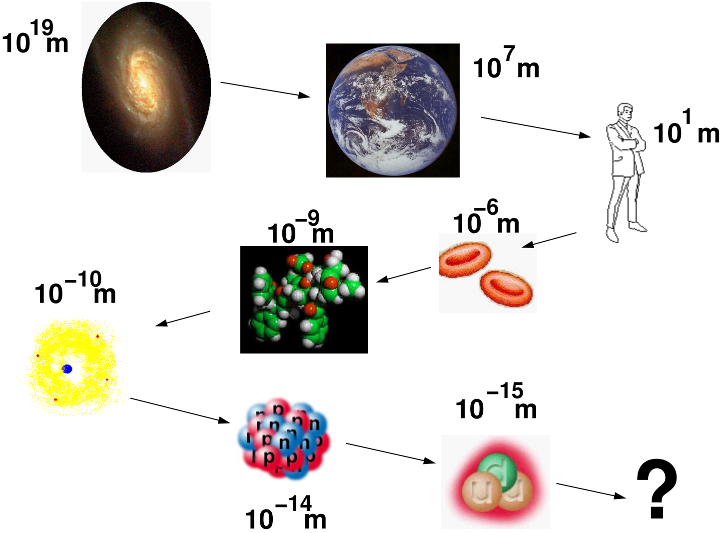
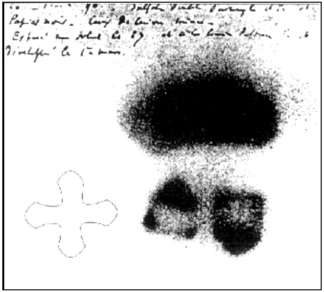
The Structure of Matter



Radioactivity and Nuclear Decay

- At the end of the nineteenth century Henri Becquerel discovers the spontaneous emission of ‘rays’.
- The surprise was that no energy input was required.
- These rays carry off huge amounts of energy.
- Some examples of ‘rays’.



Original Photographic Plate Developed by Henri Becquerel.

$$^{212}_{84}\mathrm{Po} \rightarrow {}^{208}_{82}\mathrm{Pb} + {}^{4}_{2}\mathrm{He}(\alpha)$$

$$^{212}_{83}\mathrm{Bi} \rightarrow {}^{212}_{84}\mathrm{Po} + e^{-}(\beta) + \bar{\nu}_e(\text{undetected})$$

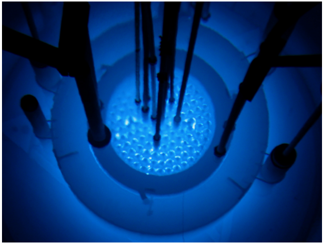
$$^{137}_{55}\mathrm{Cs} \rightarrow {}^{137}_{56}\mathrm{Ba}(0.662\ \mathrm{keV}) + e^{-} + \bar{\nu}_e(\text{undetected})$$

$$\hookrightarrow {}^{137}_{56}\mathrm{Ba}(0.0\ \mathrm{keV}) + \gamma$$

Why Should You Care?

1. Massive release of energy from a small amount of material.

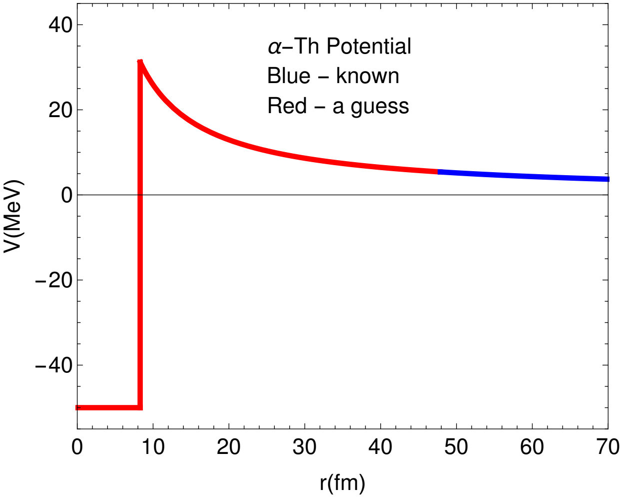
Weapons

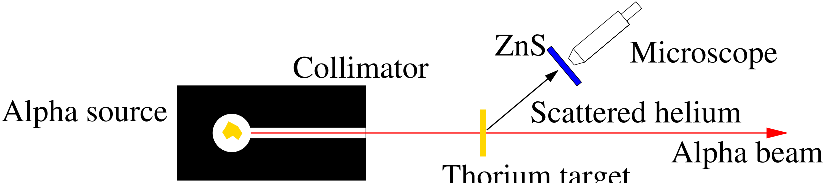


Energy source

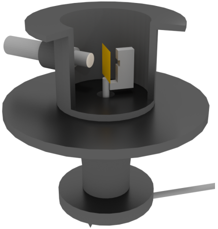
2. How can we explain it? $\longrightarrow$ Why does the Sun shine?
3. Gobs of current uses.
    1. Food treatments.
    2. Smoke detectors.
    3. Medical applications (PET scans).
    4. Environmental, medical, and biological monitoring.

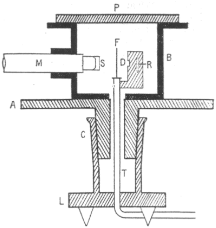
The $^{4}\mathrm{He} - {}^{234}_{90}\mathrm{Th}$ Potential



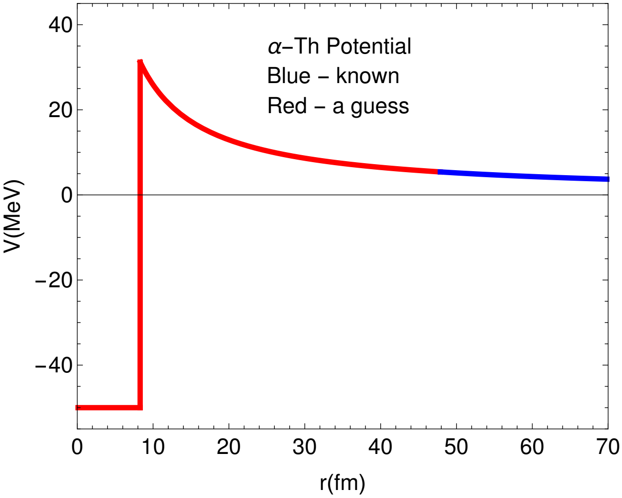


$$^{210}_{84}\mathrm{Po} \rightarrow {}^{4}_{2}\mathrm{He} + {}^{206}_{82}\mathrm{Pb}$$





The $^4\mathrm{He} - {}^{234}_{90}\mathrm{Th}$ Potential



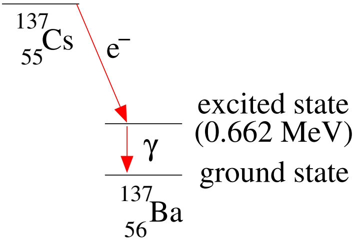
Milking the Cow

- This 'clock' ticks by producing a short-lived, radioactive material.
- Start with a liquid containing the radioactive isotope ^{137}Cs that decays very slowly.

$$^{137}\text{Cs} \rightarrow e^- + {}^{137}\text{Ba}(0.662\ \text{MeV})$$

- The number "0.662 MeV" means there is still energy (0.662 MeV) stored in the Ba-137 nucleus.
- The excited Ba-137 then emits a high-energy photon or gamma ray to reach the stable ground state of ^{137}Ba.

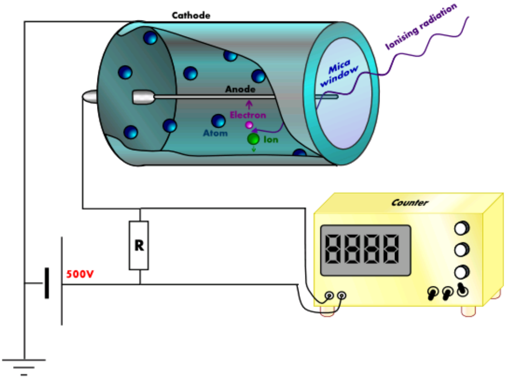
$$^{137}\text{Ba}(0.662) \rightarrow {}^{137}\text{Ba}(0.0) + \gamma$$



Decay scheme of cesium-137.

Geiger-Muller Tube

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 in the Geiger plateau.



Using the Reduced χ^2

The χ^2 and reduced χ^2 are defined as

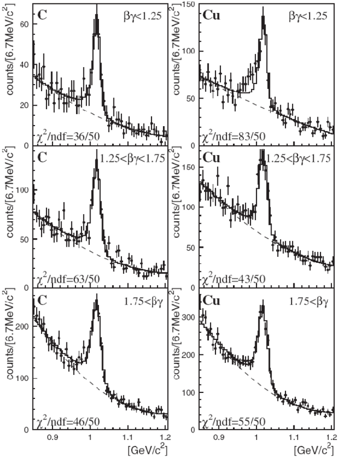
$$\chi^2 = \sum_{i=1}^{N} \frac{((y_i - f(x_i))^2}{\sigma_i^2}$$

and

$$reduced\ \chi^2 = \frac{\chi^2}{N - d.o.f}$$

where N is the number of data points. In *Mathematica* the estimated variance is equal to the reduced χ^2 if the proper weighting is used.

R. Muto, *et al.*, Phys. Rev. Lett., **98**, 042501 (2007).



Probability Distribution Functions

When Do You Use a Gaussian Probability Distribution Function?

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Do these conditions apply for radioactive decay?

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Do these conditions apply for radioactive decay? NO!

Poisson Statistics

$$P(m : n, p) = \frac{1}{m!}\mu^m e^{-\mu} \qquad \mu = np$$

m - no. of events μ - average n - no. of trials p - probability of an event

Probability of a discrete event occurring m times in a particular time period.

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Probability of a discrete event occurring m times in a particular time period.

- Number of soldiers killed by horse-kicks each year in Prussian cavalry corp (famous example in by a book of Ladislaus Josephovich Bortkiewicz (1868-1931)).
- Number of yeast cells for brewing Guinness (William Sealy Gosset (1876-1937)).
- The number of phone calls arriving at a call center per minute.
- The number of deaths per year in a given age group.
- The number of jumps in a stock price in a given time interval.
- The number of mutations in a given stretch of DNA after a certain amount of radiation.
- The proportion of cells infected at a given multiplicity of infection.

Probability Distributions

- Binomial distribution:

$$P(m; n, p) = \frac{n!}{m!(n-m)!} p^m q^{n-m} \qquad q = 1 - p$$

n - total number of events; m - number of events of probability p

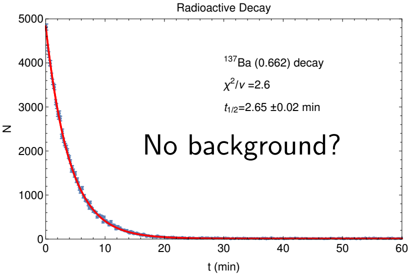
- For $p << 1$ one obtains the Poisson distribution

$$P(m; n, p) = \frac{1}{m!} \mu^m e^{-\mu} \qquad \mu = np$$

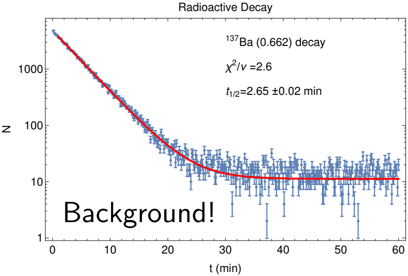
- What is the difference between a Gaussian distribution and a Poisson?
  Gaussian - random, independent, continuous variations.
  Poisson - discrete, random, positive variations.

Semi-log Plots

Time dependence of the $^{137}\mathrm{Ba}(0.662)$ decay on a linear scale.



Semi-log plot reveals the background is significant.



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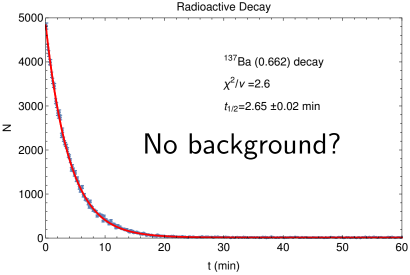

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