1st ICTP-Trieste/ICTP-SAIFR School on Particle Physics: Dark Matter and Particle Physics – Some exercises

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Below are a list of questions, some simple, some involved, that will help illustrate some of the points raised in lectures. The questions approximately follow the order of topics in the lectures, but you should feel free to approach them in any order you wish.

1 Lecture IV

Question 1. *Minimal DM* The "original" WIMP was a particle coupled to the Z. Show that the direct detection scattering cross section off a nucleus ${}^A_Z N$ through Z exchange for a Dirac fermion with hypercharge Y is

$$\sigma(\chi N \to \chi N) = \frac{G_F^2 M_N^2}{2\pi} Y^2 \left(N - (1 - 4s_W^2)Z\right)^2 \tag{1}$$

Question 2. *A model for Inelastic Dark Matter* By decomposing a Dirac 4-spinor as two 2-spinors,

$$\psi = \begin{pmatrix} \eta \\ \bar{\xi} \end{pmatrix} \tag{2}$$

Determine the mass eigenstates for a mass term of the form $m\bar{\psi}\psi + \frac{\delta_1}{2}(\eta\eta + \bar{\eta}\bar{\eta}) + \frac{\delta_2}{2}\left(\xi\xi + \bar{\xi}\bar{\xi}\right)$. Assume there is a coupling to a vector boson, A_μ, of the form $\bar{\psi}\gamma^\mu A_\mu \psi$. Determine what this is in terms of the mass eigenstates.

Question 3. *Inelastic Dark Matter in Direct Detection* The rate equation for direct detection, ignoring experimental effects like efficiencies, thresholds *etc*, is

$$\frac{dR}{dE} = \frac{N_T m_N \rho_\chi}{2\mu_{N\chi}^2 m_\chi} \int_{v_{min}}^{v_{esc}} d^3v \frac{f(v, v_\oplus)}{v} \sigma_N F^2(E) \ . \tag{3}$$

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Use the Standard Halo Model to draw the shape of the recoil spectrum (ignore the form factor) for a) elastic DM and b) inelastic DM. Is the modulation expected to be larger or smaller for iDM?

Question 4. *Modulation signals* Consider the Earth's daily rotation and its orbit around the Sun. Compare these modulating velocities to the Sun's motion in the Galaxy. Estimate how big the daily modulation signal at DAMA would be.