1. Draw at least one lowest order Feynman diagram for each of the following processes and identify the inteaction involved:

   a) $\mu^- + \mu^+ \to \gamma + \gamma$

   b) $\nu_\mu + e^- \to \mu^- + \nu_e$

2. Draw at least one lowest order Feynman diagram for each of the following weak interaction processes:

   a) $\bar{\nu}_e + p \to e^+ + n$

   b) $\nu_\mu + p \to \nu_\mu + p$

   c) $\tau^- \to \nu_\tau + e^- + \bar{\nu}_e$

3. Draw the lowest order Feynman diagrams for the process $\nu_e + e^- \to \nu_e + e^-$ with Z^0 or $W^\pm$ as the mediator (one diagram of each type is sufficient). Do corresponding diagrams also exist for the process $\nu_\mu + e^- \to \nu_\mu + e^-$?

4. In cosmology, matter can generally be modelled as a fluid whose properties are determined by an equation of state of the form $p = w\rho$. In the early universe, the energy density was dominated by relativistic particles, i.e. radiation, for which $w = 1/3$. The radiation-dominated era was followed by a period dominated by non-relativistic matter, or just matter for short, for which $w = 0$. Currently, the universe is dominated by dark energy which behaves like vacuum energy and for which $w = -1$. Solve the continuity equation $\dot{\rho} + 3(\dot{a}/a)(\rho + p) = 0$ to determine the evolution of the energy density as a function of the scale factor, $\rho(a)$, for matter, radiation, and vacuum energy.

5. The matter-dominated period started when the age of the universe was $t \approx 5.0 \times 10^4$ years and ended at $t \approx 1.0 \times 10^{10}$ years. According to the previous problem, $\rho \propto a^{-3}$ in matter-dominated universe. Use this to solve for $a(t)$ from the Friedmann equation $(\dot{a}/a)^2 = 8\pi G\rho/3$ in matter-dominated universe (the functional form is enough, no need to substitute any numerical values).