1

The Shroud of Turin 2

- Supposed burial garment of Christ.
- Linen cloth $\approx 14' \times 14'$ with two faint images of the front and back of a $5'7''$ man bearing markings corresponding to thorn marks, lacerations (from flogging), bruises, and blood stains.
- First emerged in 1354 carried by Sir Geoffroi de Charny seigneur de Lirey, a knight.
- Public exhibitions started in 1389 (and charged an entrance fee).
- Moved to the royal chapel of the Cathedral of San Giovanni Battista in Turin, Sicily in 1578.
- Original exhibitions were sanctioned by the pope as a 'representation' of the true Shroud.
- Since then no pope has challenged its authenticity.
- Dating the Shroud
  - Images look like photographic negatives.
  - Tests begun in the early 1970's were inconclusive.
  - The church only permitted small amounts of the Shroud to be dated.
  - In 1989 the Shroud was dated using radiocarbon methods.

How Old is the Shroud of Turin? 3

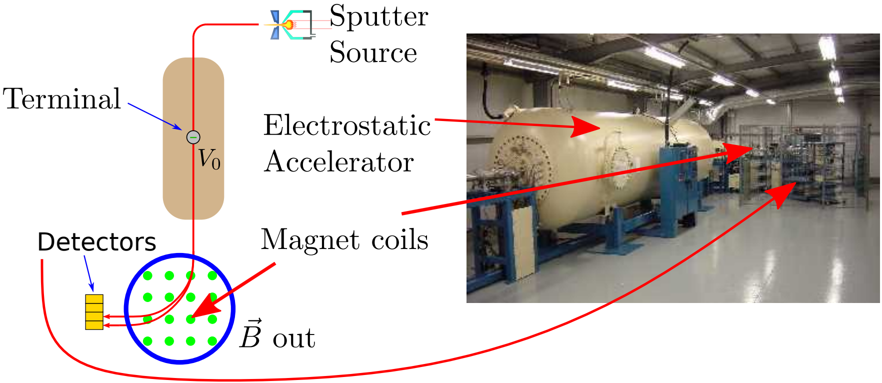
How Old is the Shroud of Turin? 4

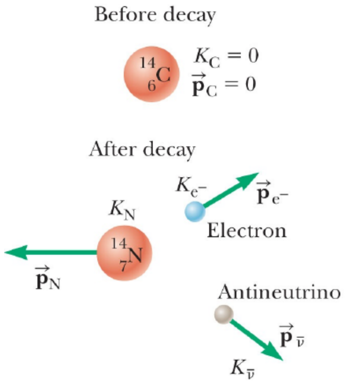
- Mass Spectrometry

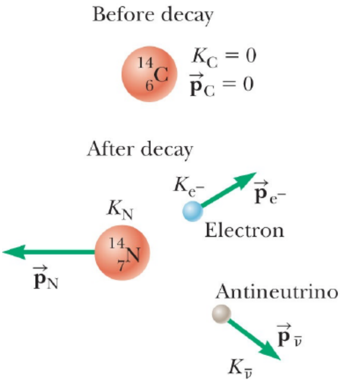
How Old is the Shroud of Turin? 5

- Mass Spectrometry
- Radiocarbon Dating.

A Mass Spectrometer

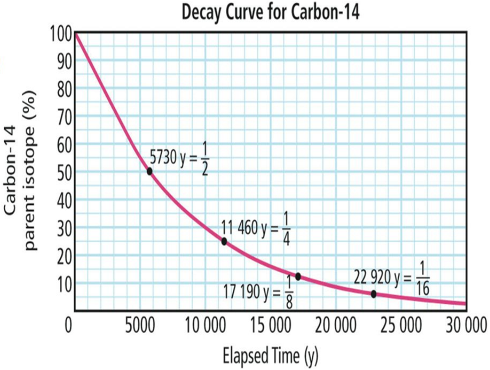



Before decay
$^{14}_{6}C$
$K_C = 0$
$\vec{p}_C = 0$
After decay
K_{e^-}
$\vec{p}_{e^-}$
Electron
K_N
$^{14}_{7}N$
$\vec{p}_N$
Antineutrino
$\vec{p}_{\bar{\nu}}$
$K_{\bar{\nu}}$



Carbon Ratios

$^{12}_{6}C$	$^{13}_{6}C$	$^{14}_{6}C$
98.89%	1.11%	10^{-10}%

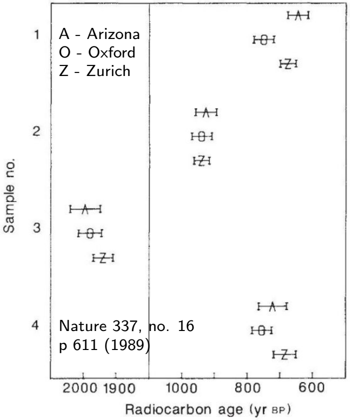


The radioactive isotope $^{14}\mathrm{C}$ decays via

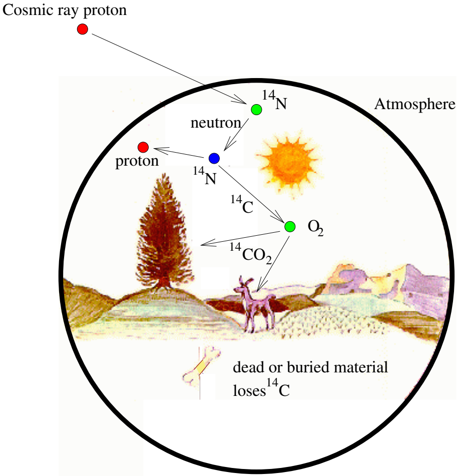
$$^{14}\mathrm{C} \rightarrow {}^{14}\mathrm{N} + \beta^- + \overline{\nu}$$

where β^- is an electron and $\overline{\nu}$ is a particle called the neutrino. The ratio $R_\mathrm{C} = {}^{14}\mathrm{C}/{}^{12}\mathrm{C}$ was measured in 1989 to determine the age of the shroud. The results are shown here. The shroud is sample 1. The other samples are controls. Ages are in years BP (before 1950). Note the break in the age scale.

How old is the shroud? The typical uncertainty in these measurements is about 40 years. Are the results of the three labs consistent?



Laboratory	R
Arizona	1.20×10^{-12}
Oxford	1.18×10^{-12}
Zurich	1.19×10^{-12}



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Reaction Chain

$$^{14}_{7}\mathrm{N} + ^{1}_{1}\mathrm{H} \rightarrow ^{14}_{8}\mathrm{O} + ^{1}_{0}\mathrm{n}$$

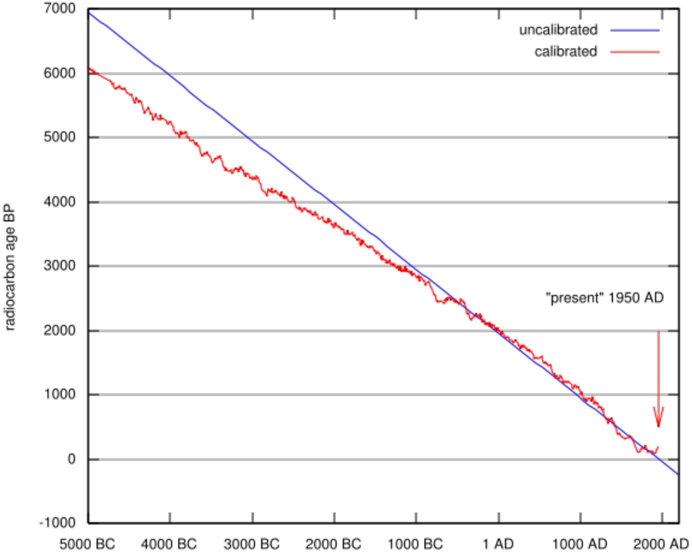
$$^{14}_{8}\mathrm{O} \rightarrow ^{14}_{7}\mathrm{N} + e^{+} + \overline{\nu}$$

$$^{14}_{7}\mathrm{N} + ^{1}_{0}\mathrm{n} \rightarrow ^{14}_{6}\mathrm{C} + ^{1}_{1}\mathrm{H}$$

$$^{14}_{7}\mathrm{N} \rightarrow ^{14}_{6}\mathrm{C} + e^{+} + \overline{\nu}$$

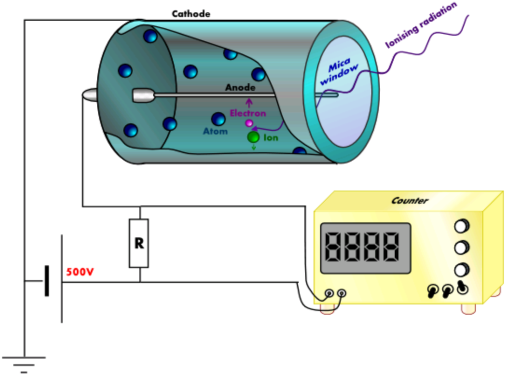
						2 He Helium
	5 B Boron	6 C Carbon	7 N Nitrogen	8 O Oxygen	9 F Fluorine	10 Ne Neon
	13 Al Aluminium	14 Si Silicon	15 P Phosphorus	16 S Sulfur	17 Cl Chlorine	18 Ar Argon
30 Zn Zinc	31 Ga Gallium	32 Ge Germanium	33 As Arsenic	34 Se Selenium	35 Br Bromine	36 Kr Krypton
48 Cd Cadmium	49 In Indium	50 Sn Tin	51 Sb Antimony	52 Te Tellurium	53 I Iodine	54 Xe Xenon

Radiocarbon Calibration Curve



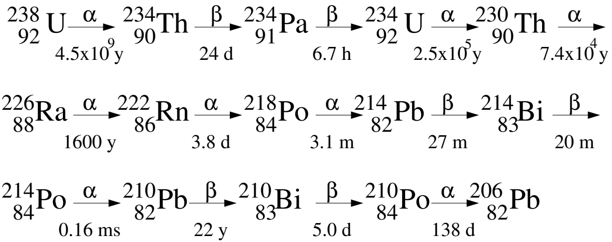
A freshly prepared sample of a radioactive isotope has an activity of $R_0 = 3.7 \times 10^8 \text{ decays/s}$. After a time $\Delta t = 4$ *hr* the activity has dropped to $R_1 = 3.0 \times 10^8 \text{ decays/s}$. What is the decay constant?

A Geiger-Muller tube (or GM tube) is the sensing element of a Geiger counter instrument that can detect a single particle of ionizing radiation. It is a type of gaseous ionization detector with an operating voltage on the Geiger plateau.



The Age of the Earth 14

The figure below shows the decay scheme for $^{238}\mathrm{U}$ which can be approximated as $^{238}\mathrm{U} \rightarrow {}^{206}\mathrm{Pb} +$ other decay products where the half-life is determined by that first step. Why? A rock is found containing $m_U = 0.0042$ kg of $^{238}\mathrm{U}$ and $m_{Pb} = 0.0024$ kg of $^{206}\mathrm{Pb}$. Assume the rock contained no lead at all when it was formed so all the lead present is from the decay of uranium. What is the age of the rock? What does this say about the age of the Earth?



The figure below shows … which can be approximated as $^{238}\mathrm{U}$ – … ucts where the half-life is determined by that fi… und containing $m_U = 0.0042\ kg$ of ^{238}… $^{206}\mathrm{Pb}$. Assume the rock contained no lead … all the lead present is from the decay of urani… rock? What does this say about the age of th…

$^{238}_{92}\mathrm{U} \xrightarrow[4.5\times10^{9}\,y]{\alpha}$ … $^{230}_{90}\mathrm{Th} \xrightarrow[7.4\times10^{4}\,y]{\alpha}$

$^{226}_{88}\mathrm{Ra} \xrightarrow[1600\,y]{\alpha}$ … $^{214}_{83}\mathrm{Bi} \xrightarrow[20\,m]{\beta}$

$^{214}_{84}\mathrm{Po} \xrightarrow[0.16\,ms]{\alpha} {}^{210}_{82}\mathrm{Pb} \xrightarrow[22\,y]{\beta} {}^{210}_{83}\mathrm{Bi} \xrightarrow[5.0\,d]{\beta} {}^{210}_{84}\mathrm{Po} \xrightarrow[138\,d]{\alpha} {}^{206}_{82}\mathrm{Pb}$

After the sudden release of radioactivity from the Chernobyl nuclear reactor accident in 1986, the radioactivity of milk in Poland rose to $R_{\mathcal{I}} = 1500\ Bq/L$ due to iodine-131 present in the grass eaten by dairy cattle ($1\ Bq = 1\ \mathrm{decay/s}$). Radioactive iodine, with half-life $t_{\mathcal{I}} = 8.04\ days$, is particularly hazardous because the thyroid gland concentrates iodine. The Chernobyl accident caused a measurable increase in thyroid cancers among children in Belarus. (a) For comparison, find the activity $\mathcal{R}_{\mathrm{K}}$ of milk due to potassium. Assume that one liter of milk contains a mass $m_K = 2.5\ g$ of potassium, of which a fraction $f = 0.0117\%$ is the isotope $^{40}\mathrm{K}$ which beta decays with half-life $t_{\mathcal{K}} = 1.28 \times 10^9\ yr$. (b) After what time interval would the activity due to iodine fall below that due to potassium?

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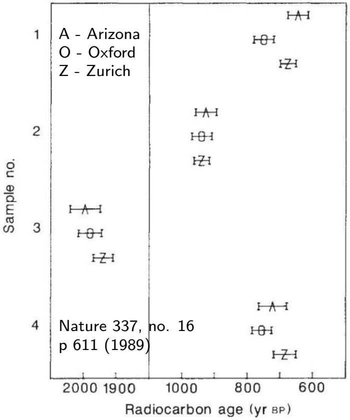

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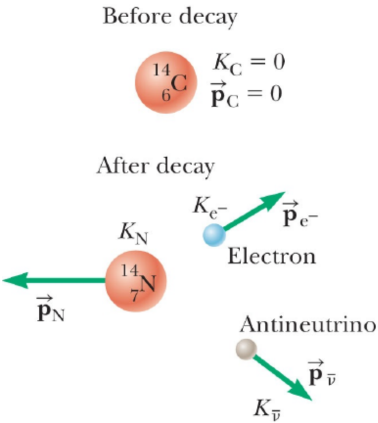

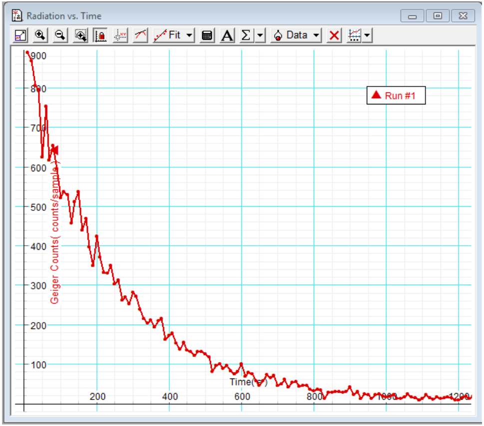

^{14}C decay

^{137}Ba decay

hydrogen 1 H 1.0079																		helium 2 He 4.0026
lithium 3 Li 6.941	beryllium 4 Be 9.0122												boron 5 B 10.811	carbon 6 C 12.011	nitrogen 7 N 14.007	oxygen 8 O 15.999	fluorine 9 F 18.998	neon 10 Ne 20.180
sodium 11 Na 22.990	magnesium 12 Mg 24.305												aluminium 13 Al 26.982	silicon 14 Si 28.086	phosphorus 15 P 30.974	sulfur 16 S 32.065	chlorine 17 Cl 35.453	argon 18 Ar 39.948
potassium 19 K 39.098	calcium 20 Ca 40.078		scandium 21 Sc 44.956	titanium 22 Ti 47.867	vanadium 23 V 50.942	chromium 24 Cr 51.996	manganese 25 Mn 54.938	iron 26 Fe 55.845	cobalt 27 Co 58.933	nickel 28 Ni 58.693	copper 29 Cu 63.546	zinc 30 Zn 65.39	gallium 31 Ga 69.723	germanium 32 Ge 72.61	arsenic 33 As 74.922	selenium 34 Se 78.96	bromine 35 Br 79.904	krypton 36 Kr 83.80
rubidium 37 Rb 85.468	strontium 38 Sr 87.62		yttrium 39 Y 88.906	zirconium 40 Zr 91.224	niobium 41 Nb 92.906	molybdenum 42 Mo 95.94	technetium 43 Tc [98]	ruthenium 44 Ru 101.07	rhodium 45 Rh 102.91	palladium 46 Pd 106.42	silver 47 Ag 107.87	cadmium 48 Cd 112.41	indium 49 In 114.82	tin 50 Sn 118.71	antimony 51 Sb 121.76	tellurium 52 Te 127.60	iodine 53 I 126.90	xenon 54 Xe 131.29
caesium 55 Cs 132.91	barium 56 Ba 137.33	57-70 *	lutetium 71 Lu 174.97	hafnium 72 Hf 178.49	tantalum 73 Ta 180.95	tungsten 74 W 183.84	rhenium 75 Re 186.21	osmium 76 Os 190.23	iridium 77 Ir 192.22	platinum 78 Pt 195.08	gold 79 Au 196.97	mercury 80 Hg 200.59	thallium 81 Tl 204.38	lead 82 Pb 207.2	bismuth 83 Bi 208.98	polonium 84 Po [209]	astatine 85 At [210]	radon 86 Rn [222]
francium 87 Fr [223]	radium 88 Ra [226]	89-102 * *	lawrencium 103 Lr [262]	rutherfordium 104 Rf [261]	dubnium 105 Db [262]	seaborgium 106 Sg [266]	bohrium 107 Bh [264]	hassium 108 Hs [269]	meitnerium 109 Mt [268]	ununnilium 110 Uun [271]	unununium 111 Uuu [272]	ununbium 112 Uub [277]		ununquadium 114 Uuq [289]				

*Lanthanide series	lanthanum 57 La 138.91	cerium 58 Ce 140.12	praseodymium 59 Pr 140.91	neodymium 60 Nd 144.24	promethium 61 Pm [145]	samarium 62 Sm 150.36	europium 63 Eu 151.96	gadolinium 64 Gd 157.25	terbium 65 Tb 158.93	dysprosium 66 Dy 162.50	holmium 67 Ho 164.93	erbium 68 Er 167.26	thulium 69 Tm 168.93	ytterbium 70 Yb 173.04
* *Actinide series	actinium 89 Ac [227]	thorium 90 Th 232.04	protactinium 91 Pa 231.04	uranium 92 U 238.03	neptunium 93 Np [237]	plutonium 94 Pu [244]	americium 95 Am [243]	curium 96 Cm [247]	berkelium 97 Bk [247]	californium 98 Cf [251]	einsteinium 99 Es [252]	fermium 100 Fm [257]	mendelevium 101 Md [258]	nobelium 102 No [259]

Video is here.

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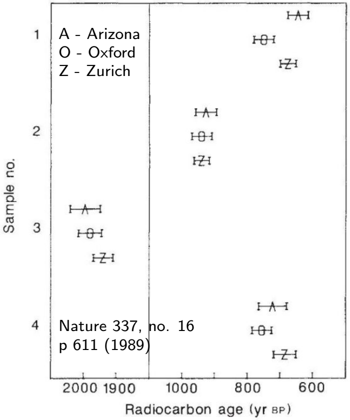

Laboratory	R
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Appendix H: Nuclear Safety

All of the radioactive sources we will use in class are very low-level isotopes referred to as "license-free" sources. The following guidelines should be followed for handling radioactive materials in the classroom.

1. Eating, drinking, and application of cosmetics in the laboratory are not permitted.
2. Pipetting by mouth is never permitted. Use suction devices such as pipette filters.
3. Gloves and lab coats should be worn when working with all liquid isotopes.
4. Before leaving the lab, wash your hands thoroughly and check for possible contamination with a survey instrument.
5. All radioactive liquid wastes are to be poured into the liquid waste container, NEVER into a sink.
6. Report all spills, wounds, or other emergencies to your instructor.
7. Maintain good housekeeping at all times in the lab.
8. Store radioactive material only in the designated storage area. Do not remove sources from the lab.