Physics 112: General Physics II: Electricity, Magnetism, and Optics
Radioactive Decay Power

Problem 1: (20 pts.) The New Horizons spacecraft, launched in 2006, spent 9.5 years on its journey to Pluto. It derives its electric power from the heat generated by 10 kg of $^{238}_{94}$Pu, which has an activity of 6.3×10^{15} Bq. Each decay emits an alpha particle with an energy of 5.6 MeV. What is the total thermal power generated by this plutonium source?

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The original (parent) nucleus is Plutonium-238: $^{238}_{94}\text{Pu}$, with $Z = 94$ and $A = 238$. If it decays by alpha decay, then it decays to the element with $Z = 92$ and $A = 234$, which is Uranium-234: $^{234}_{92}\text{U}$. The reaction is thus

$$^{238}_{94}\text{Pu} \rightarrow {}^{234}_{92}\text{U} + \alpha$$

The energy per decay arises from the mass difference:

$$\begin{aligned}
\Delta m &= m_{\text{Pu}} - (m_{\text{U}} + m_{\alpha}) \\
\Delta m &= 238.049\,56\,\text{u} - (234.040\,952\,\text{u} + 4.002\,603\,\text{u}) \\
\Delta m &= 238.049\,56\,\text{u} \\
&\quad -238.043\,555\,\text{u} \\
\Delta m &= \quad 0.006\,01\,\text{u} \\
\Delta E &= (\Delta m)c^2 = (0.006\,01\,\text{u})c^2 \\
\Delta E &= 5.59\,\text{MeV}
\end{aligned}$$

If the activity is $R = 6.30 \times 10^{15}$ Bq, then the power (*i.e.* Joules per second) is

$$\begin{aligned}
P &= R \times \Delta E \\
P &= (6.30 \times 10^{15}\,\text{Bq}) \times (5.59\,\text{MeV/decay}) \\
P &= (6.30 \times 10^{15}\,\text{decays/s}) \times (5.59\,\text{MeV/decay}) \\
P &= (3.52 \times 10^{16}\,\text{MeV/s}) \times \left(\frac{1 \times 10^{6}\,\text{eV}}{1\,\text{MeV}} \times \frac{1.602 \times 10^{-19}\,\text{J}}{1\,\text{eV}} \right) \\
P &= \boxed{5650\,\text{W}}
\end{aligned}$$