Heat Diffusion from an Optical Source in a Low-Temperature Experiment

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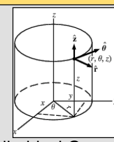
INTRODUCTION

System of Study

A fiber optical cable is coated by a film of liquid helium and cooled to near absolute zero, where quantum mechanical properties of the system are studied by using a laser to send short pulses of light through the cable to evaporate pulses of helium vapor. Doing so requires an optical source. To characterize the vapor pulses, the flow of thermal energy back into the fiber as well as into the liquid helium film must be considered.

The static states of the system are described by Laplace's equation in cylindrical coordinates while the evolution of the system with time obeys Poisson's equation (the heat equation) in cylindrical coordinates. These equations (second-order partial differential equations), combined with the appropriate boundary conditions on the cable, are used to obtain an equation for the temperature of the cable as a function of spatial coordinates and time.



Cylindrical Geometry

$$\nabla^2 T = 0$$

Laplace's Equation

$$\nabla^2 T = k \frac{\partial T}{\partial t}$$

Poisson's Equation

General Approach

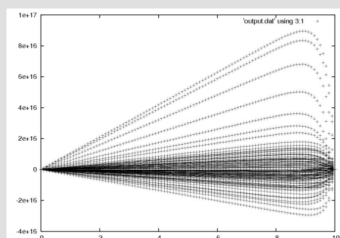
Modeling complex, time variant boundary conditions due to aspects of the low-temperature experiment beyond the system of study require computer simulation. The FORTRAN language is used to model the system. This language is well-suited to numerical and scientific computation and coordinates with pre-existing codes to model the experiment.

Whenever feasible, analytical methods are combined with the numerical approaches, which fall into two categories, grid-analytic and Monte Carlo.

GRID-ANALYTIC APPROACH

Process

- Solve Laplace's or Poisson's equation analytically to obtain a general solution.
- Using FORTRAN, create a coordinate grid.
- Again using FORTRAN, impose boundary conditions at a discrete number of points, according to the coordinate grid.
- Using the boundary conditions and the general solution, use FORTRAN to obtain the necessary constants and parameters for the particular solution.



Z Dependence of Temperature Variance from Grid-Analytic Approach

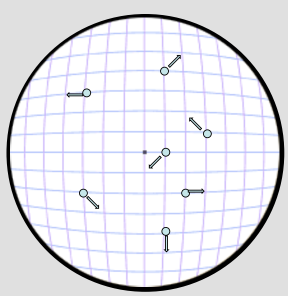
Reliability and Stability

Using the grid-analytic approach to model different variations of the problem at hand produced results that were consistently qualitatively correct, but were often quantitatively incorrect. This dichotomy and the instability of array operations in the limit of high grid density led us to abandon this approach in favor of one better-suited to the statistical nature of diffusive processes.

MONTE CARLO APPROACH

Statistical Nature of Diffusion

Diffusion results from the random motion and collisions of particles. Diffusive processes can be modeled using random walk methods. The heat equation is concerned with changes in energy densities and is mathematically equivalent to equations describing diffusion. Therefore, changes in energy densities can be modeled by conceptualized, randomly-walking heat-carrying particles. A large number of these particles are dispersed from boundary regions of the material continuum (in our case, the fiber optical cable) according to initial concentration conditions, and take random steps until they reach a predetermined region of the interior of the continuum.



Cross Section of Fiber Optical Cable

Future Work

The current status of the project involves developing a simulation of heat diffusion using a Monte Carlo approach.

Particles in the interior of the fiber optical cable are allowed to randomly "walk" within the interior. However, the concentration of particles as they near the boundary of the cable is monitored and manipulated as necessary with each step to ensure compliance with the boundary conditions. Imposing these criteria on these conceptualized particles will yield a diffusion that approximates and models physical heat diffusion.

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