Time-dependent perturbation theory: The exponential damping force

Introduction

This exercise is modelled after Problem 5.23 in the book Modern Quantum Mechanics, Second Edition by J.J. Sakurai and Jim Napolitano.

Background

Here, we will look at an example of the application of time-dependent perturbation theory (TDPT). Background on TDPT will not be provided here, but we refer students to, e.g., Section 5.7 in the Sakurai book mentioned in the introduction section.

The exercise starts by initializing the system in the ground state of the harmonic oscillator potential, and starting at $t = 0$, we apply a force that is exponentially damped over time, $F(t) = F_0 \exp -t/\tau$. The net effect is that the ground state is initially displaced from the origin and slowly returns back to where it started. For this problem, one can use TDPT to calculate an analytical expression that approximates the population in the first excited state as a function of time, given a force of amplitude F_0 and damping constant τ.

The flowfile

The flowfile here is divided into two panels. The top panel calculates the first three energy states of the harmonic oscillator. These states are then used in the bottom panel as we plot the overlap of the forced state with these three energy states as a function of time in the *Scalar Time Trace* plot. Additionally, in the bottom panel, we calculate the difference between the numerical result and TDPT result for the population in the first excited state as a function of time. For the approximation to hold, this difference should be close to zero.

The Exercise

- Vary the amplitude of the force and timescale of the damping. Observe the behavior of the system. What is the timescale of the oscillations you see?
- Why do the oscillations happen on this timescale?
- For what range of parameters F_0 and τ does the TDPT approximation break down?
- What causes the TDPT approximation to break down?