Radiation / Radioactivity / Radioactive Decay
Radioactive Particles / Common Isotopes
Counting

Common Radio isotopes

Common Carbon 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:

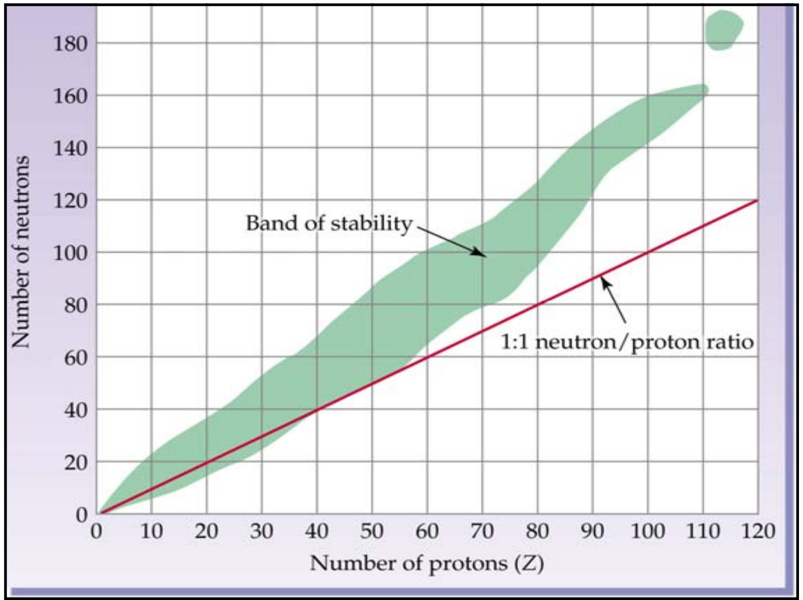
C-14 dating

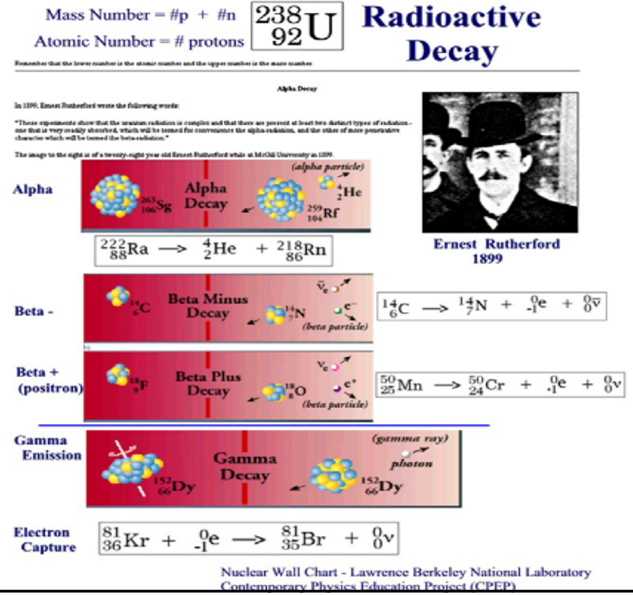
Half-life and equations

Counting: Understand the basis (+/-) of Film vs.

Geiger Counter vs. LSC vs. PI

Terms: Radioactivity / Exposure / Dose





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.

Alpha

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

Ernest Rutherford
1899

Beta -

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

Beta +
(positron)

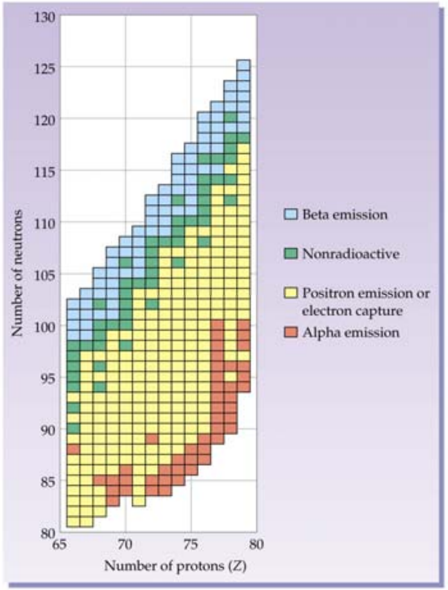
$^{50}_{25}Mn \longrightarrow {}^{50}_{24}Cr + {}^{0}_{+1}e + {}^{0}_{0}v$

Gamma Emission

Electron Capture

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

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



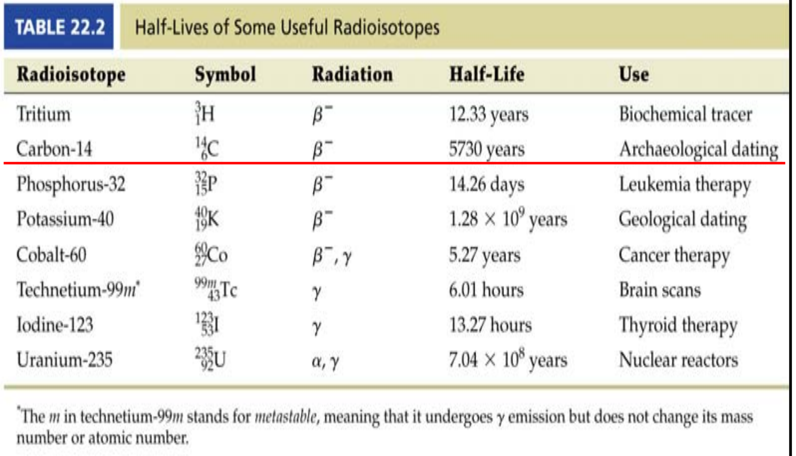


TABLE 22.2 Half-Lives of Some Useful Radioisotopes

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

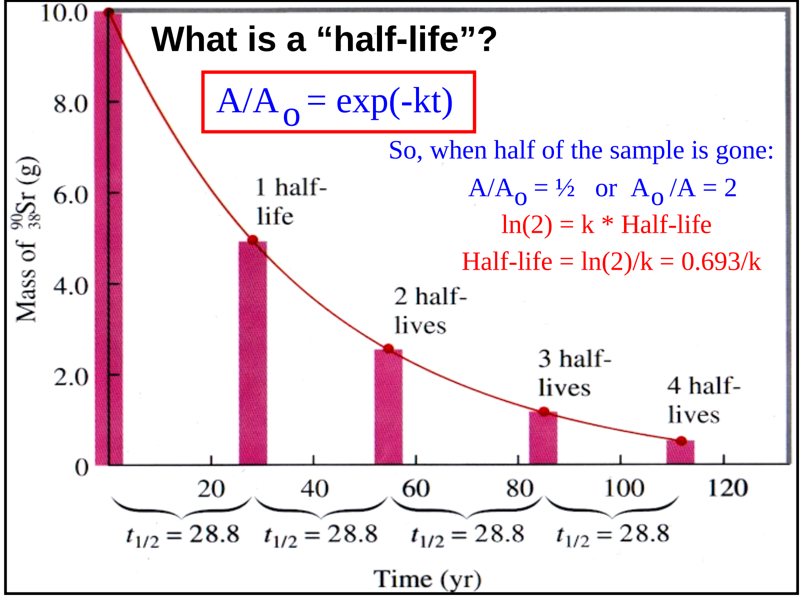
Relative abundance of these isotopes in atmospheric CO_2

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”?



$$\boxed{A/A_o = \exp(-kt)}$$

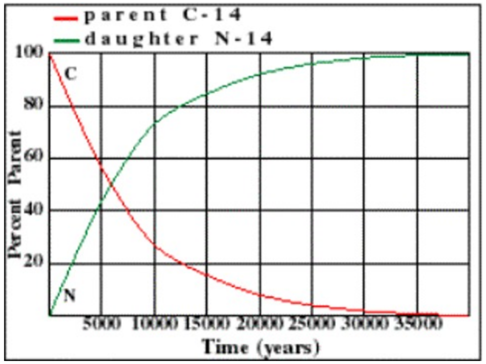
So, when half of the sample is gone:

$A/A_o = ½$ or $A_o/A = 2$

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

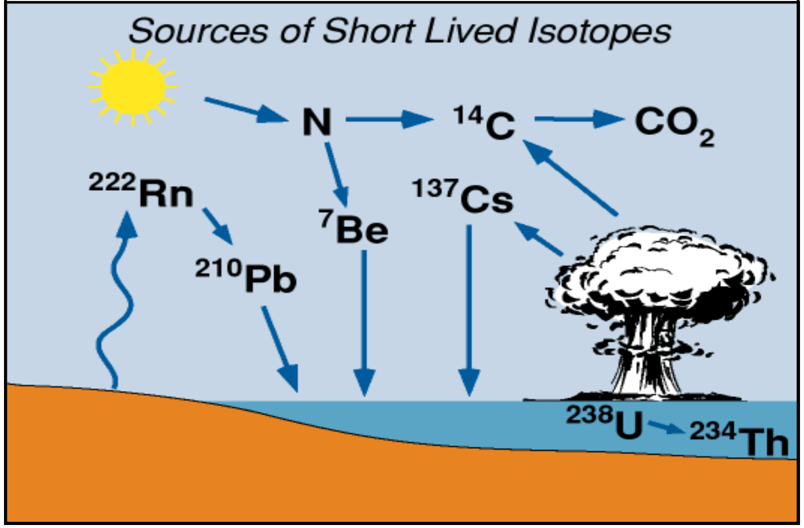
$\text{Half-life} = \ln(2)/k = 0.693/k$

Carbon-14 Decay



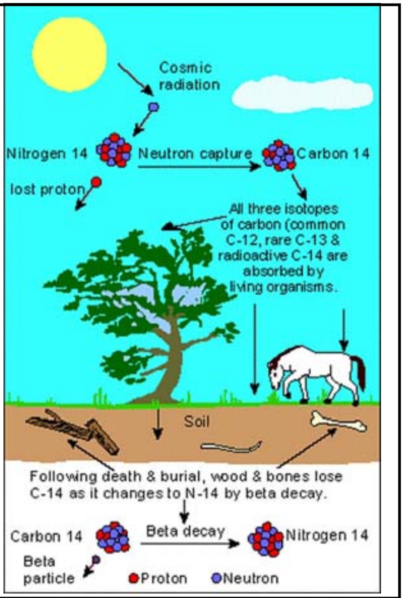
Half-life of C-14 is ~5730 years

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.



Determining the age of a specimen

$T = 8033 \ln (L/R)$

T : Time, in years, since death
R : C-14/C-12 ratio in sample
L : Atmospheric ratio

(ln : Natural logarithm)

RADIOCARBON DATING 601

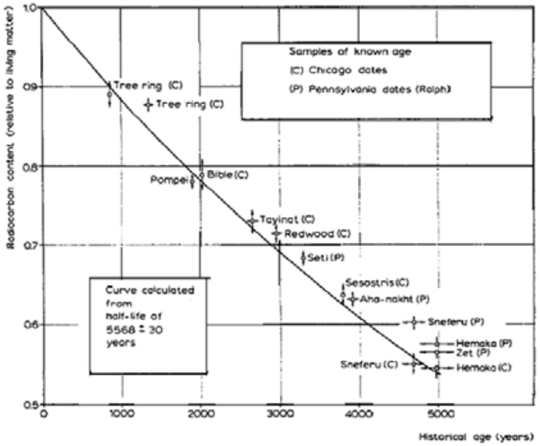


Fig. 3. Curve of Knowns.

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

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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)

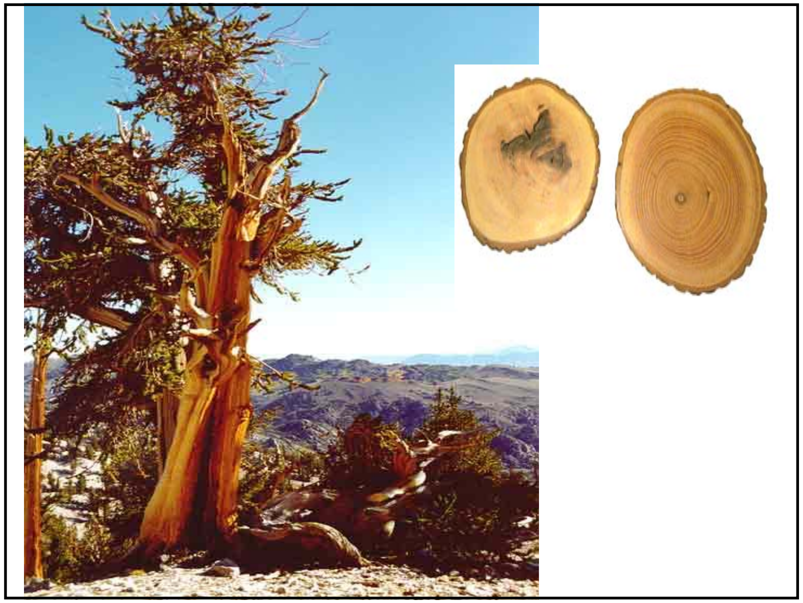
2. Over time, the abundance of carbon-14 in the atmosphere has undergone variations. These result directly from fluctuations in the flux of cosmic rays, burning of fossil fuels and atmospheric testing of nuclear bombs in the period following WWII.
   ????????

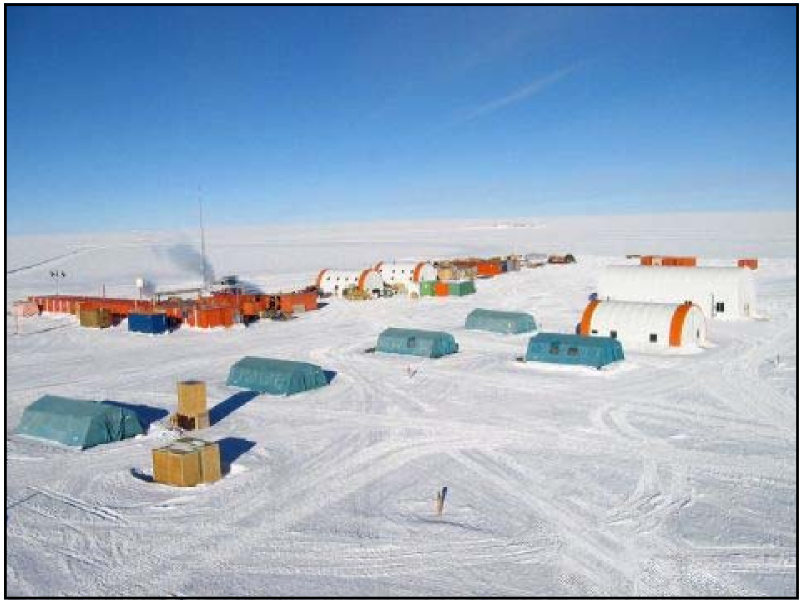
Solution:

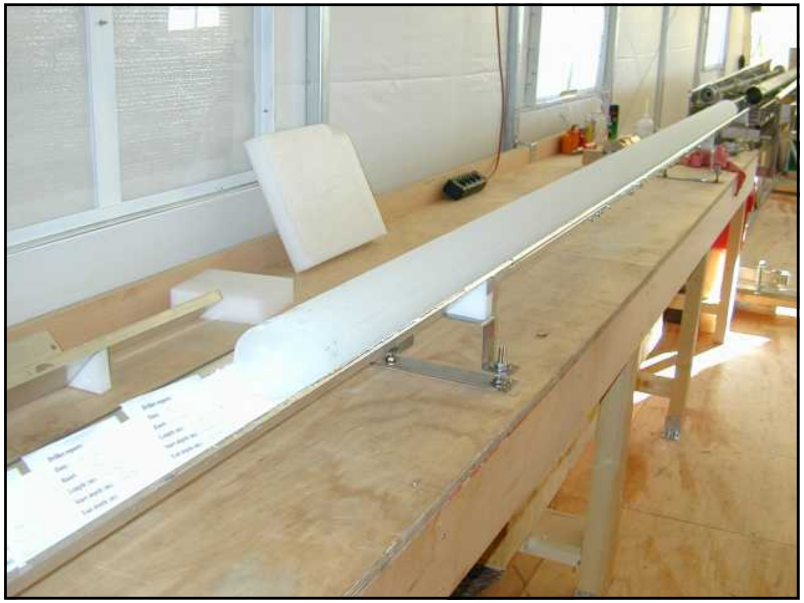
Measure C14/C12 ratio in samples of KNOWN ages.

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.

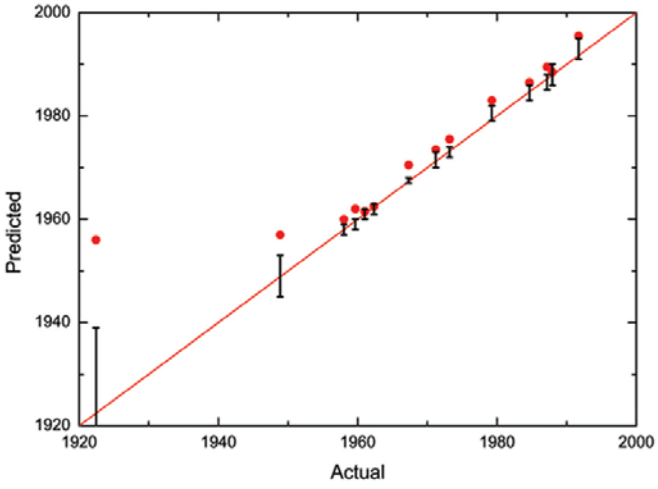


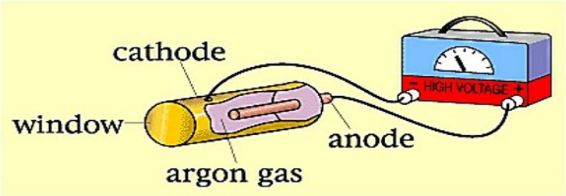
Figure 2. Predicting the year of birth by the ^{14}C of eye lens crystallines.

Counting Radioactivity

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

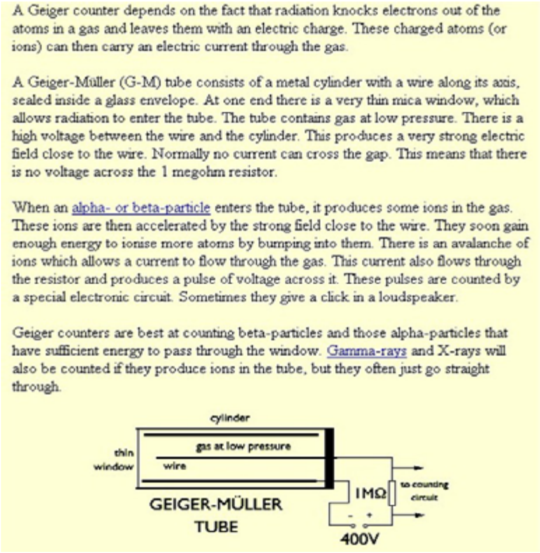
Geiger Counters

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

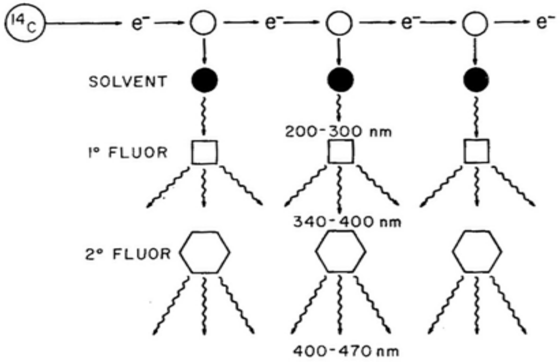
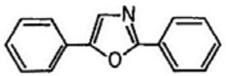


Figure 3-2. Interaction of β particles with aromatic solvents and subsequent fluor excitation. e^- represents the emitted β particles, ○ indicates a solvent molecule in its ground state, and ● denotes solvent molecules in the triplet state. (From E. Rapkin, *Preparation of Samples for Liquid Scintillation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

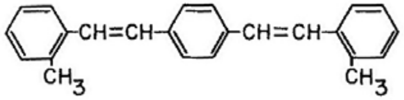


PPO

$\lambda_f \sim 365 / 380$

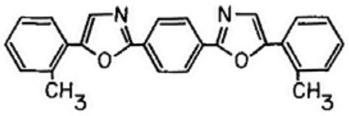
2,5-diphenyloxazole

(phenyl-oxazole-phenyl)



bis-MSB

$\lambda_f \sim 420 / 441$



dimethyl-POPOP

Photomultiplier Tubes

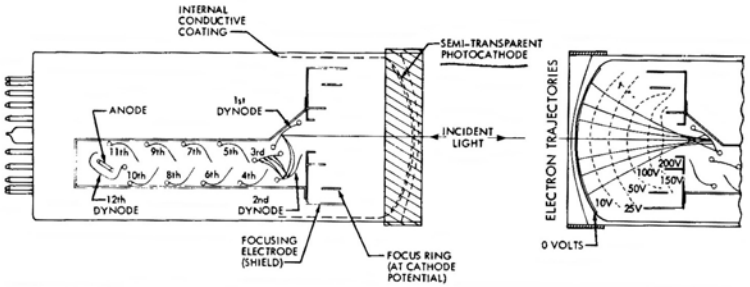


Figure 3-8. Beckman-RCA Bialkali 12-stage Photomultiplier Tube. (Courtesy of Beckman Instruments, Inc., Instruction Manual 1553-D.)

~ 10^{-9} seconds

3-5 e^- / e^- / dynode

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

PhosphorImager

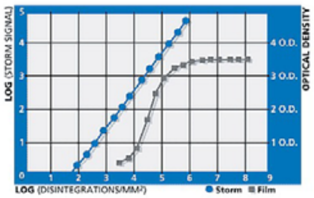
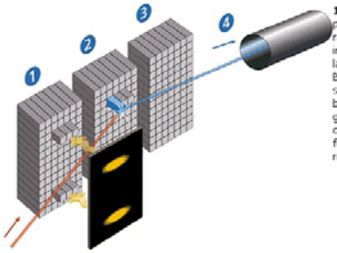
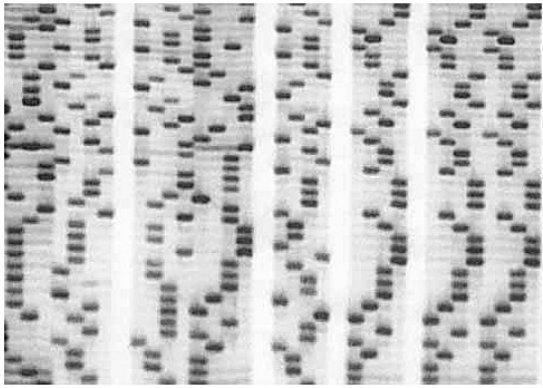


Fig 1. With five orders of linear dynamic range, Storm captures the image from both strong and weak signals in a single exposure. The Storm system's linear dynamic range is 1000 times greater than film.

How storage phosphor works



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:

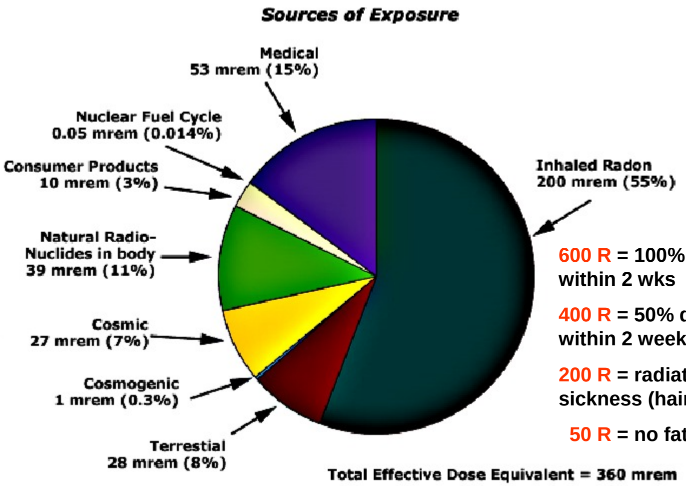
Roentgen - It is the **amount of radiation** required to liberate positive and negative charges of one esu of charge in 1 cm*3 at STP. This corresponds to the generation of approximately **2.08×10^9 ion pairs.**

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**.*



Sources of Exposure

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%)