Week 5 Lecture 1 – Decay Processes

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Decay Processes

-- Alpha and Beta decay in everyday life

-- Alpha Decay revisited

--- Energetics & Tunneling

--- Angular momentum

-- Beta Decay revisited

3rd Homework due today

Ionization-based Smoke Detectors

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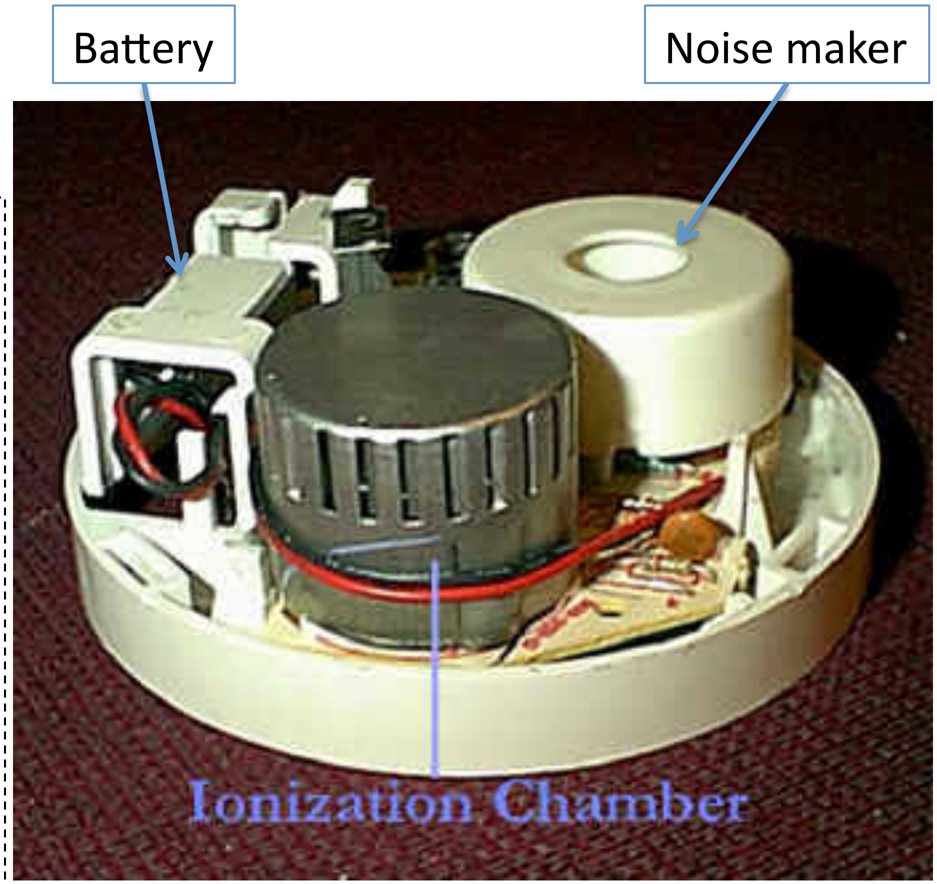
Web sez: "Inside an ionization detector is a small amount (perhaps 1/5000th of a gram) of americium-241. The radioactive element americium has a half-life of 432 years, and is a good source of alpha particles. Another way to talk about the amount of americium in the detector is to say that a typical detector contains 0.9 microcurie of americium-241."

Something doesn't sound right here…

$$A = \lambda N \quad \rightarrow \quad N = A/\lambda$$



^{241}Am alpha decay

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Q: What do we expect for the alpha decay of the ^{241}Am ground state?

$$ {}^{241}_{95}Am \xrightarrow{?} {}^{237}_{93}Np^{2-} + {}^{4}_{2}He^{2+} + Q_\alpha $$

$$ \frac{5}{2}- \quad \xrightarrow{?} \quad \frac{5}{2}+ \qquad 0+ $$

$$ Q_\alpha = \Delta\left({}^{241}Am\right) - \left[\Delta\left({}^{237}Np\right) + \Delta\left({}^{4}He\right)\right] $$

$$ Q_\alpha = 52.936 - \left[44.873 + 2.425\right] = 5.638\,MeV $$

A: We should not expect the alpha decay of the ^{241}Am ground state to go to the ground state of the ^{237}Np daughter due to the parity difference. Rather this decay feeds an excited state with the same angular momentum AND parity. The alpha decay Q-value is a little smaller because some energy is left behind in the neptunium daughter.

$$ {}^{241}_{95}Am \rightarrow {}^{237m}_{93}Np^{2-} + {}^{4}_{2}He^{2+} + \left(Q_\alpha - 0.05954\,MeV\right) $$

$$ \frac{5}{2}- \quad \xrightarrow{OK} \quad \frac{5}{2}- \quad 0+ $$

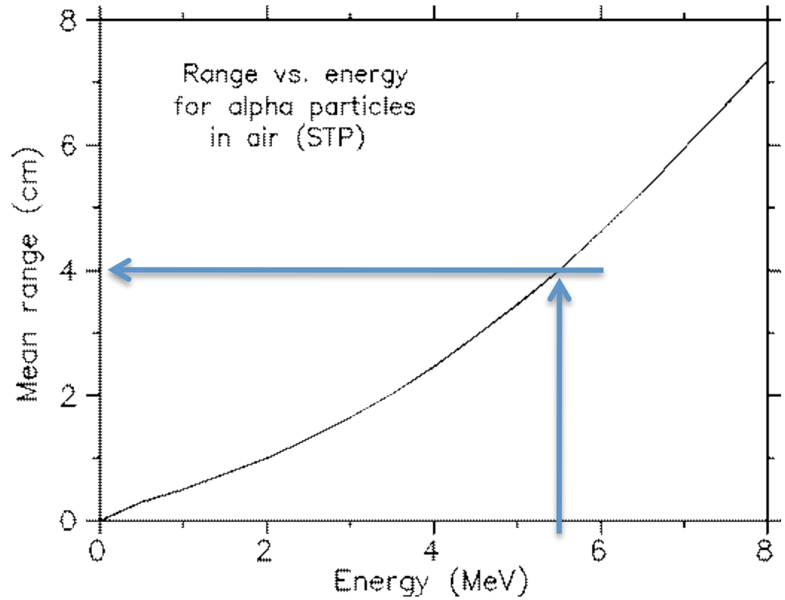
The excitation energy is subsequently released by an *Internal Transition* (the emission of a gamma ray) finally leaving the ^{237}Np in its ground state. [Q: what is the parity of a photon?]

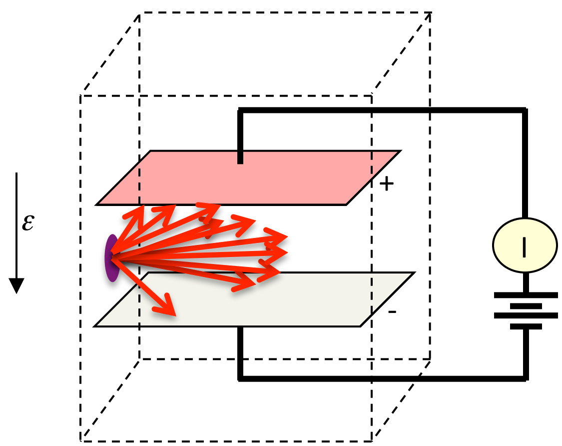
$$ {}^{237m}_{93}Np \rightarrow {}^{237}_{93}Np + \gamma $$

How does the smoke detector work?

1) Consider what happens when the alpha particle from this decay leaves the source and travels through air.
   It has a finite range.

1) Consider what happens to the kinetic energy of the alpha particle as it travels through the air.
   It slows down and creates +/- ions that end up predominantly as N_2^+, O_2^-





3) Imagine that the alpha particles travel through a region with an applied electric field. The N_2^+, O_2^- ions can be collected and the number of ions measured as a current.

4) Finally imagine what happens when small (smoke, soot) particles enter the chamber with the ions. The current is disrupted.

Radon in the basement?

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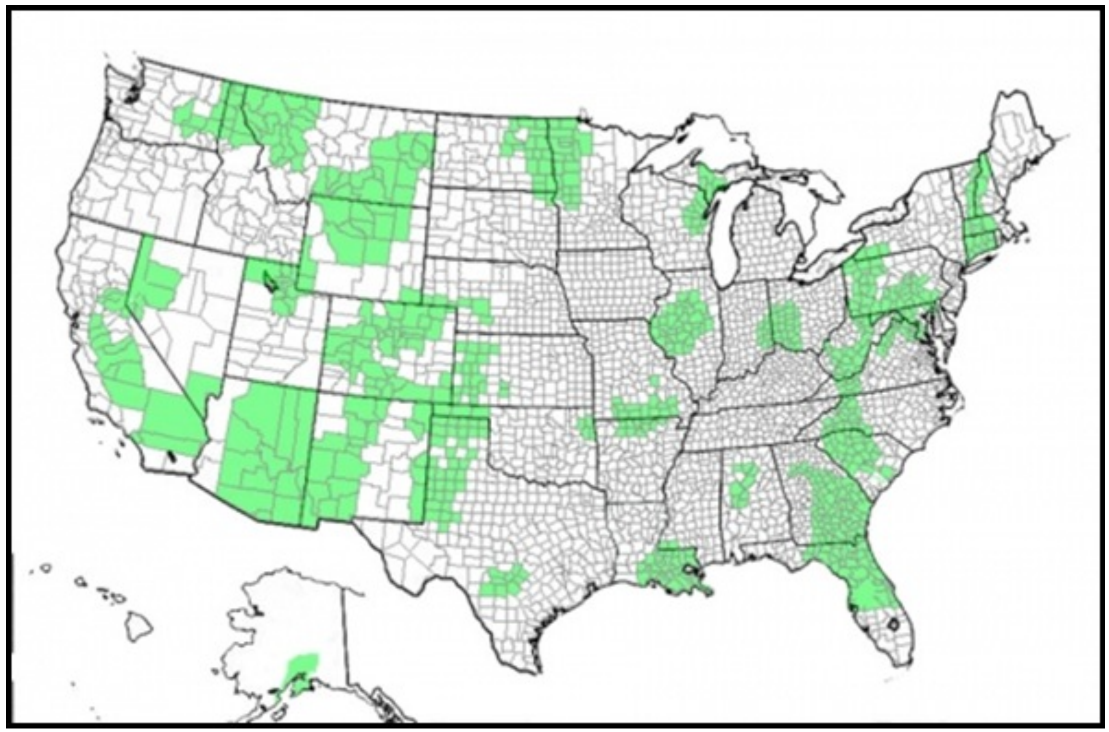
Web sez: "Radon is a radioactive gas that increases the risk of lung cancer. It is a decay product of uranium and its elevated levels in the water supply is usually associated with the prevalence of uranium in the surrounding bedrock."

"The gas enters the house primarily through cracks and gaps in the foundation, floor drains, and sumps, and concentrations build up indoors. Radon can also enter the home through well water and be released during showering or other uses. In rare cases, it is found in masonry building materials. Radon is thought to be the second leading cause of lung cancer in the United States, after smoking."

Web sez: "Every square mile of surface soil, to a depth of 6 inches (2.6 km^2 to a depth of 15 cm), contains ~1 gram of radium, which releases radon in small amounts to the atmosphere. The average concentration of radon in the atmosphere is about 150 atoms in each *ml* of air. Typical domestic exposures are about 100 Bq/m^3 indoors, and 10-20 Bq/m^3 outdoors, and much lower over the oceans."



http://www.absoluteastronomy.com/topics/Radon

Natural Activities

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4n Natural Radioactivity Series

$$^{232}Th \xrightarrow[\alpha,10^{10}\,yr]{} {}^{228}Ra \xrightarrow[\beta]{} {}^{228}Ac \xrightarrow[\beta]{} {}^{228}Th$$

$$^{228}Th \xrightarrow[\alpha,1.9\,yr]{} {}^{224}Ra \xrightarrow[\alpha,4d]{} {}^{220}Rn \xrightarrow[\alpha,56s]{} {}^{216}Po \xrightarrow[\alpha,0.2s]{} \boxed{^{212}Pb}$$

$$\boxed{^{212}Pb} \xrightarrow[\beta,11hr]{} {}^{212}Bi \xrightarrow[\beta,61m]{} {}^{212}Po \xrightarrow[\alpha,0.3\mu s]{} {}^{208}Pb$$

$$^{212}Bi \xrightarrow[\alpha]{} {}^{208}Tl \xrightarrow[\beta,3m]{} {}^{208m}Pb \xrightarrow{\gamma} {}^{208}Pb$$

4n+2 Natural Radioactivity Series

$$^{238}U \xrightarrow[\alpha,4x10^{9}\,yr]{} {}^{234}Th \xrightarrow[\beta,24d]{} {}^{234}Pa \xrightarrow[\beta,6hr]{} {}^{234}U$$

$$^{234}U \xrightarrow[\alpha,2x10^{5}\,yr]{} {}^{230}Th \xrightarrow[\alpha,7x10^{4}\,yr]{} {}^{226}Ra \xrightarrow[\alpha,1600yr]{} {}^{222}Rn \xrightarrow[\alpha,4d]{} \boxed{^{218}Po}$$

$$\boxed{^{218}Po} \xrightarrow[\alpha,3m]{} {}^{214}Pb \xrightarrow[\beta,26m]{} {}^{214}Bi \xrightarrow[\beta,20m]{} {}^{214}Po \xrightarrow[\alpha,0.2ms]{} {}^{210}Pb$$

$$^{210}Pb \xrightarrow[\beta,22yr]{} {}^{210}Bi \xrightarrow[\beta,5d]{} {}^{210}Po \xrightarrow[\alpha,138d]{} {}^{206}Pb$$

Spacecraft Power – RTG's

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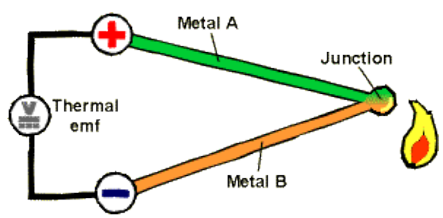
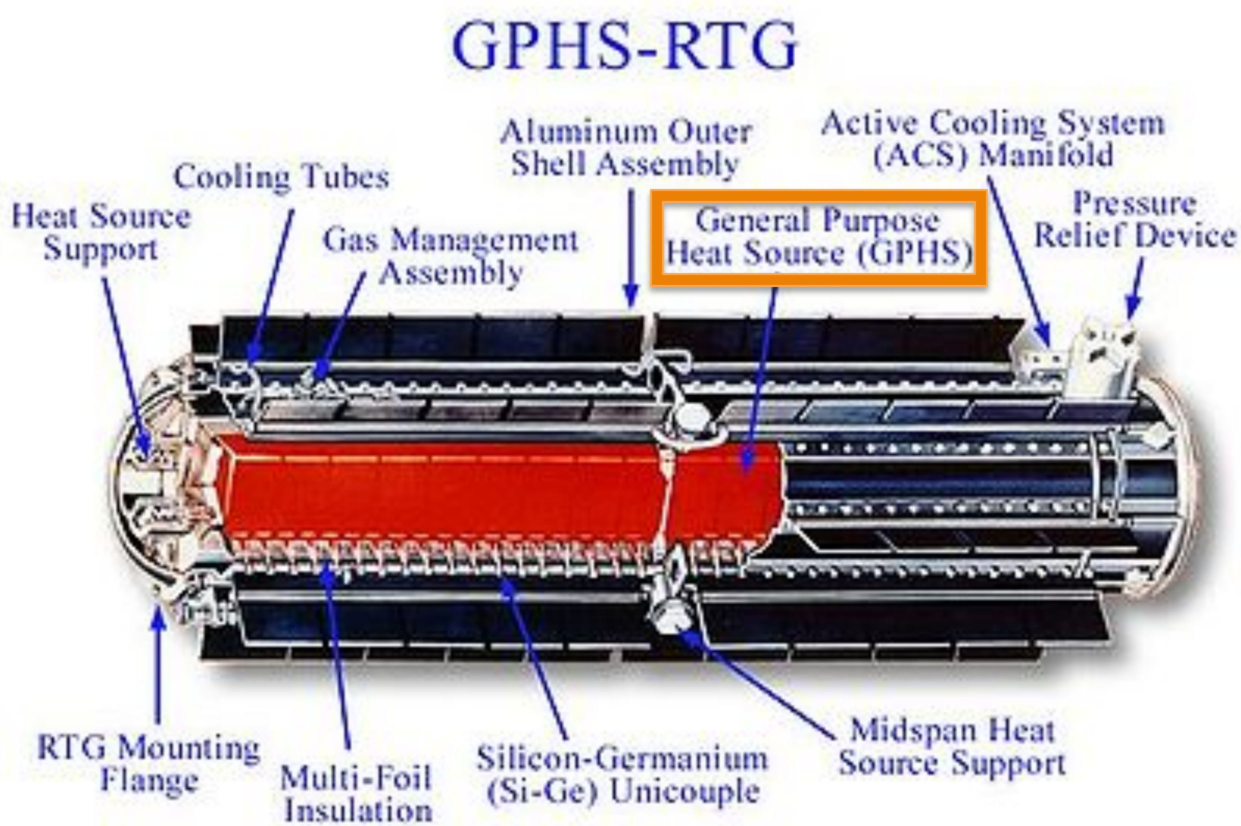
A radioisotope thermoelectric generator (RTG, RITEG) is an electrical generator which obtains its power from radioactive decay. The heat released by the decay of a suitable nuclide is converted into electricity by the Seebeck effect using thermocouples. Famous spacecraft for deep-space powered by RTGs include Voyager I & II launched in 1977.





Spacecraft Power – ^{238}Pu

Web sez: "Most RTGs use ^{238}Pu which decays with a half-life of 87.7 years. RTGs using this material will therefore diminish in power output by or 0.787% of their capacity per year. Thus, with a starting [electrical] capacity of 470 W, after 23 years it would have a capacity of 0.834 * 470 W = 392 W. However, the bi-metallic thermocouples used to convert thermal energy into electrical energy degrade as well; at the beginning of 2001, the [electrical] power generated by the Voyager RTGs had dropped to 315 W for Voyager 1 and to 319 W for Voyager 2. Therefore in early 2001, the thermocouples were working at about 80% of their original capacity."

$$^{238}_{94}Pu \rightarrow \, ^{234}_{92}U^{2-} + \, ^{4}_{2}He^{2+} + Q_\alpha$$

$$0+ \quad \rightarrow \quad 0+ \qquad\quad 0+$$