# Massachusetts Institute of Technology

## Department of Physics

Course: 8.701 – Introduction to Nuclear and Particle Physics
Term: Fall 2020
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## Discussion Problems

from recitation on **November 10th, 2020**

### Problem 1: Mass Spectroscopy

The binding energy of an atomic nucleus can be calculated if the atomic mass is accurately known. At the start of the 20th century, the method of mass spectrometry was developed. The deflection of an ion with charge $Q$ in an electric and magnetic field allows the simultaneous measurement of its momentum and kinetic energy. Discuss and explain how such a measurement can be performed.

- One can use electric and magnetic fields to separate ions of different mass but varying velocity. The radius of curvature $r_E$ of the ion path in an electric field is given by $r_E = \frac{M}{Q} \cdot \frac{v^2}{E}$ and radius of curvature $r_E$ of the ion path in an magnetic field is given by $r_M = \frac{M}{Q} \cdot \frac{v}{B}$.

### Problem 2: Nuclear Powered Satellites

The $\alpha$ decay of $^{238}$ Pu ($\tau = 127$ years) into a long lived $^{234}$ U ($\tau = 3.5 \times 10^5$ years) releases 5.49 MeV kinetic energy. The produced heat can be converted into useful electricity by radio-thermal generators (RTG). The Voyager 2 space probe, which was launched on August 20, 1977, flew past four planets, including Saturn which it reach on August 26, 1981. How much plutonium would an RTG on Voyager 2 with 5.5 % efficiency have to carry to deliver at least 395W electric power when the probe flies past Saturn? How much electric power electric power would be available at Neptune which Voyager 2 reach August 24, 1989?

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*Here we need to figure out how much power per kilo we get out of plutonium.*
*Per second, we get*

$$(0.055)(5.47\,MeV)\left|\frac{dN}{dt}\right| = 0.302\,MeV\,\frac{1.6\times10^{-13}\,J}{MeV}\,\frac{N_0}{127\,yr\left(\pi\times10^{7}\,\frac{s}{yr}\right)}e^{-\frac{t}{\tau}} = 1.21\times10^{-23}W\left(N_0 e^{-\frac{t}{\tau}}\right)$$

*Setting this equal 395 W in 4 years of decay, we find:*

$$N_0 = \frac{395}{1.21\times10^{-23}e^{-\frac{4}{127}}} = 3.36\times10^{25}\text{ nuclei}$$

$$M = N_0\frac{238\,g}{N_a} = 13.3\,kg$$

*Here we just use our solution above, with t= 12 years*

$$P = 1.21\times10^{-23}W\left(3.36\times10^{25}\right)e^{-\frac{12}{127}} = 370\,W$$

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