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"

Nuclear Energy - fission and fusion

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

C-14 and radiocarbon dating

Counting: Film / Geiger Counter / LSC / PI

Terms: Radioactivity / Exposure / Dose

Hackert – CH370

Goals for this unit:

Early History of the Nuclear Atom

Radioactive Decay – know common forms of decay

Balance decay reactions

Nuclear Energy – fission rxns. vs. fusion

C-14 dating - Half-life and equations

Counting: Understand the basis (+/-) of

Film vs. Geiger Counter vs. LSC vs. PI

Terms: Radioactivity / Exposure / Dose

The Nobel Prize is an international award given yearly since 1901 for achievements in physics, chemistry, medicine, literature and for peace. In 1968, the Bank of Sweden instituted the Prize in Economic Sciences in Memory of Alfred Nobel, founder of the Nobel Prize.

The Prize Winners are announced in October every year. They receive their awards (a prize amount, a gold medal and a diploma) on December 10, the anniversary of Nobel's death.

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)

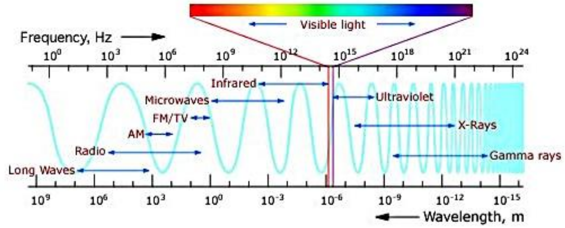
1911 – Rutherford (Au foil exp. / nuclear atom)

1912 – von Laue (X-rays as waves)

1920 – Rutherford (predicts neutron)

The Electromagnetic Spectrum

X-rays have wavelengths much shorter than visible light, but longer than high energy gamma rays. Their wavelength is well suited to study crystal structures and details of the human body. In addition, several objects and processes in the Universe emit X-rays. These X-rays are the messangers revealing information of the cosmos.



X-rays is presented with the support of The Knut and Alice Wallenberg Foundation.

The Discovery of X-rays

The apparition was so awful that Wilhelm Conrad Röntgen wondered if he had taken leave of his senses. He could hardly have been more surprised if he had looked into a mirror and no reflection stared back. It was approaching midnight on November 8, 1895. For sometime scientists had been reporting bizarre apparitions when they electrified the thin gas in vacuum tubes. The English physicist William Crookes, who saw unearthly luminous clouds floating in the air, had become convinced that he was producing ectoplasm, much beloved of Victorian seances, and had turned to spiritualism as a result. In Germany Röntgen was doing similar experiments and now, alone in the night, his imagination ran wild.

Earlier that day, as the November dusk darkened the laboratory, he had noticed that whenever he made sparks in the tube, a fluorescent screen at the other end of the laboratory table glowed slightly. This was the signal that he had been looking for, the sign that invisible rays were being produced in the spark tube, crossing the room and striking the screen, producing the faint glimmer. To track the rays he had been putting pieces of card in their way, but the screen continued to glow whether the cards were there or not as if the rays were able to pass clean through them. He then tried to block the rays with metal but thin pieces of copper and aluminium were as transparent as the card had been.

He moved a piece of lead near to the screen, watching its shadow sharpen, and it was then that he dropped it in surprise: he had seen the dark skeletal pattern of the bones as his hand moved across the face of the screen. Still doubting what he saw he took out some photographic film for a permanent record. Röntgen had made one of the most monumental discoveries in the history of science: X-rays, and seen for the first time images that are today common in every hospital casualty department.

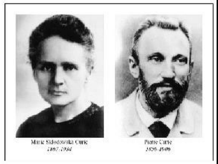
Six weeks later, on the Sunday before Christmas 1895, he invited his wife Bertha into the laboratory and took a shadow-graph of the bones of her hand with her wedding ring clearly visible. This is one of the most famous images in photographic history and propelled him within two more weeks into an international celebrity. The medical implications were immediately realised and the first images of fractured bones were being made by January 1896 even though none yet knew what the mystery rays were.

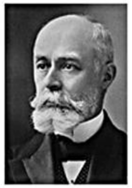
The Nobel Prize in Physics 1903

"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

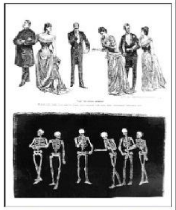




Antoine Henri Becquerel
1/2 of the prize
France

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)
- 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

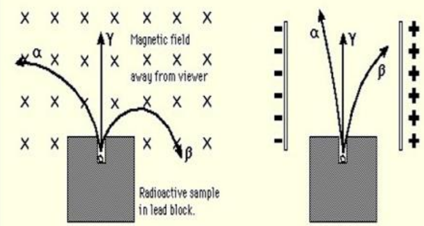
United Kingdom and New Zealand

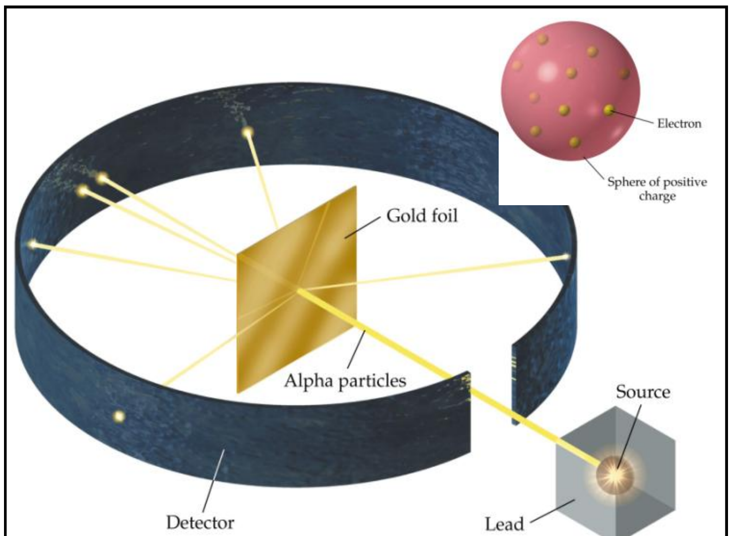
Victoria University
Manchester, United Kingdom

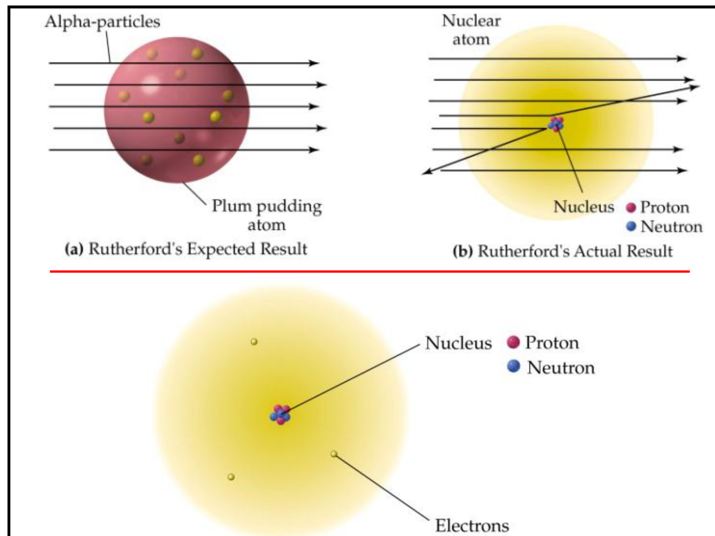
b. 1871
(in Nelson, New Zealand)
d. 1937

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.

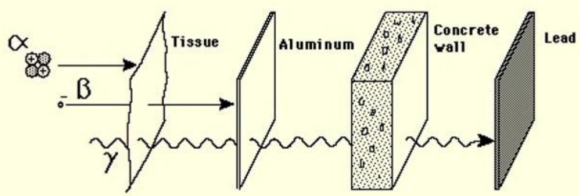






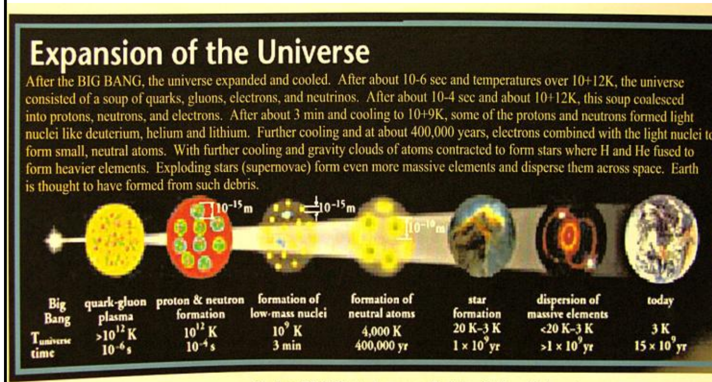
Penetration of Matter

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



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

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.

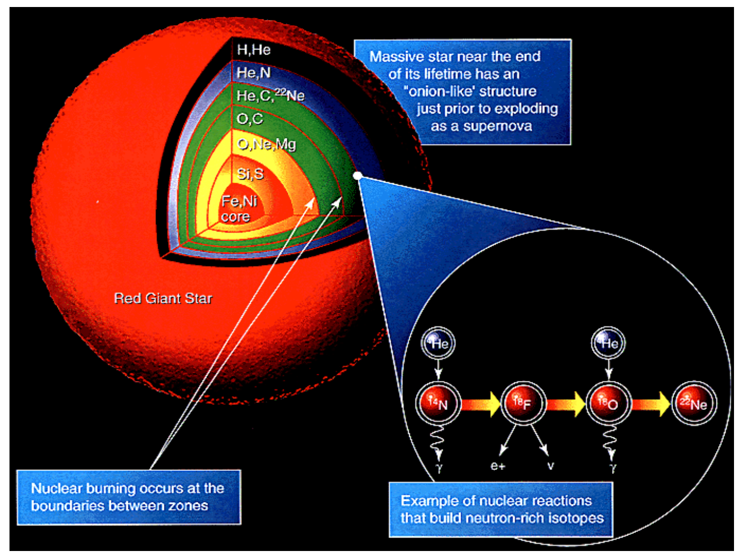
$${}^1H + {}^1H \rightarrow {}^2H + e^+ + \nu \qquad {}^1H + {}^1H \rightarrow {}^2H + e^+ + \nu$$

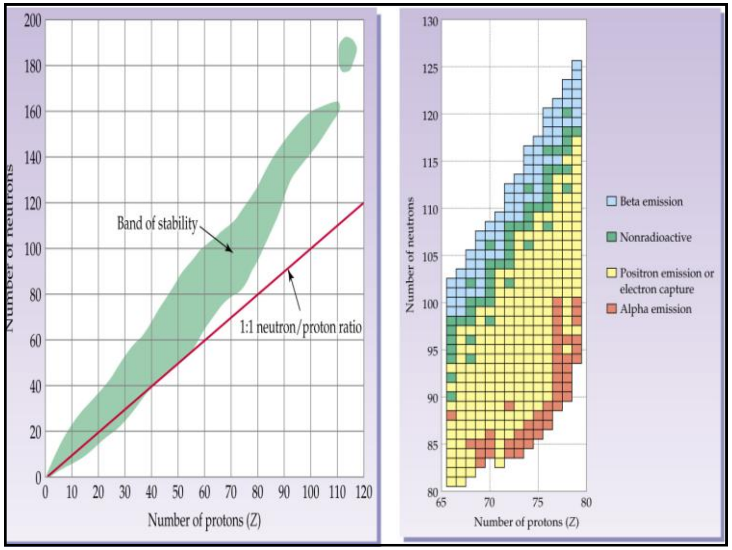
$$e^+ + e^- \rightarrow \gamma + \gamma \qquad e^+ + e^- \rightarrow \gamma + \gamma$$

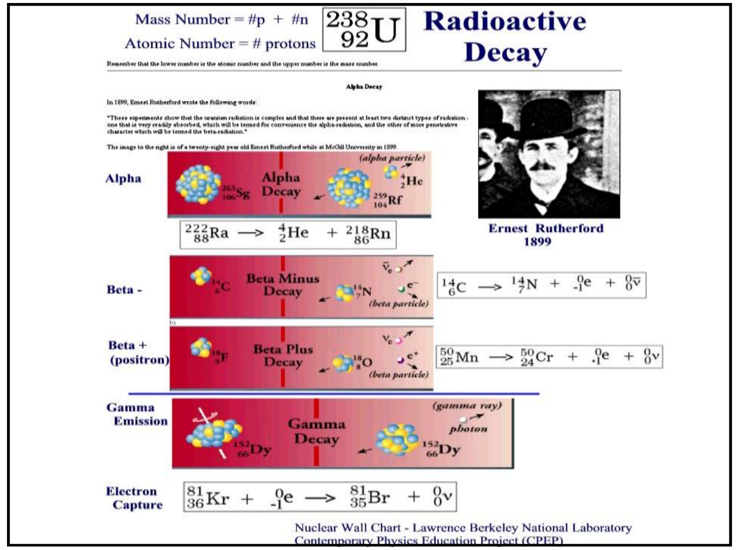
$${}^2H + {}^1H \rightarrow {}^3He + \gamma \qquad {}^2H + {}^1H \rightarrow {}^3He + \gamma$$

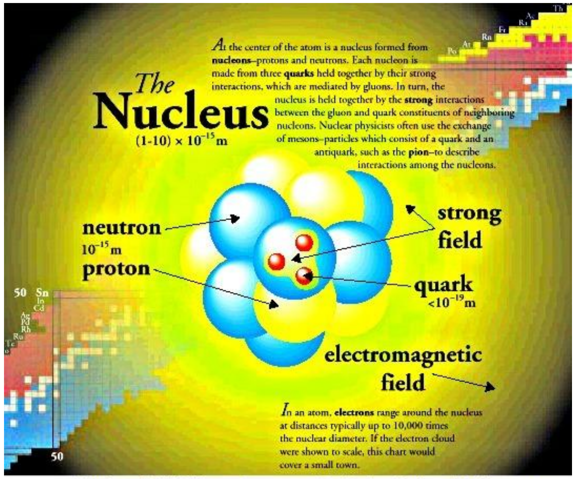
$${}^3He + {}^3He \rightarrow {}^4He + {}^1H + {}^1H$$

Fusion cycle of the Sun



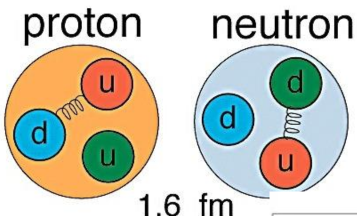






Nuclear Wall Chart - Lawrence Berkeley National Laboratory
Contemporary Physics Education Project (CPEP)

Protons and Neutrons 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 Particle "Zoo"

The Particle "Zoo" | Forces | Fred Reines

The Particle Zoo

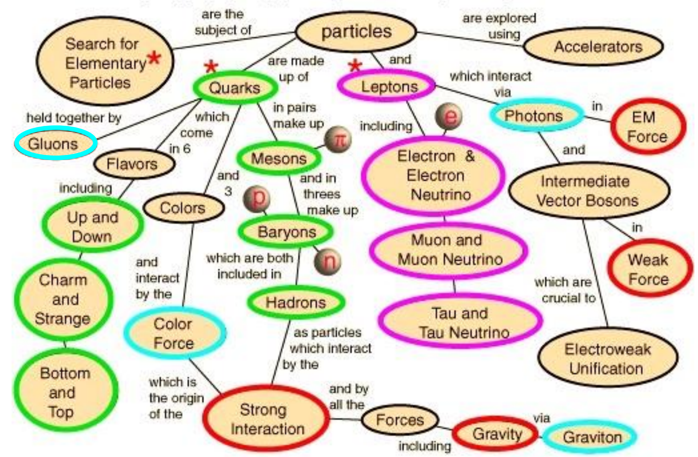
http://www.ps.uci.edu/~superk/particles.html

Matter Particles - Quarks and Leptons					
First Generation		Second Generation		Third Generation	
Symbol	Name	Symbol	Name	Symbol	Name
u	up quark	c	charm quark	t	top quark
d	down quark	s	strange quark	b	bottom quark
e	electron	μ	muon	τ	tau
ν_e	electron neutrino	ν_μ	muon neutrino	ν_τ	tau neutrino

Force Particles		
Symbol	Name	Remarks
γ	Photon	better known to us as "light"; neutral; carries electromagnetic force
W,Z	W and Z bosons	very heavy; W is charged, Z is neutral; carry the weak nuclear force
g	gluon	carries the strong nuclear force, comes in 8 color combinations
G	graviton	hypothesized mediator of gravitation; never observed

Particle Concepts Roadmap

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



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)

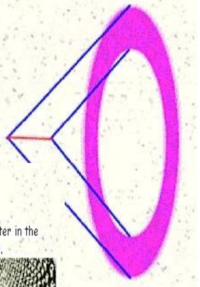
The electron neutrino (a lepton) was postulated in 1930 by Fermi to avoid a violation of conservation of energy and momentum during beta decay. It was not experimentally observed until 1953. It is thought that neutrinos left over from the Big Bang are the most abundant particles in the universe. Solar 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."***

Cherenkov Light

Below: Illustration of the conical geometry of Cherenkov radiation.

To detect the high-energy particles which result from neutrino interactions, Super-Kamiokande exploits a phenomenon known as Cherenkov radiation.

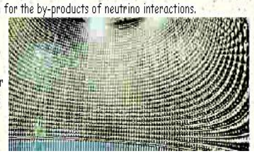
Charged particles (and only charged particles) traversing the water with a velocity greater than 75% of the speed of light radiate light in a conical pattern around the direction of the track, as at left. Bluish Cherenkov light is transmitted through the highly-pure water of the tank, and eventually falls on the inner wall of the detector, which is covered with photo-multiplier tubes (PMT's). These PMT's are each sensitive to illumination by a single photon of light - a light level approximately the same as the light visible on Earth from a candle at the distance of the moon!

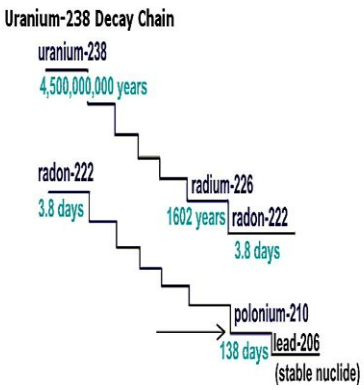


The Detector

The Super-Kamiokande detector is a 50,000 ton tank of water, located approximately 1 km underground. The water in the tank acts as both the target for neutrinos, and the detecting medium for the by-products of neutrino interactions.

The inside surface of the tank is lined with 11,146 50-cm diameter light collectors called "photo-multiplier tubes". In addition to the inner detector, which is used for physics studies, an additional layer of water called the outer detector is also instrumented light sensors to detect any charged particles entering the central volume, and to shield it by absorbing any neutrons produced in the nearby rock.

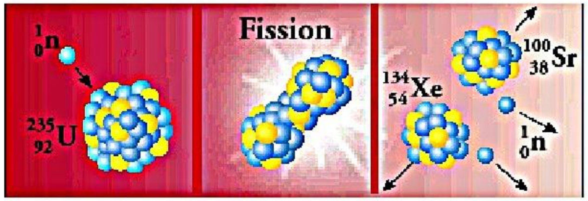




URANIUM 238 (U238) RADIOACTIVE DECAY

type of radiation	nuclide	half-life
	uranium—238	4.5 x10^9 years
α	thorium—234	24.5 days
β	protactinium—234	1.14 minutes
β	uranium—234	2.33 x10^5 years
α	thorium—230	8.3 x10^4 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 x10^{-4} seconds
α	lead—210	22 years
β	bismuth—210	5 days
β	polonium—210	140 days
α	lead—206	stable

Nuclear Fission Energy



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

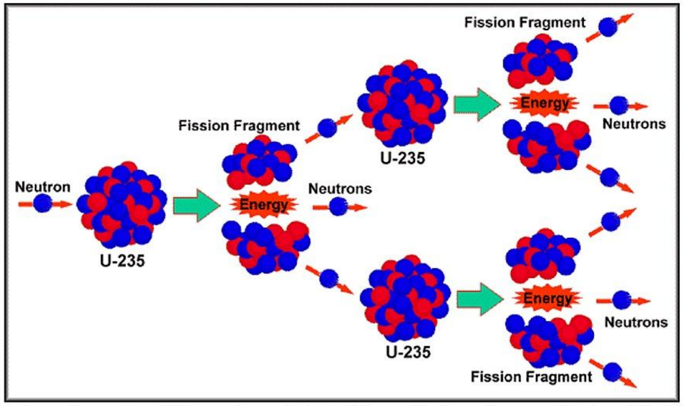
The relevant nuclear reactions can be written as follows:

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

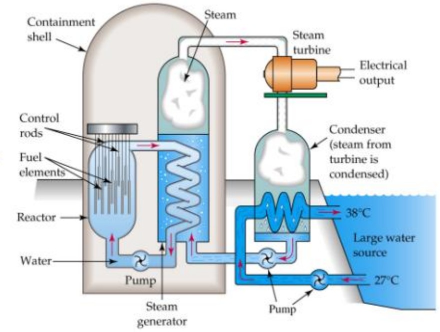
$$^{238}U + {}^{1}n \rightarrow {}^{239}U + \text{gamma rays} \quad (2)$$

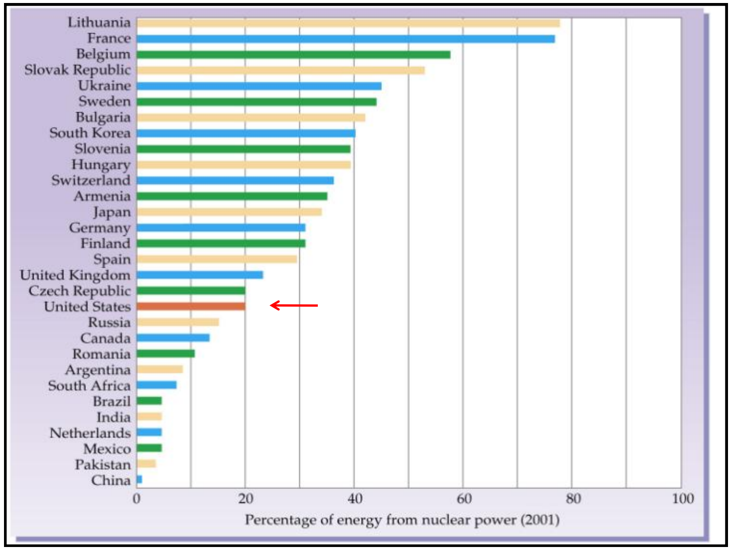
$$^{239}U \rightarrow {}^{239}Np \rightarrow {}^{239}Pu \quad \text{(a series of beta decays).} \quad (3)$$

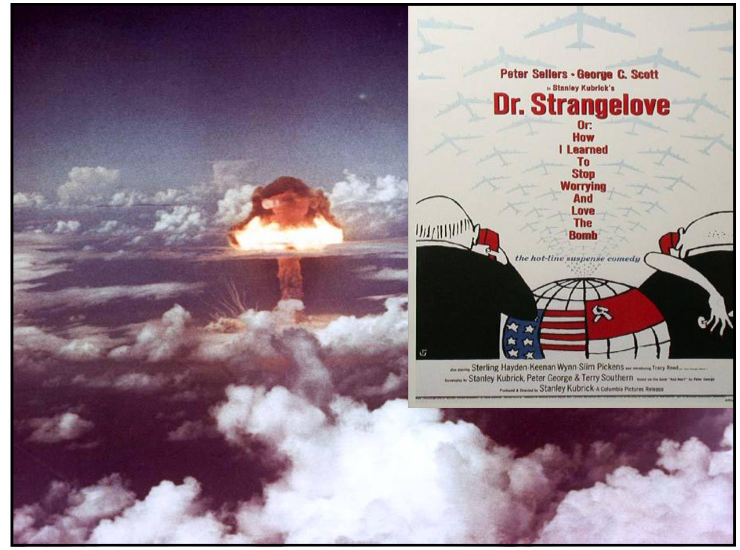
Nuclear Wall Chart - Lawrence Berkeley National Laboratory
Contemporary Physics Education Project (CPEP)

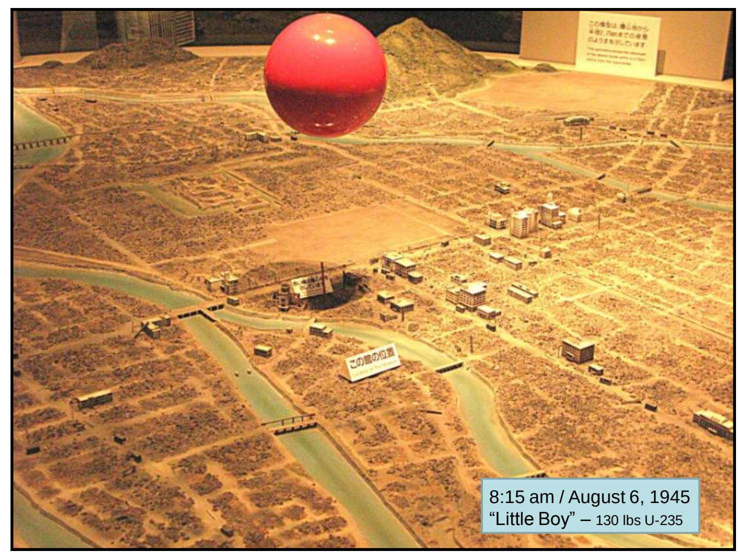


Fission of uranium 235 nucleus. Adapted from *Nuclear Energy. Nuclear Waste**.




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
0
20
40
60
80
100
Percentage of energy from nuclear power (2001)


Peter Sellers · George C. Scott
Dr. Strangelove
Or: How I Learned To Stop Worrying And Love The Bomb
the hot-line suspense comedy


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

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,

$$E = mc^2$$

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.

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.

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

$$I = I_0 e^{-\lambda t}$$

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?**

What is a "half-life"?

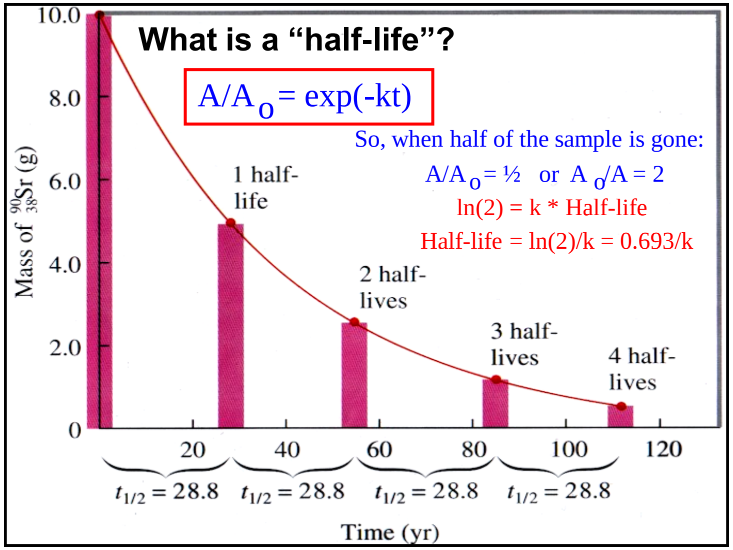
$A/A_o = \exp(-kt)$

So, when half of the sample is gone:

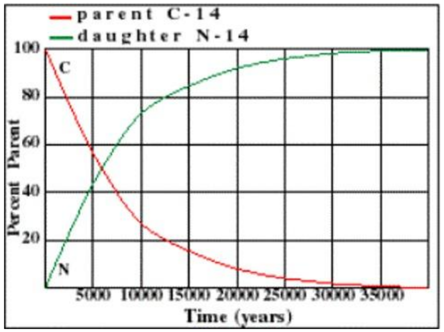
$A/A_o = ½$ or $A_o/A = 2$

ln(2) = k * Half-life

Half-life = ln(2)/k = 0.693/k

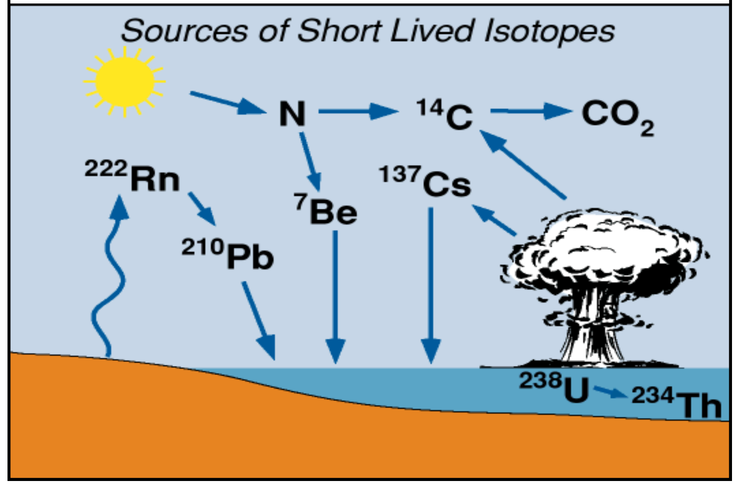


Carbon-14 Decay



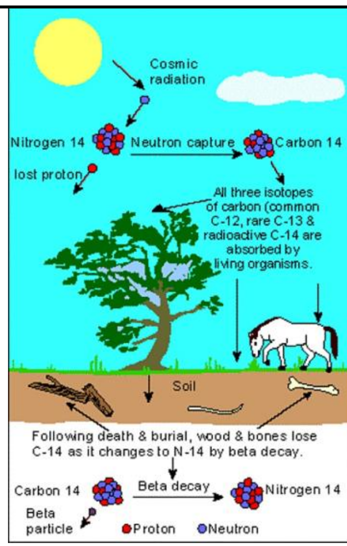
Half-life of C-14 is ~5730 years

Where does carbon-14 come from?



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.



RADIOCARBON DATING 601

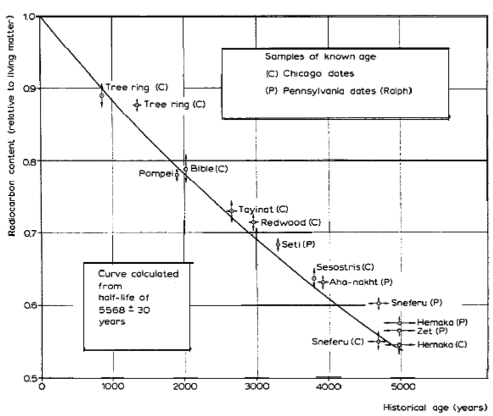


Fig. 3. Curve of Knowns.

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

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)

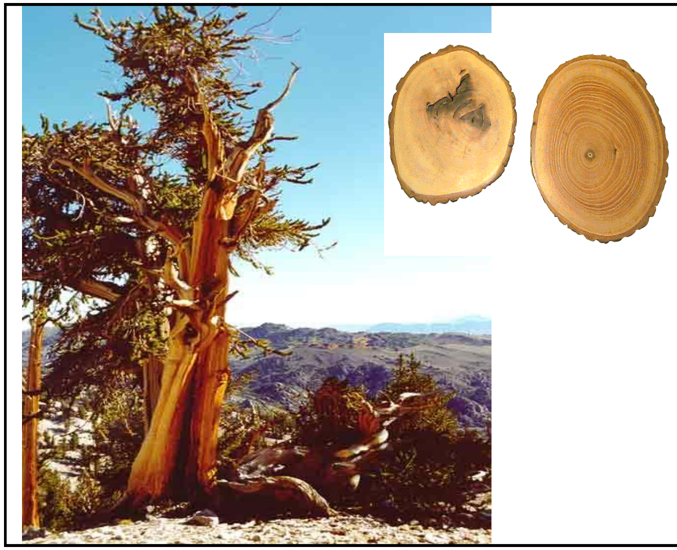
2. Over time, the abundance of carbon-14 in the atmosphere has undergone variations. These result directly from fluctuations in the flux of cosmic rays, burning of fossil fuels and atmospheric testing of nuclear bombs in the period following WWII.
   ????????

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.



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.

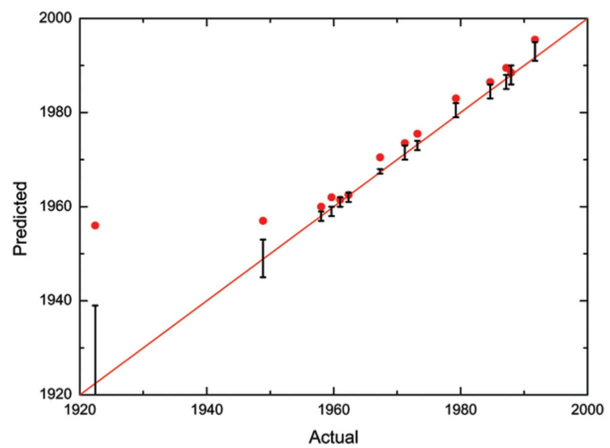


Figure 2. Predicting the year of birth by the ^{14}C of eye lens crystallines.

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

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:

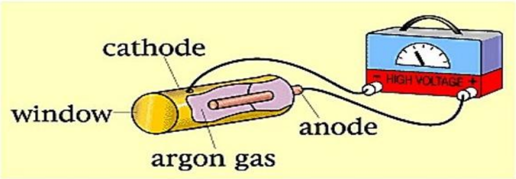
$$\text{95\% Confidence Interval: } \left(C - 1.96\sqrt{C}\right) \text{ to } \left(C + 1.96\sqrt{C}\right)$$

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!

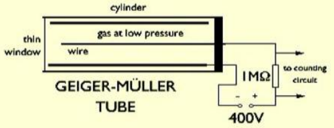
Geiger moved from England to teach in Germany in 1907 and quickly he perfected an automatic way to count these particles (tic tic tic tic ….).

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

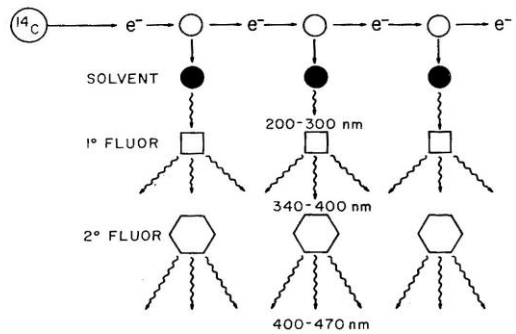
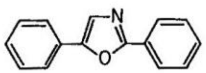


Figure 3-2. Interaction of β particles with aromatic solvents and subsequent fluor excitation. e^- represents the emitted β particles, ○ indicates a solvent molecule in its ground state, and ● denotes solvent molecules in the triplet state. (From E. Rapkin, *Preparation of Samples for Liquid Scintillation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

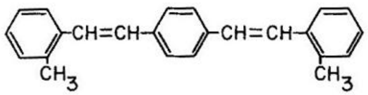


PPO

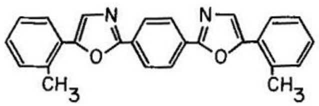
$\lambda_f \sim 365/380$

2,5-diphenyloxazole

(phenyl-oxazole-phenyl)



bis-MSB



dimethyl-POPOP

$\lambda_f \sim 420/441$

Photomultiplier Tubes

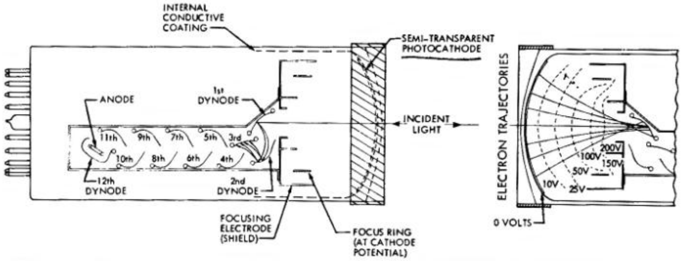


Figure 3-8. Beckman-RCA Bialkali 12-stage Photomultiplier Tube. (Courtesy of Beckman Instruments, Inc., Instruction Manual 1553-D.)

$\sim 10^{-9}$ seconds

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

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

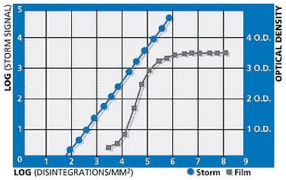
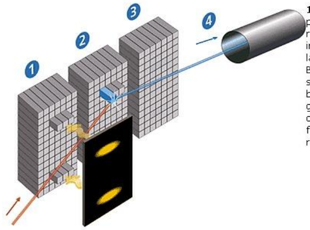


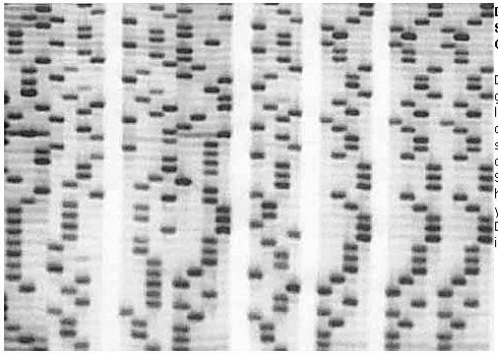
Fig 1. With five orders of linear dynamic range, Storm captures the image from both strong and weak signals in a single exposure. The Storm system's linear dynamic range is 1000 times greater than film.

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.

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.)***

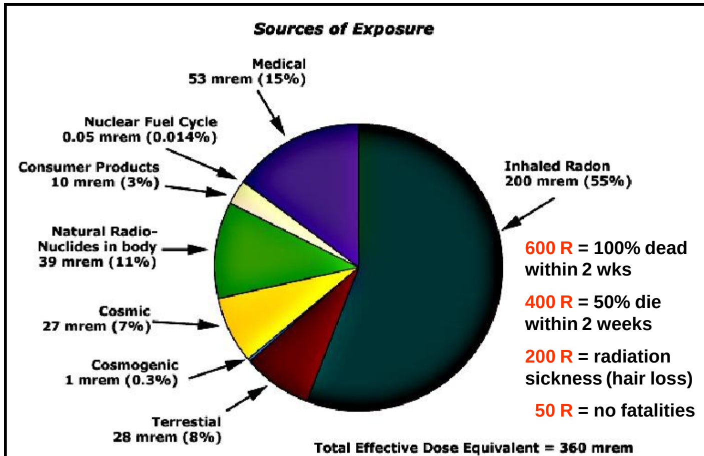
1 Sv = 100 rem**. **1 rem is the average dose received in 3 years of exposure to natural radiation.

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.



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