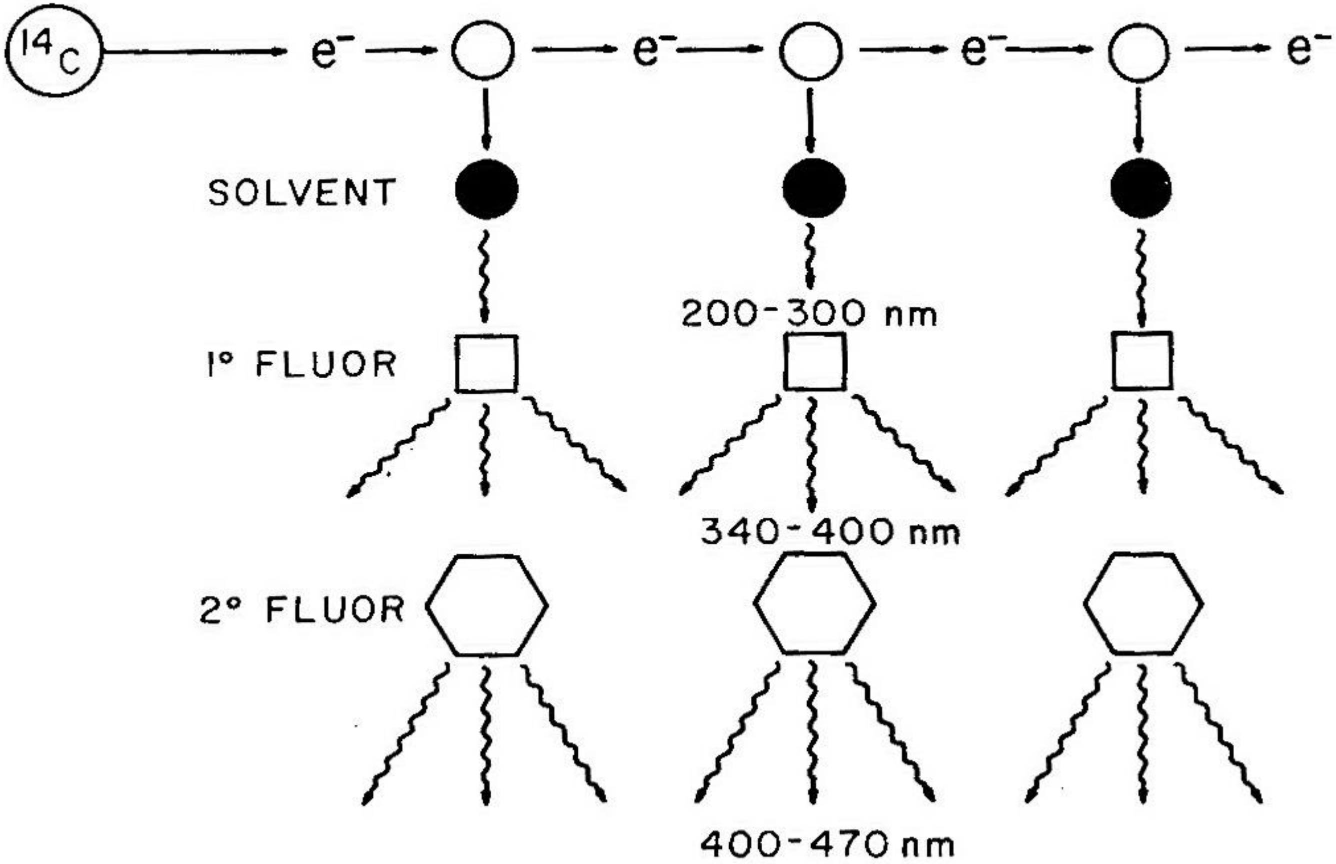
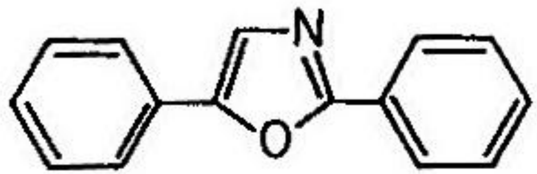


Figure 3-2. Interaction of β particles with aromatic solvents and subsequent fluor excitation. e^- represents the emitted β particles, ○ indicates a solvent molecule in its ground state, and ● denotes solvent molecules in the triplet state. (From E. Rapkin, *Preparation of Samples for Liquid Scintillation Counting*, Picker Nuclear Corp., White Plains, New York.)

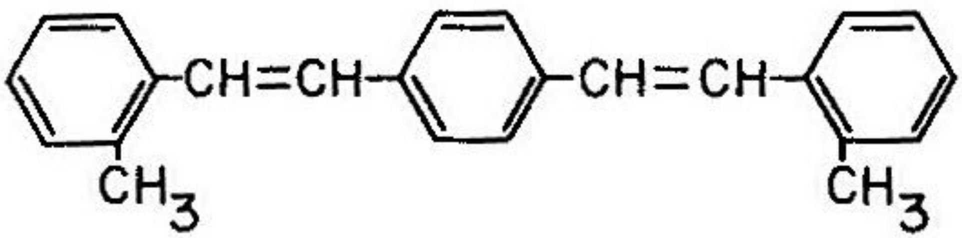


PPO

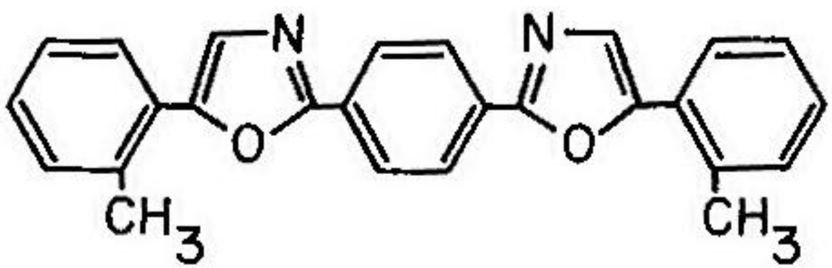
$\lambda_f \sim 365 / 380$

2,5-diphenyloxazole

(phenyl-oxazole-phenyl)



bis-MSB



dimethyl-POPOP

$\lambda_f \sim 420 / 441$

Photomultiplier Tubes

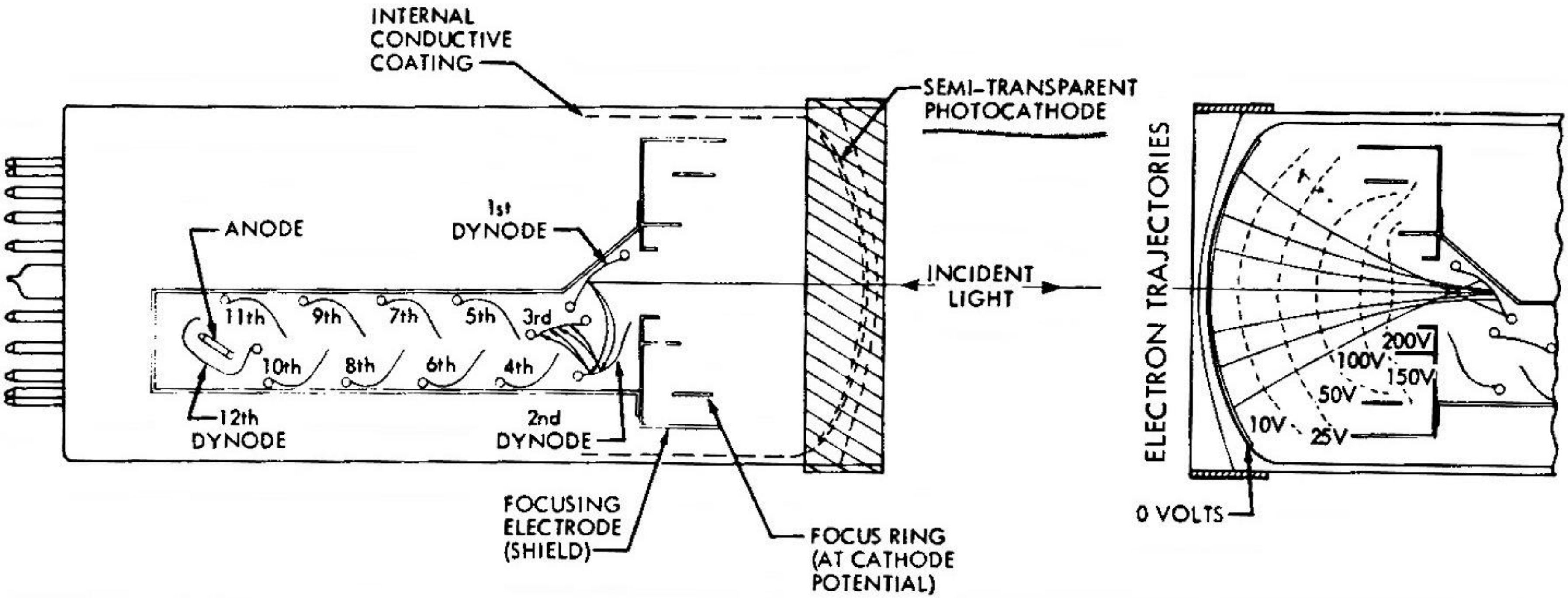


Figure 3-8. Beckman-RCA Bialkali 12-stage Photomultiplier Tube. (Courtesy of Beckman Instruments, Inc., Instruction Manual 1553-D.)

$\sim 10^{-9}$ seconds

$3\text{-}5\ e^- / e^- /$ dynode

$\Rightarrow 1\ e^- \rightarrow 10^6\ e^-$

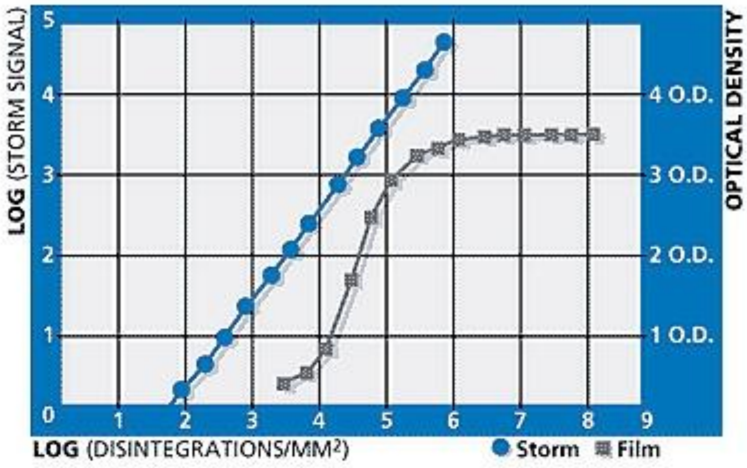
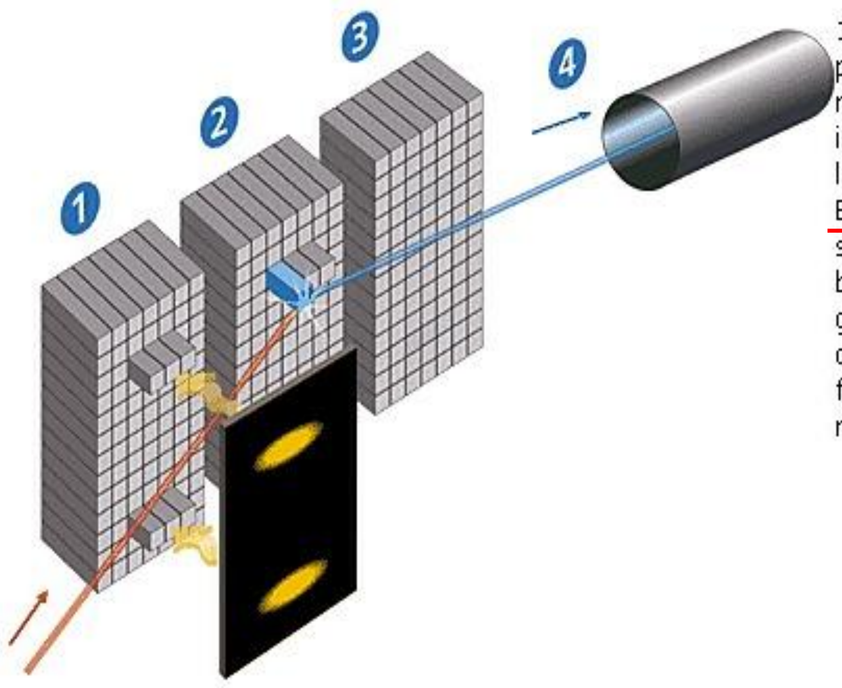


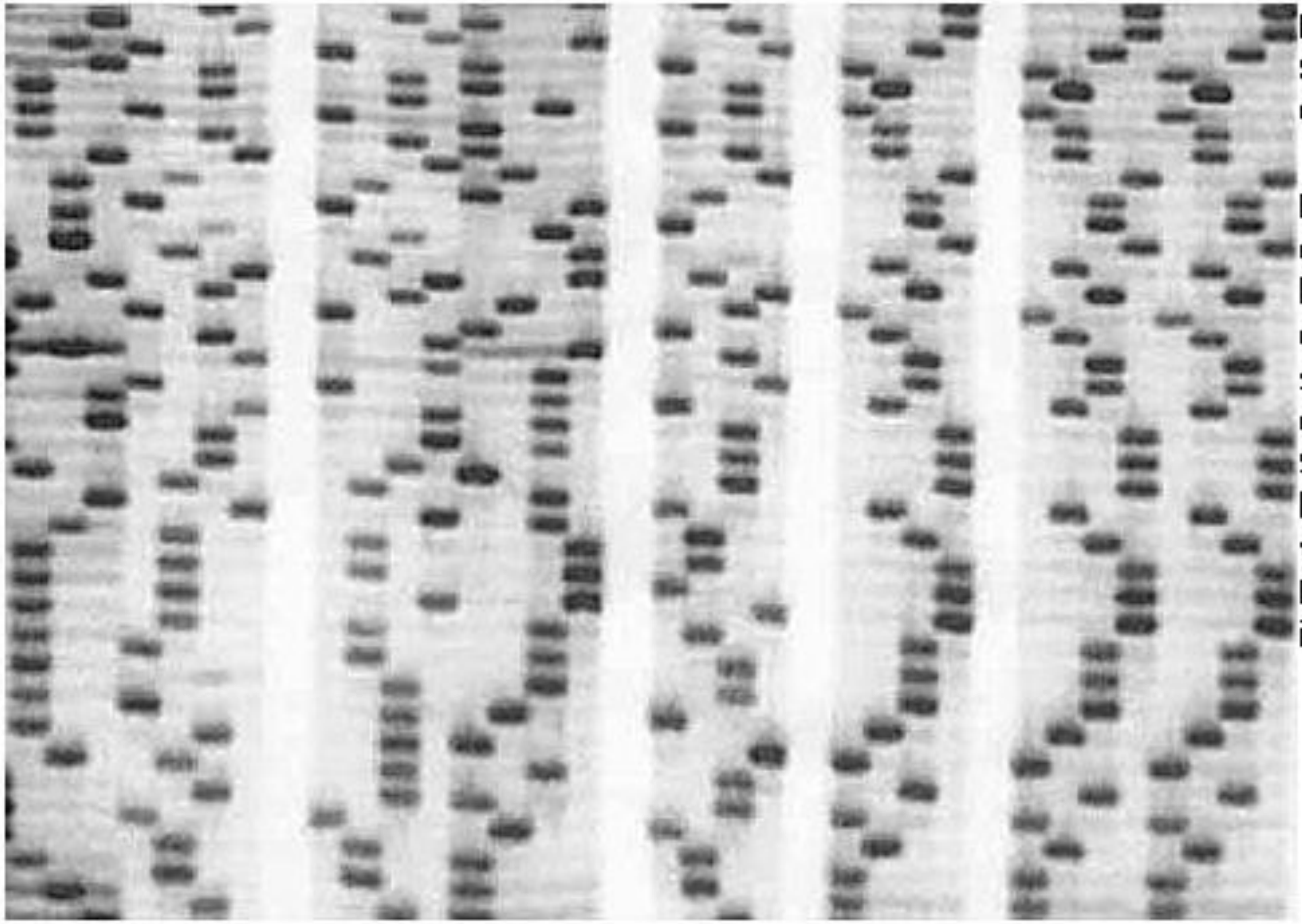
Fig 1. With five orders of linear dynamic range, Storm captures the image from both strong and weak signals in a single exposure. The Storm system's linear dynamic range is 1000 times greater than film.

How storage phosphor works

PhosphorImager



1.Exposure of the storage phosphor screen to ionizing radiation induces latent image formation **2.** During laser scanning, the BaFBR:EU+2 crystals in the screen release energy as blue light **3.** and return to ground state **4.** Blue light is collected and measured to form a quantitative representation of the sample.



DNA Sequencing Gels

DNA Sequencing gels and other large samples fit on the Storm system's 35 x 43 cm scan area. Storm offers the high resolution you need for DNA base identification.

Storm has a 35 x 43 cm (14" x 17") sample area that accepts large samples so you can scan sequencing-sized gels. Or, you can use the large sample area to expose many small gels and blots simultaneously for maximum throughput. Sample exposures take place in cassettes -- not in the instrument -- so the Storm system is always available for scanning. With the Windows NT operating system, scanning can continue even while you're using the same computer to analyze your data and prepare your results for presentation.

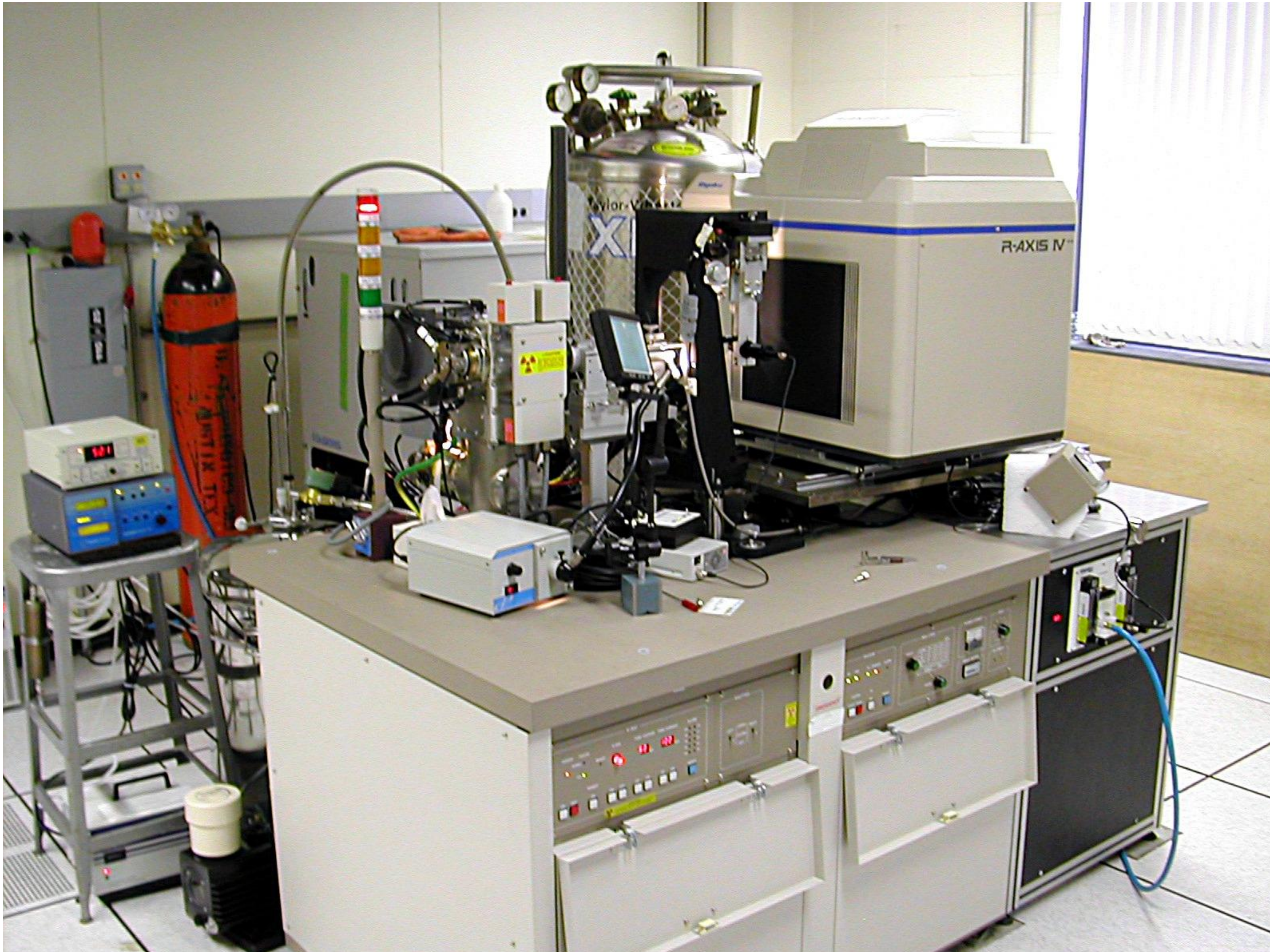

R-AXIS IV

TABLE 22.2 Half-Lives of Some Useful Radioisotopes

Radioisotope	Symbol	Radiation	Half-Life	Use
Tritium	${}^{3}_{1}H$	β^-	12.33 years	Biochemical tracer
Carbon-14	${}^{14}_{6}C$	β^-	5730 years	Archaeological dating
Phosphorus-32	${}^{32}_{15}P$	β^-	14.26 days	Leukemia therapy
Potassium-40	${}^{40}_{19}K$	β^-	1.28×10^9 years	Geological dating
Cobalt-60	${}^{60}_{27}Co$	β^-, γ	5.27 years	Cancer therapy
Technetium-99*m**	${}^{99m}_{43}Tc$	γ	6.01 hours	Brain scans
Iodine-123	${}^{123}_{53}I$	γ	13.27 hours	Thyroid therapy
Uranium-235	${}^{235}_{92}U$	α, γ	7.04×10^8 years	Nuclear reactors

*The *m* in technetium-99*m* stands for *metastable*, meaning that it undergoes γ emission but does not change its mass number or atomic number.

The Nobel Prize in Chemistry 1960

"for his method to use carbon-14 for age determination in archaeology, geology, geophysics, and other branches of science"

Willard Frank Libby

USA

Common Isotopes of Carbon

Relative abundance of these isotopes in atmospheric CO_2

C^{12} - 98.89 %
C^{13} - 1.11 %
C^{14} - 0.0000000001 %

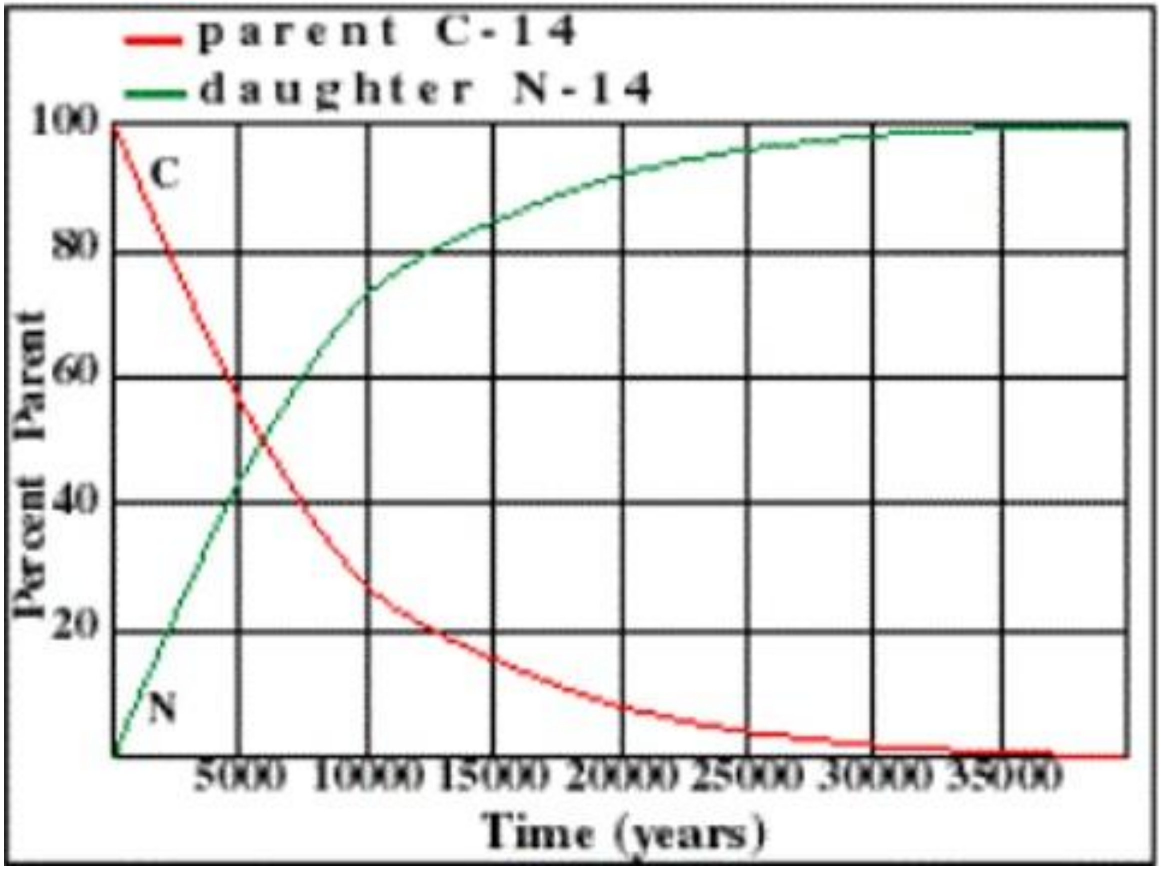
C-14 Dating

1. What is a "half-life"

2. Where does carbon-14 come from?

3. How is radiocarbon dating done?
   What assumptions must we make?

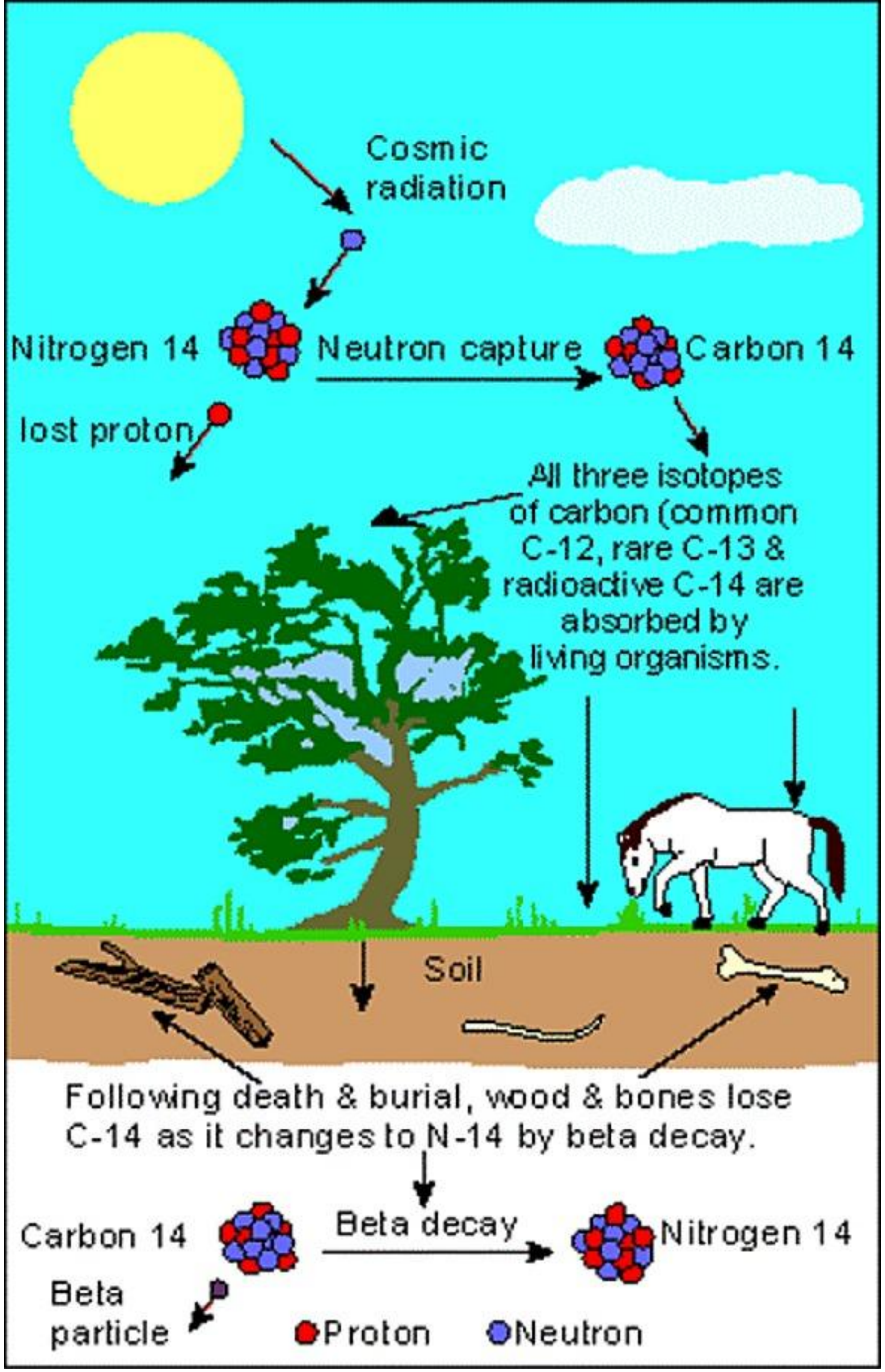
Carbon-14 Decay



Half-life of C-14 is ~5730 years

As long as an animal / human is alive, the percentage of C^{14} present in his body is the same as that in the atmosphere. This is because the food that we eat ultimately comes from plants. And carbon present in plants is produced from atmospheric CO_2 during photosynthesis.

However when a plant / animal / human dies, intake of carbon ceases. C^{12} and C^{13} being stable remains, but C^{14} decays. Thus by measuring the amount of C^{14} left, the age of a fossil is computed. This computation is based on the assumption that the amount of C^{14} present in the atmosphere has remained constant.



Complications

The simplified approach described above does not tell the whole story, There are two principal sources of error:

1. The original half-life of carbon-14 measured by Libby has not withstood the test of time. The currently accepted half-life of this nucleus is 5730 years, Libby's measurement of 5668 years is still used (for consistency) in calculations.

(can correct for this with math)

2. Over time, the abundance of carbon-14 in the atmosphere has undergone variations. These result directly from fluctuations in the flux of cosmic rays, burning of fossil fuels and atmospheric testing of nuclear bombs in the period following WWII.

????????

Solution:

Measure C14/C12 ratio in samples of KNOWN ages.

Plot ratios v. age, use these for calibration.

Allow for uncertainties in all measured C14/C12 ratios.

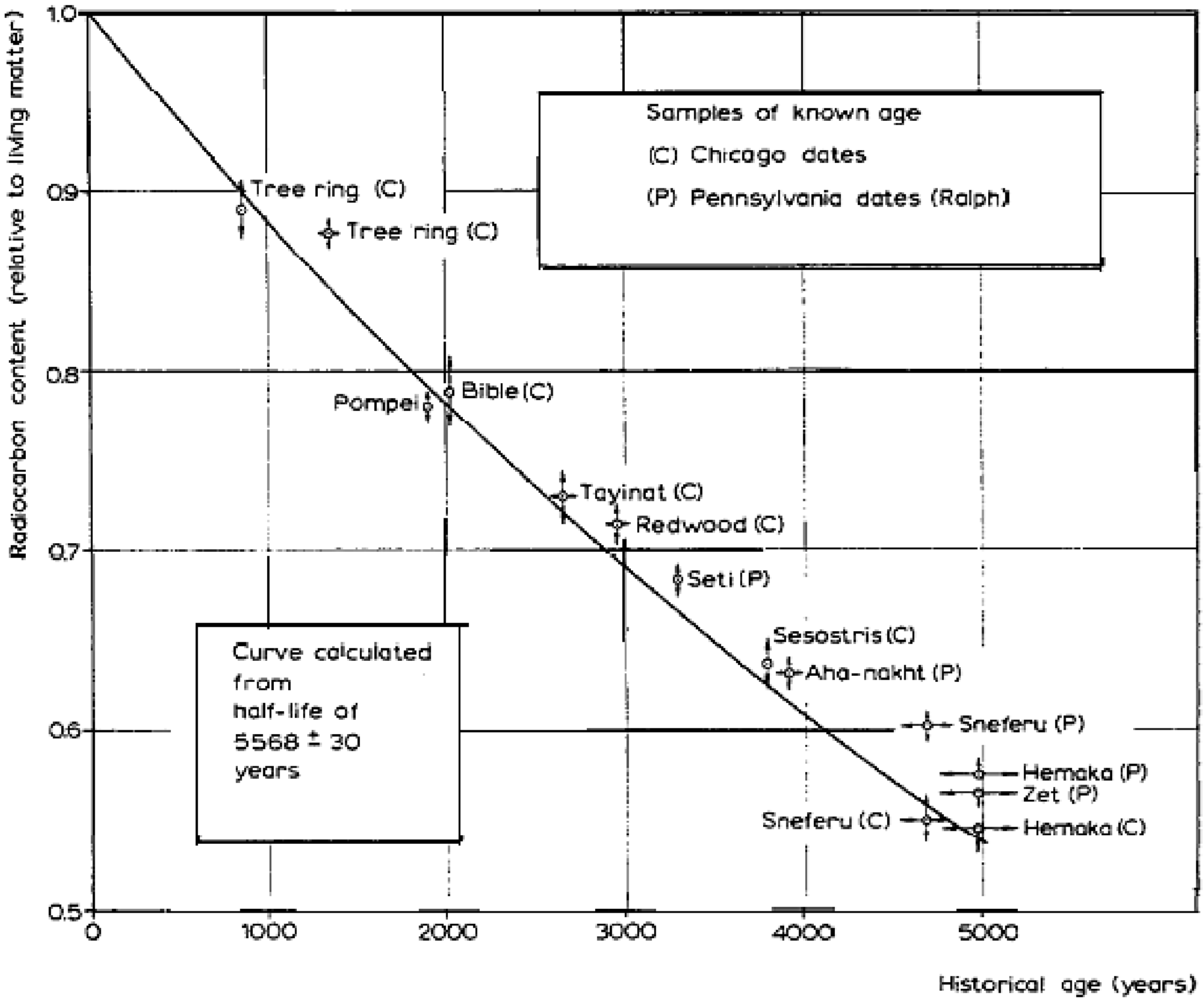


Fig. 3. Curve of Knowns.

http://nobelprize.org/nobel_prizes/chemistry/laureates/1960/libby-lecture.html

Forensic Uses

Radiocarbon Dating of the Human Eye Lens Crystallines Reveal Proteins without Carbon Turnover throughout Life

Niels Lynnerup[1*], Henrik Kjeldsen[2], Steffen Heegaard[3], Christina Jacobsen[1], Jan Heinemeier[2] 2008

Lens crystallines are special proteins in the eye lens. Because the epithelial basement membrane (lens capsule) completely encloses the lens, desquamation of aging cells is impossible, and due to the complete absence of blood vessels or transport of metabolites in this area, there is no subsequent remodelling of these fibers, nor removal of degraded lens fibers. Human tissue ultimately derives its ^{14}C content from the atmospheric carbon dioxide. The ^{14}C content of the lens proteins thus reflects the atmospheric content of ^{14}C when the lens crystallines were formed. Precise radiocarbon dating is made possible by comparing the ^{14}C content of the lens crystallines to the so-called bomb pulse, i.e. a plot of the atmospheric ^{14}C content since the Second World War, when there was a significant increase due to nuclear-bomb testing. Since the change in concentration is significant even on a yearly basis this allows very accurate dating.

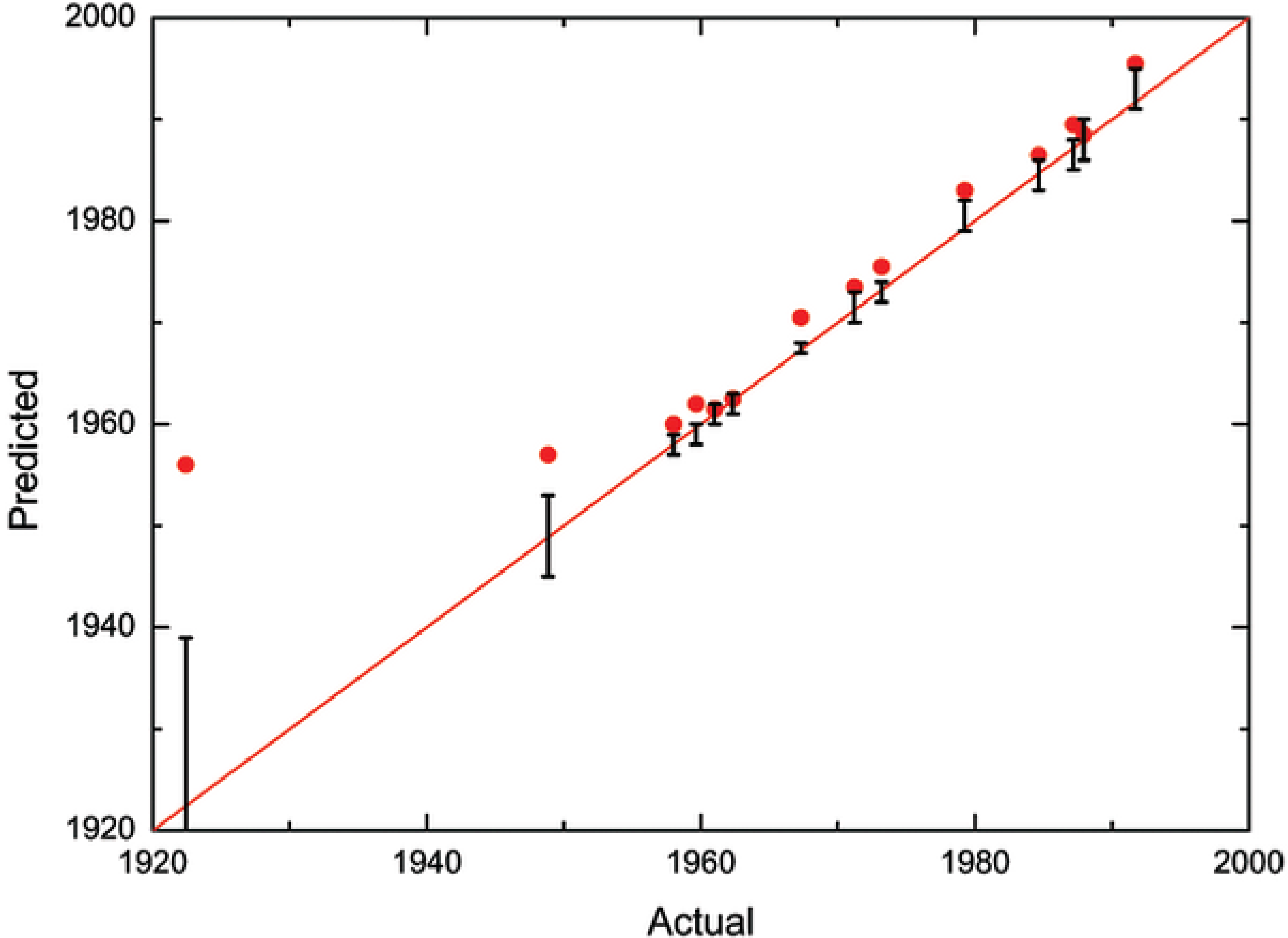
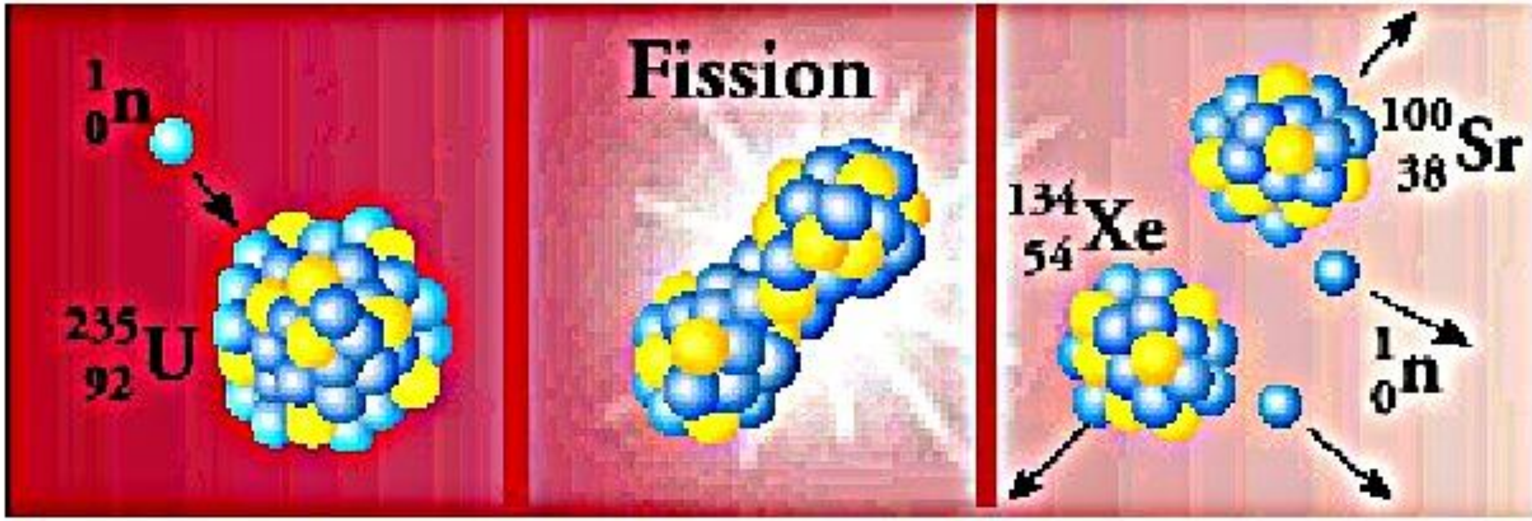


Figure 2. Predicting the year of birth by the ^{14}C of eye lens crystallines.

Nuclear Fission Energy

[Nuclear Wall Chart – Lawrence Berkeley Natl. Laboratory]



. Fission of ^{235}U after absorption of a thermal neutron.

The relevant nuclear reactions can be written as follows:

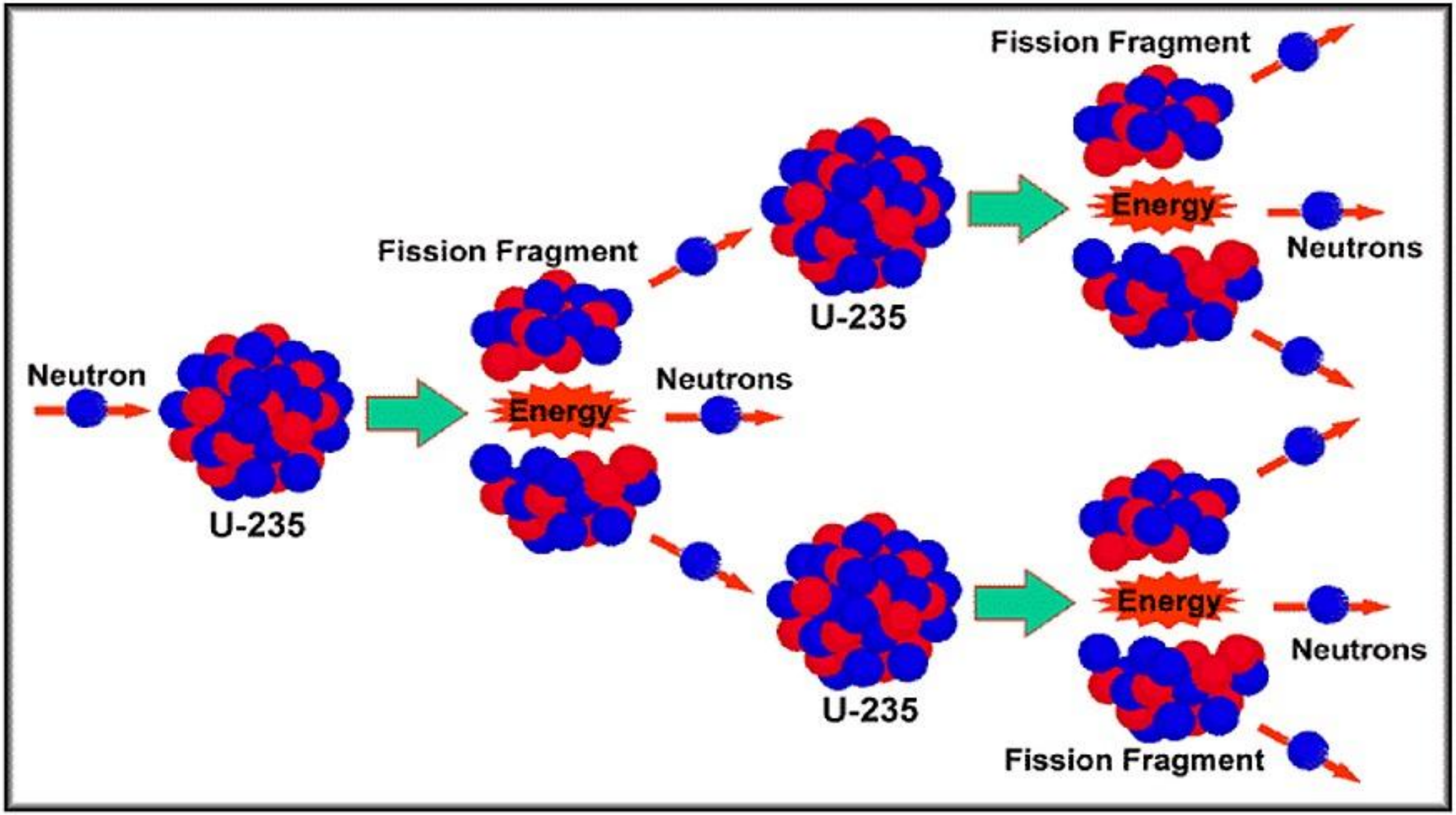
$$^{235}\mathrm{U} + {}^{1}\mathrm{n} \rightarrow \text{fission products + neutrons + energy (\sim200 MeV)} \qquad (1)$$

$$^{238}\mathrm{U} + {}^{1}\mathrm{n} \rightarrow {}^{239}\mathrm{U} + \text{gamma rays} \qquad (2)$$

$$^{239}\mathrm{U} \rightarrow {}^{239}\mathrm{Np} \rightarrow {}^{239}\mathrm{Pu} \qquad \text{(a series of beta decays).} \qquad (3)$$

Mass defect = sum of mass of nucleons - mass of nucleus

Binding energy = $\Delta m \times c^2$



Fission of uranium 235 nucleus. Adapted from *Nuclear Energy. Nuclear Waste*.

U-235 (~0.7% abundance) is the only fissile isotope that is found in significant quantity in nature.. The fission of one atom of U-235 generates ~200 MeV = 3.2 × 10^{-11} J or **over 80 x 10(+12) J/kg** (1 eV is 96.5 kJ/mole)

Mass defect

$$^{226}_{88}Ra \rightarrow {}^{222}_{86}Rn + {}^{4}_{2}\alpha$$

$$\Delta m = m_{parent} - m_{products}$$

$$= {}^{226}_{88}Ra - (m_{^{222}_{86}Rn} + m_{^{4}_{2}\alpha})$$

$$= 226.025410\ u - (222.017578\ u + 4.002603\ u)$$

$$= 0.005229\ u$$

Energy equivalence

$$\Delta m = 0.005229 \text{ u} \times 1.660539 \times 10^{-27} \text{ kg / u}$$

$$\Delta m = 8.62829... \times 10^{-30} \text{kg}$$

$$E = mc^2$$

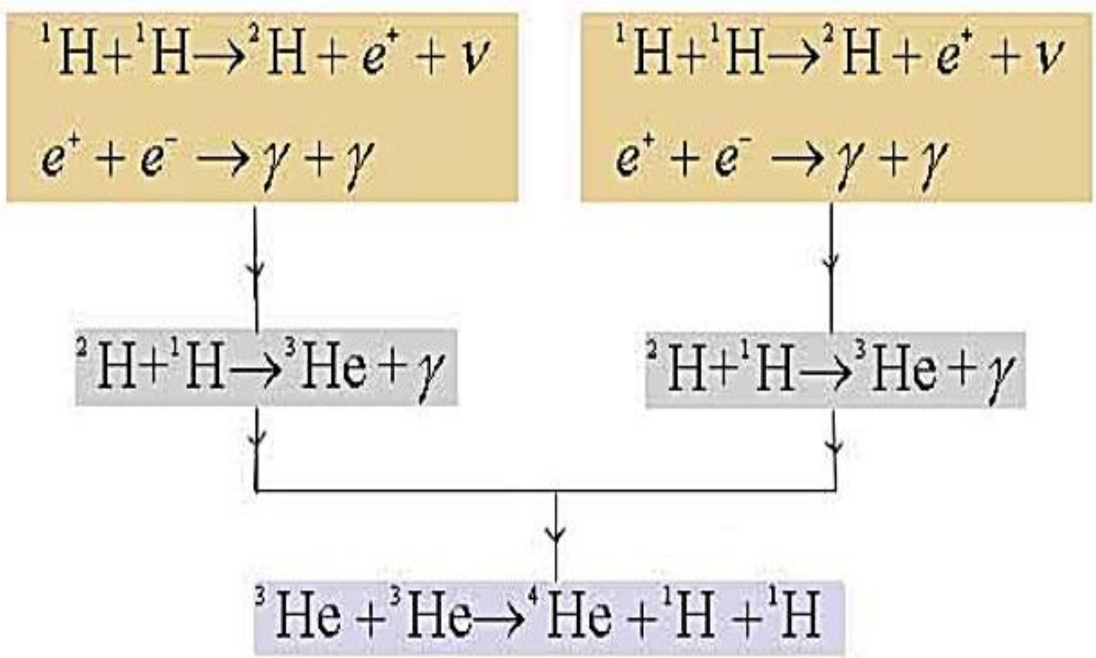
$$= 8.66829... \times 10^{-30} \text{kg} \times (3.00 \times 10^{8} \text{ m / s})^2$$

$$= 7.8146... \times 10^{-13} \; J$$

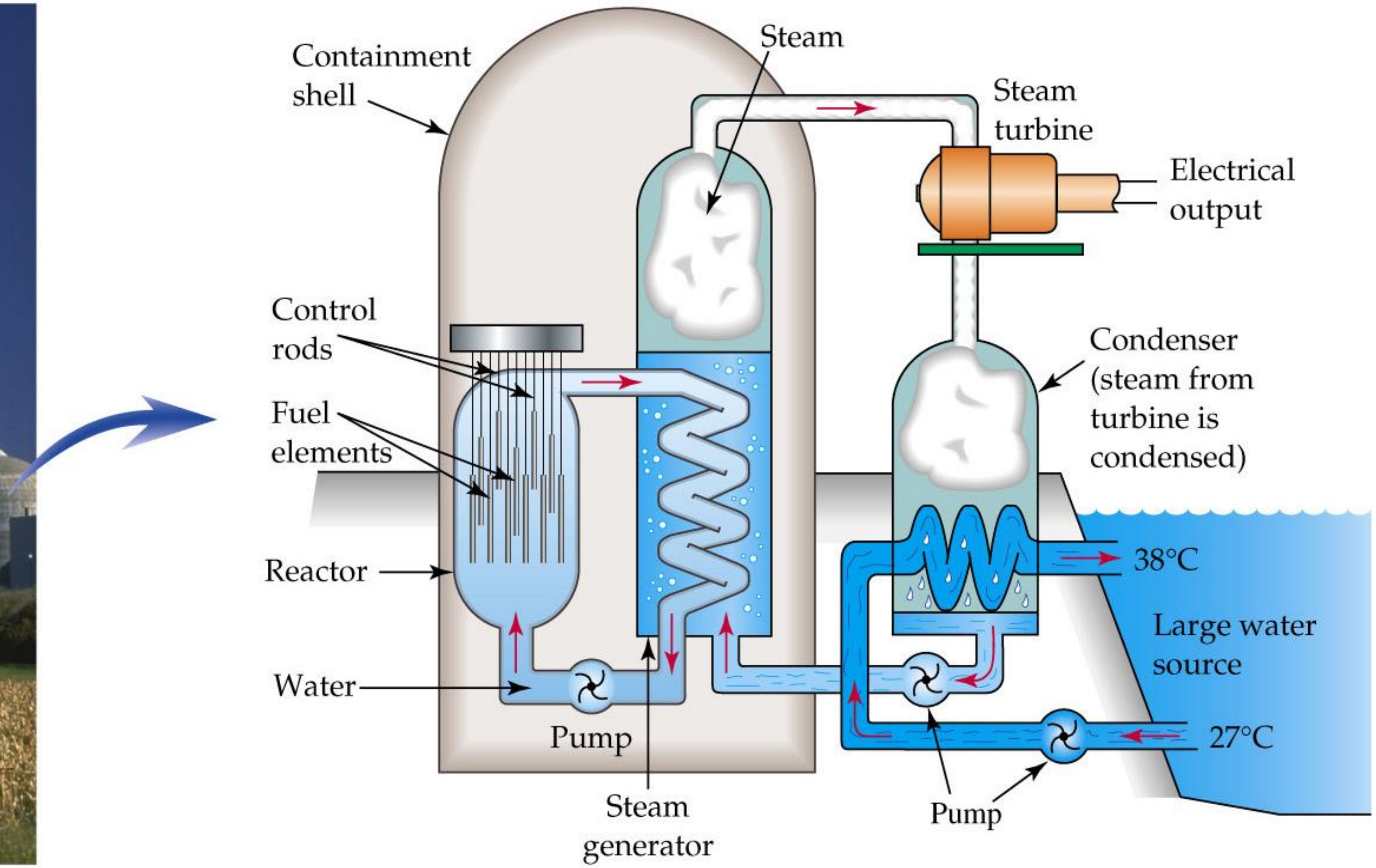
or 4.7 x 10^8 KJ/mole!!

Thermonuclear Fusion in the Sun and other Stars

The sun radiates energy at the rate of 3.9 X 10^{26} W (watts) and has been doing so for several billion years. The sun burns hydrogen in a "nuclear furnace." The fusion reaction in the sun is a multistep process in which hydrogen is burned into helium, hydrogen being the "fuel" and helium the "ashes." The figure below shows the cycle.



Fusion cycle of the Sun



$$\Delta \text{ Energy} = \Delta m \times c^2$$

Nuclear Fusion - Hydrogen Bomb

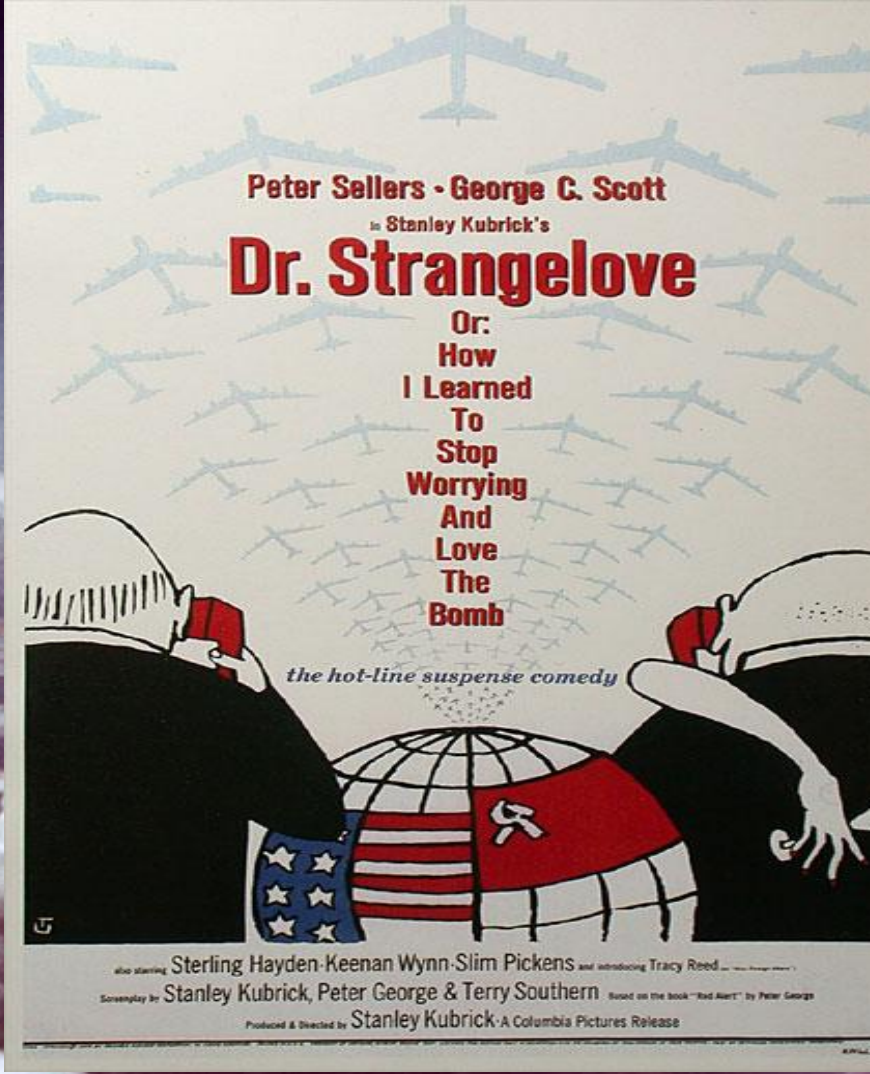
Fusion releases energy due to the overall loss in mass. If you add up the masses of the particles which go into a fusion reaction, and you add up the masses of the particles which come out, there is frequently a difference. According to Einstein's famous law relating energy and mass,

$$E = mc^2 ,$$

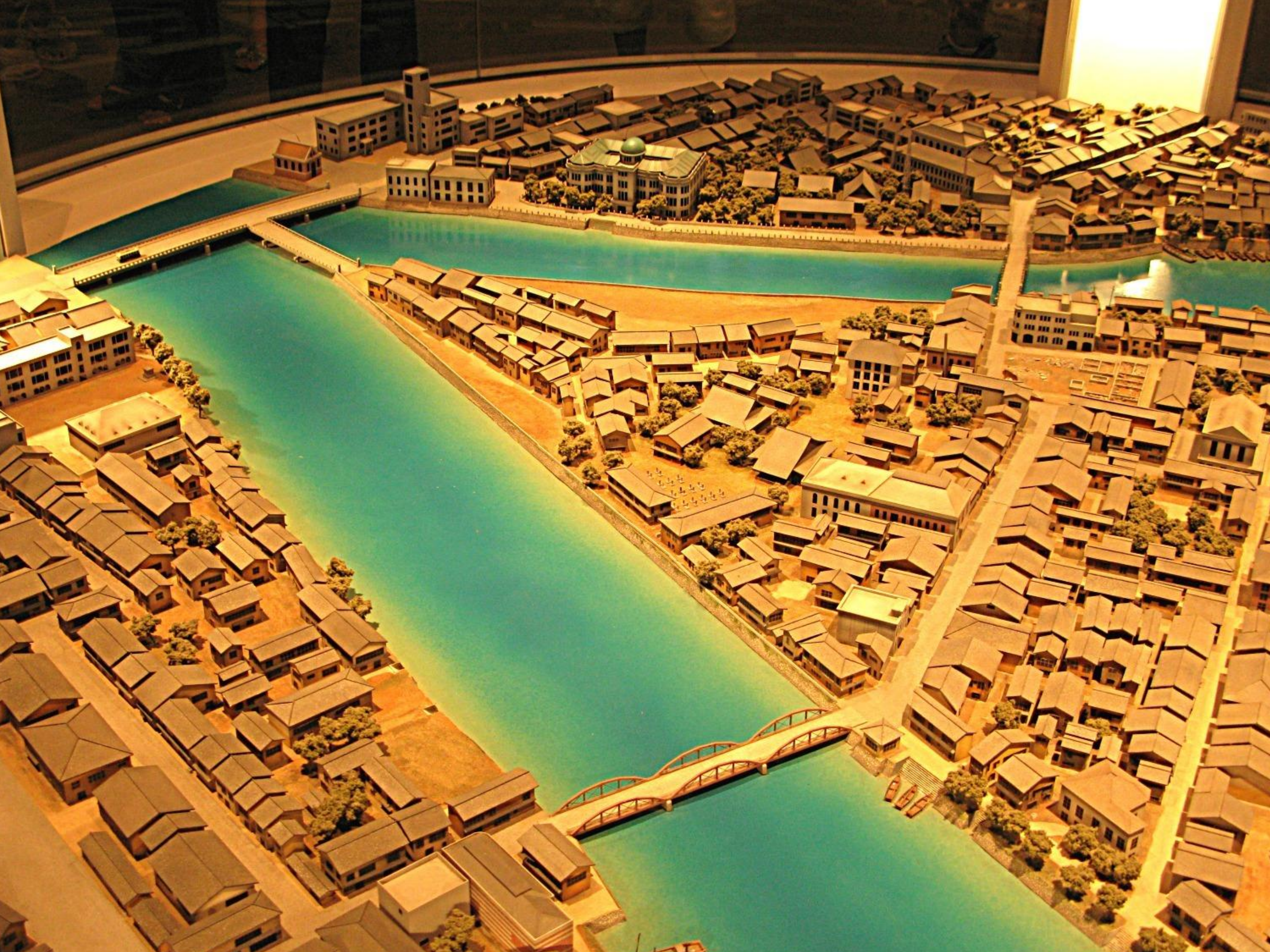
$$\Delta \text{Energy} = \Delta m \times c^2$$

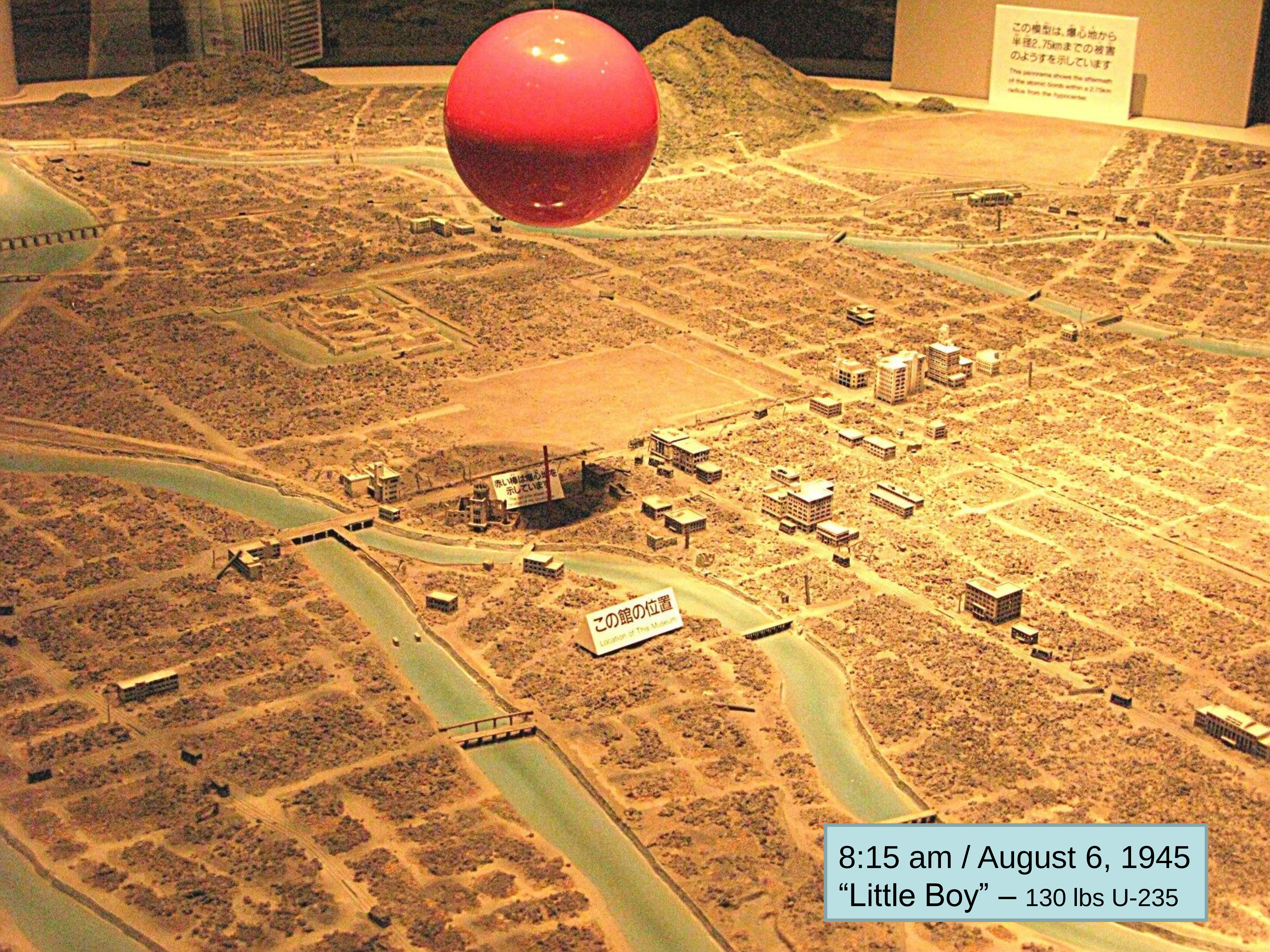
the "mass difference" can take the form of energy. Fusion reactions involving nuclei lighter than iron typically release energy, but fusion reactions involving nuclei heavier than iron typically absorb energy. The amount of energy released depends on the specifics of the reaction. The reaction used in the hydrogen bomb, though, produces one of the greatest changes in mass.

The hydrogen bomb is thousands of times more powerful than an atomic bomb. There have not been any hydrogen bombs used in warfare, however there have been hydrogen bomb tests. Most of these tests are done underwater due to risk of destruction. To give you an idea of how strong the H-bomb is, think about this. This atomic bomb dropped on Hiroshima, Japan which killed over 140,000 people had the power of 13 kilotons. A common hydrogen bomb has the power of up to 10 megatons. All the explosions in World War II totalled "only" 2 megatons -- 20% of the power of ONE common hydrogen bomb.



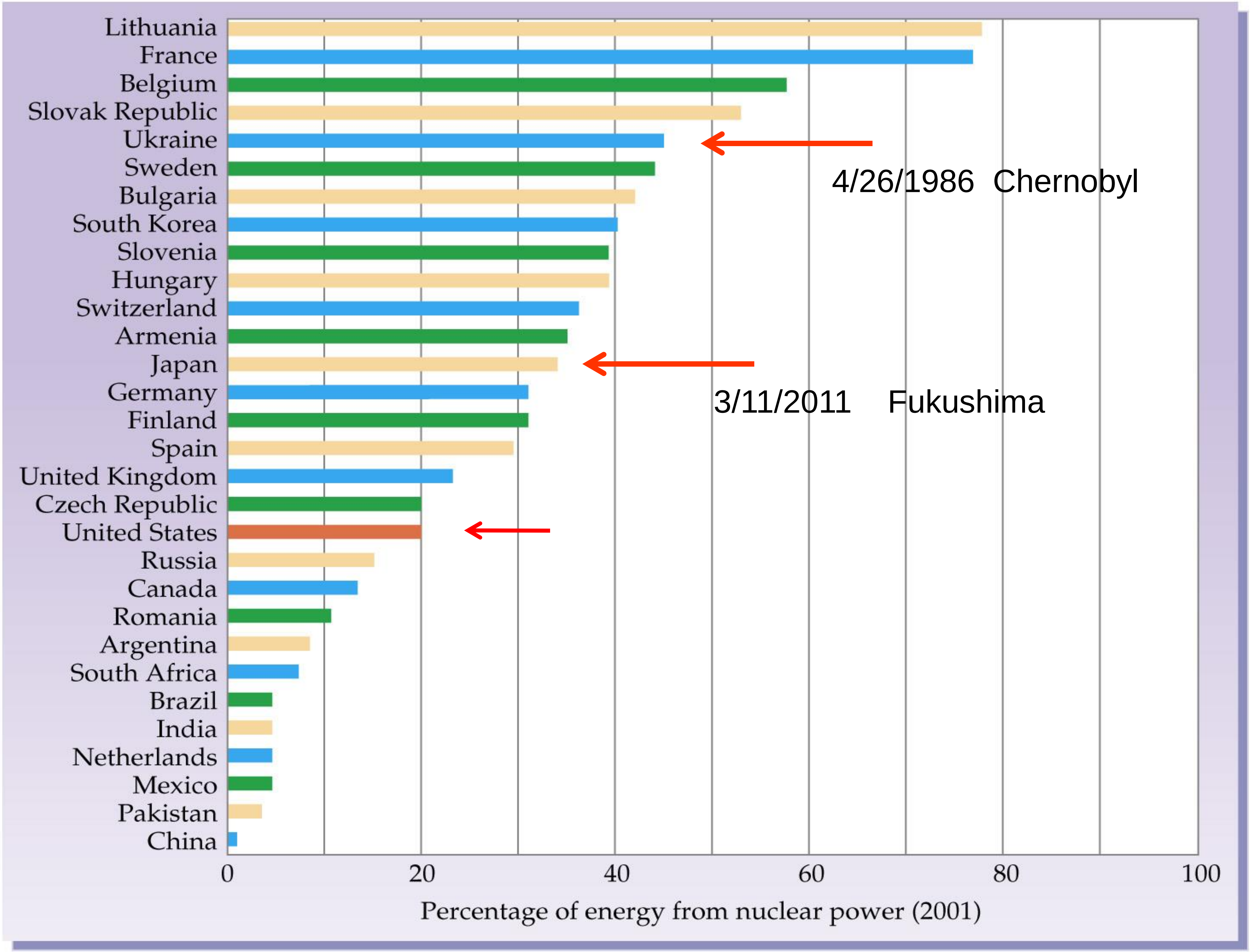
Peter Sellers · George C. Scott
in Stanley Kubrick's
Dr. Strangelove
Or:
How
I Learned
To
Stop
Worrying
And
Love
The
Bomb
the hot-line suspense comedy
also starring Sterling Hayden · Keenan Wynn · Slim Pickens and introducing Tracy Reed
Screenplay by Stanley Kubrick, Peter George & Terry Southern Based on the book "Red Alert" by Peter George
Produced & Directed by Stanley Kubrick · A Columbia Pictures Release





8:15 am / August 6, 1945
“Little Boy” – 130 lbs U-235

広島県産業奨励館（「原爆ドーム」：爆心地から約160メートル）
この建物は、チェコの建築家ヤン・レツルの設計監督により1915（大正４）年４月に完成し、特徴ある緑色のドームによって市民に親しまれていました。原爆はこの建物の南東約160メートルの上空約580メートルでさく裂したため、建物は大破・全焼して館内にいた全員が即死しました。その後、原爆の惨禍を全世界に伝えるとともに、世界平和へのシンボルとして1996（平成８）年12月、ユネスコの世界遺産一覧表に登録されました。
（被爆前の広島県産業奨励館）
The Hiroshima Prefectural Industrial
(Approx. 160 meters from the



Lithuania
France
Belgium
Slovak Republic
Ukraine
Sweden
Bulgaria
South Korea
Slovenia
Hungary
Switzerland
Armenia
Japan
Germany
Finland
Spain
United Kingdom
Czech Republic
United States
Russia
Canada
Romania
Argentina
South Africa
Brazil
India
Netherlands
Mexico
Pakistan
China
4/26/1986 Chernobyl
3/11/2011 Fukushima
0
20
40
60
80
100
Percentage of energy from nuclear power (2001)

Since nuclear radiation affects people, we must be able to measure radioactivity. We also need to relate the amount of radiation received by the body to its physiological effects. Two terms used to relate the amount of radiation received by the body are exposure and dose.

Radioactivity

Original unit - amt of **radioactivity** was the ***curie* (Ci) -** activity of one gram of radium-226.

Today ***1 curie* = *3.7 10+10 radioactive decays per second*** [exactly].

International System of Units (SI) the **becquerel (Bq)** has replaced the curie, where

***1 becquerel* = *1 radioactive decay per second* = *2.703 10-11 Ci*.**

*The magnitude of radiation **exposures** is specified in terms of the **radiation dose**.*

Exposure:

Roentgen - It is the **amount of radiation** required to liberate positive and negative charges of one esu of charge in 1 cm*3 at STP. This corresponds to the generation of approximately **2.08×10^9 ion pairs.**

Dose: *There are two important categories of **dose**:*

*1. **Rad**: **radiation absorbed dose**, also known as the **physical dose**, defined by the amount of energy deposited in a unit mass in human tissue. The original unit is the **rad [100 erg/g]**; it is now being widely replaced by the **SI unit, the** gray (Gy) [1 J/kg], where **1 gray = 100 rad**.*

*2. **Rem**: The **Roentgen equivalent in man** or **biological dose** or **dose equivalent**, expressed in units of **rem** or, in the **SI system**, **sievert (Sv)**. This dose reflects the fact that the biological damage caused by a particle depends not only on the total energy deposited but also on the rate of energy loss per unit distance traversed by the particle (or "**linear energy transfer**"). **(Q ~ 1 for gamma or beta; ~ 5 protons; ~ 20 for alpha particles.)***

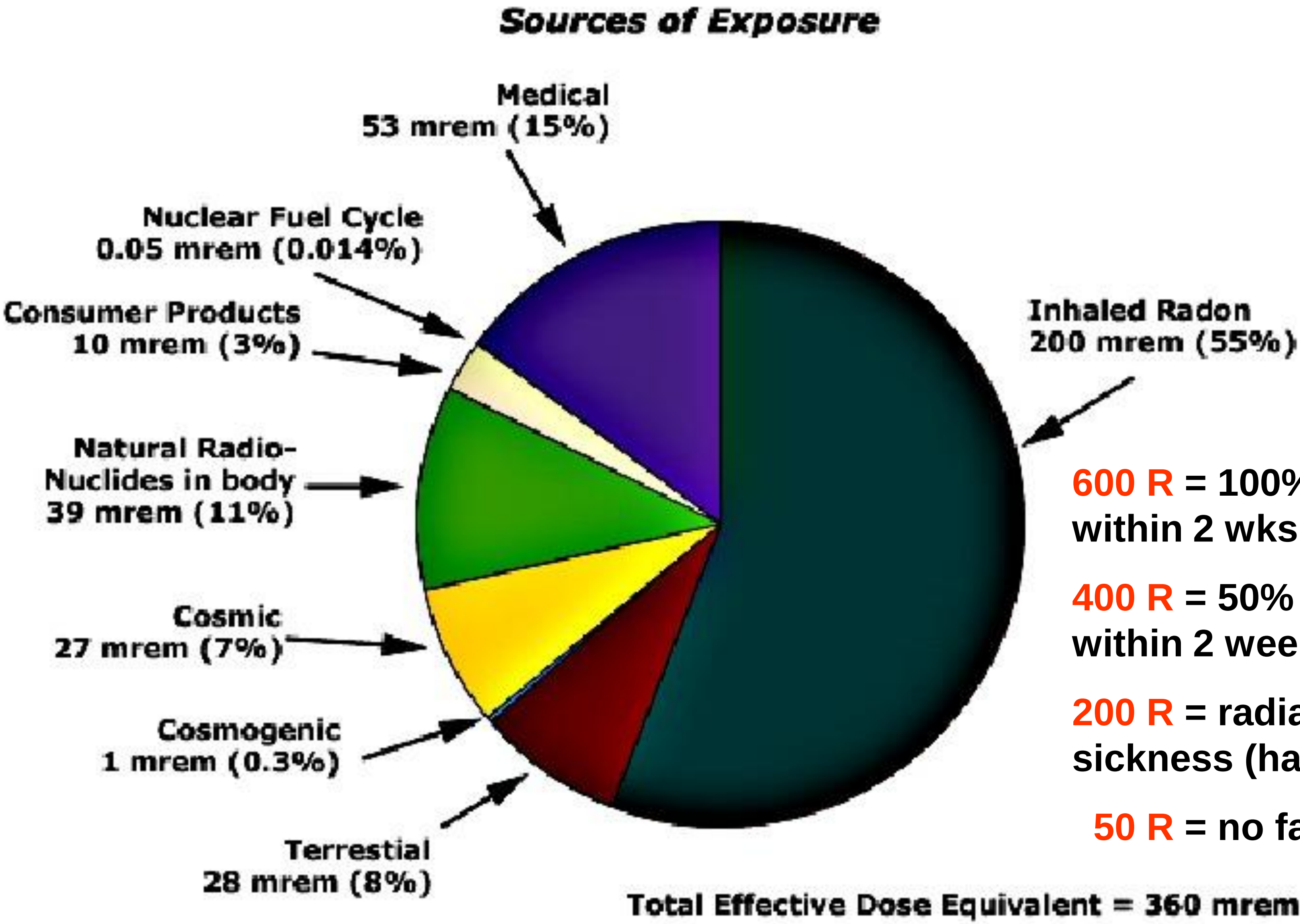
***1 Sv = 100 rem**. **1 rem is the average dose received in 3 years of exposure to natural radiation**.*

Although a dose of just 25 rems causes some detectable changes in blood, doses to near 100 rems usually have no immediate harmful effects. Doses above 100 rems cause the first signs of radiation sickness including:

nausea
vomiting
headache
some loss of white blood cells

Doses of 300 rems or more cause temporary hair loss, but also severe loss of white blood cells, which are the body's main defense against infection, makes radiation victims highly vulnerable to disease. Radiation also reduces production of blood platelets, which aid blood clotting, so victims of radiation sickness are also vulnerable to hemorrhaging.

Half of all people exposed to 450 rems die, and doses of 800 rems or more are always fatal. Besides the symptoms mentioned above, these people also suffer from fever and diarrhea. As of yet, there is no effective treatment--so death occurs within two to fourteen days.



600 R = 100% dead within 2 wks

400 R = 50% die within 2 weeks

200 R = radiation sickness (hair loss)

50 R = no fatalities

Natural Background Radiation = 295 mrem (82%)
Manmade Radiation = medical + consumer products = 63 mrem (18%)