Elementary Particle Physics - Exercises	**Problem sheet 02**	October 30, 2015

[Tutorials on Thursdays: 8-10 in C01-148 and 16-18 in U2-135]

Exercise 2.1:
Let us consider the reaction $p + p \to p + p + p + \bar{p}$.

1. In a fixed target experiment one of the colliding protons is at rest. How large should be the energy of the second proton, so that the reaction is kinematically allowed?
2. In the Large Hadron Collider (LHC) two protons collide with the same speed. What is the threshold energy in this case?

Exercise 2.2:
Compton scattering: A photon with wavelength λ collides elastically with a charged particle with mass m. Determine the wavelength λ' of the emerging photon after scattering at angle θ.

Exercise 2.3:
In the lecture the time evolution operator $\hat{U}_I(t, t_0)$ was defined as

$$i\partial_t \hat{U}_I(t, t_0) = g\hat{V}_I(t)\hat{U}_I(t, t_0) \ , \quad \text{with} \quad \hat{U}_I(t_0, t_0) = \mathbf{1} \ .$$

1. Derive the integral equation $\hat{U}_I(t, t_0) = \mathbf{1} - ig \int_{t_0}^{t} ds \hat{V}_I(s)\hat{U}_I(s, t_0)$.
2. Write out the iterative solution to this equation to second order in g.
3. Can you guess the structure of the exact solution?
   [hint: exponential function]

Exercise 2.4:
Show that the complex scalar field $\phi(x)$ with the Lagrange density

$$\mathcal{L} = \partial_\mu \phi(x)^* \partial^\mu \phi(x) - m^2 \phi(x)^* \phi(x)$$

satisfies the Klein-Gordon equation. What about the complex conjugated field $\phi(x)^*$? Furthermore, check that the charge $Q(t) = \int d^3x \ i[\phi(x)^* \partial^0 \phi(x) - \phi(x) \partial^0 \phi(x)^*]$ is conserved.

[hint: The corresponding current is $j^\mu(t) = i[\phi(x)^* \partial^\mu \phi(x) - \phi(x) \partial^\mu \phi(x)^*]$.]