The notebeamer Package

Mingyu Hsia, xiamyphys@hdu.edu.cn

Hangzhou Dianzi University

2024/05/06 Version 3.0b*

Abstract

This is the document for the notebeamer package, which provides an easy way to input slides on notepages quickly for making annotations.

Welcome to feedback bugs or ideas via email xiamyphys@hdu.edu.cn or GitHub.

1 Installing notebeamer and loading it

Simply download `notebeamer.cls` file from GitHub or CTAN and save it under your working directory. However, I strongly suggest to use terminal to install and update all packages to the latest version

```
sudo tlmgr update --self --all
```

To learn more, please refer to How do I update my TEX distribution?

2 Key values of this package

```
\usepackage[notelinecolor=<color>,notemargin=<margin>]{notebeamer}
```

This package has two keys: `notelinecolor` and `notemargin`.

The `notelinecolor` key can set the color notelines, the `notemargin` key can set the margin of notepages.

If you have not set the keys, the default values of the four keys will be applied

```
notelinecolor=MidnightBlue,     notemargin=.75in
```

Please set the geometry for the whole document **after** you set the notemargin, that is

```
\usepackage[notemargin=<margin>]{notebeamer}  \geometry{<keyval list>}
```

otherwise the notemargin configuration won't work.

*https://github.com/xiamyphys/notebeamer

3 The margin of notepages

The relation of the margin of notepages and the margin configuration of package geometry satisfies the following expression

```
topmargin = bottommargin = (\paperwidth-\textwidth)/3
leftmargin = rightmargin = (2\paperheight-2\textheight)/5
```

4 Commands of notebeamer

4.1 The `notechap` command

```
\notechap [<notetitle>] {<filename>}
```

This command can assign the following notetitle and the PDF file you want to input.

4.2 The `notelinenum` and `notecolumnratio` commands

```
\notelinenum{<number>}  \notecolumnratio{<number>}
```

The two commands can assign the number of notelines and the ratio of columns on following notepages respectively. The default value of the number of notelines is 27 and that of the ratio of columns is `0.5`.

4.3 The `hidenotelinetrue` and `hidenotelinefalse` commands

Notepages after the `hidenotelinetrue` command the notelines will be hidden while notepages after command `hidenotelinefalse` the notelines will be restored.

4.4 The `newnotepage`

```
\newnotepage[<number>]  \newnotepage*[<number>]
```

The `newnotepage` command can create empty notepage(s). If a star (*) is added after the command, the created empty notepage(s) won't have column rule.

4.5 The `includebeamer` command

```
\includebeamer[<number of slides per page>]{<start page>}{<end page>}
```

This commands will create notepages that were inserted images on the left sidnumber of slides per page and the last two variables can set the start page and end page of the PDF file you want to insert that assigned by the command `notechap`.

A Related packages

A.1 The fadingimage package

This package provides macros for inputting full width picture at the edges of pages quickly.

A.2 The litesolution class

This class is designed for typesetting solutions of problems in exams, textbooks, etc. The notebeamer package is contained in the litesolution class now.

Finite Versus Infinitesimal Rotations

Consider a vector

$$\mathbf{V} = \begin{pmatrix} V_x & V_y & V_z \end{pmatrix}^{\mathsf{T}} ,$$

after a rotation

$$\begin{pmatrix} V_x' \\ V_y' \\ V_z' \end{pmatrix} = R \begin{pmatrix} V_x \\ V_y \\ V_z \end{pmatrix}$$

with

$$R^{\mathsf{T}} R = R R^{\mathsf{T}} = 1 ,$$

leading to a property

$$\mathbf{V}^{\mathsf{T}} \mathbf{V} = \mathbf{V}^{\mathsf{T}} R^{\mathsf{T}} R \mathbf{V} ,$$

$$V_x'^2 + V_y'^2 + V_z'^2 = V_x^2 + V_y^2 + V_z^2 .$$

Define a rotation operator about the z-axis by angle ϕ,

$$R_z(\phi) = \begin{pmatrix} \cos\phi & -\sin\phi & 0 \\ \sin\phi & \cos\phi & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

We are particularly interested in an infinitesimal form of R_z:

$$R_z(\epsilon) = \begin{pmatrix} 1-\frac{\epsilon^2}{2} & -\epsilon & 0 \\ \epsilon & 1-\frac{\epsilon^2}{2} & 0 \\ 0 & 0 & 1 \end{pmatrix} , \quad \epsilon \to 0 .$$

Likewise, we have

$$R_x(\epsilon) = \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1-\frac{\epsilon^2}{2} & -\epsilon \\ 0 & \epsilon & 1-\frac{\epsilon^2}{2} \end{pmatrix} ,$$

and

$$R_y(\epsilon) = \begin{pmatrix} 1-\frac{\epsilon^2}{2} & 0 & \epsilon \\ 0 & 1 & 0 \\ -\epsilon & 0 & 1-\frac{\epsilon^2}{2} \end{pmatrix} .$$

Define a rotation operator about the z-axis by angle ϕ,

$$R_z(\phi) = \begin{pmatrix} \cos\phi & -\sin\phi & 0 \\ \sin\phi & \cos\phi & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

We are particularly interested in an infinitesimal form of R_z:

$$R_z(\epsilon) = \begin{pmatrix} 1-\frac{\epsilon^2}{2} & -\epsilon & 0 \\ \epsilon & 1-\frac{\epsilon^2}{2} & 0 \\ 0 & 0 & 1 \end{pmatrix} , \quad \epsilon \to 0 .$$

Mengnan Chen (HDU) Advanced Quantum Mechanics November 8, 2023 5 / 66

Likewise, we have

$$R_x(\epsilon) = \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1-\frac{\epsilon^2}{2} & -\epsilon \\ 0 & \epsilon & 1-\frac{\epsilon^2}{2} \end{pmatrix} ,$$

and

$$R_y(\epsilon) = \begin{pmatrix} 1-\frac{\epsilon^2}{2} & 0 & \epsilon \\ 0 & 1 & 0 \\ -\epsilon & 0 & 1-\frac{\epsilon^2}{2} \end{pmatrix} .$$

Mengnan Chen (HDU) Advanced Quantum Mechanics November 8, 2023 6 / 66

Elementary matrix manipulations lead to

$$R_x R_y = \begin{pmatrix} 1-\frac{\epsilon^2}{2} & 0 & \epsilon \\ \epsilon^2 & 1-\frac{\epsilon^2}{2} & -\epsilon \\ -\epsilon & \epsilon & 1-\epsilon^2 \end{pmatrix}$$

$$R_y R_x = \begin{pmatrix} 1-\frac{\epsilon^2}{2} & \epsilon^2 & \epsilon \\ 0 & 1-\frac{\epsilon^2}{2} & -\epsilon \\ -\epsilon & \epsilon & 1-\epsilon^2 \end{pmatrix}$$

$$R_x R_y - R_y R_x = \begin{pmatrix} 0 & -\epsilon^2 & 0 \\ \epsilon^2 & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix} = R_z(\epsilon^2) - 1 ,$$

where all terms of order higher than ϵ^2 have been ignored.

Infinitesimal Rotations in Quantum Mechanics

Given a rotation operation characterized by a orthogonal 3×3 matrix R, associate an operator $\mathcal{D}(R)$ in the appropriate ket space such that

$$|\alpha\rangle_R = \mathcal{D}(R)|\alpha\rangle .$$

- For describing a spin$-1/2$, system with no other degrees of freedom, $\mathcal{D}(R)$ is a 2×2 matrix;
- for a spin-1 system, $\mathcal{D}(R)$ is a 3×3 matrix.

The appropriate infinitesimal operators could be written as

$$\hat{U}(\epsilon) = 1 - \mathrm{i}\hat{G}\epsilon , \quad \hat{G} : \text{ Hermitian}$$

We therefore define the angular-momentum operator $\hat{J}_k$ for an infinitesimal rotation around the kth axis by angle $\mathrm{d}\phi$ can be obtained by letting

$$\hat{G} \to \frac{\hat{J}_k}{\hbar} , \quad \epsilon \to \mathrm{d}\phi$$

combine with the necessity of treating interactions.

A rigorous discussion of transport in an interacting mesoscopic system requires a formalism that is capable of including explicitly the interactions. Obvious candidates for such a theoretical tool are various techniques based on Green functions. Since many problems of interest involve systems far from equilibrium, we cannot use linear-response methods, such as those based on the Kubo formula, but must use an approach capable of addressing the full nonequilibrium situation. The nonequilibrum-Green-function techniques, as developed about thirty years ago by Kadanoff and Baym,[4] and by Keldysh,[5] have during the recent years gained increasing attention in the analysis of transport phenomena in mesoscopic semiconductors systems.[6] In particular, the *steady-state* situation has been addressed by a large number of papers.[7–12] Among the central results obtained in these papers is that under certain conditions (to be discussed below) a Landauer-type conductance formula[13] can be derived. This is quite appealing in view of the wide spread success of conductance formulas in the analysis of transport in mesoscopic systems.

Considerably fewer studies have been reported where an explicit time dependence is an essential feature. We are aware of an early paper in surface physics,[14] but only in the recent past have groups working in mesoscopic physics addressed this problem.[15–20,38] The work reported in this paper continues along these lines: we give the full details and expand on our short communication.[17]

Our main formal result from the nonequilibrium-Green-function approach is a general expression for the time-dependent current flowing from noninteracting leads to an interacting region. As we will discuss in Sec. II, the time dependence enters through the self-consistent parameters defining the model. We show that under certain restrictions, to be specified below, a Landauer-like formula can be obtained for the *time-averaged* current. To illustrate the utility of our approach we give results for an exactly solvable noninteracting case, which displays an interesting, and experimentally measurable, nonadiabatic behavior. We also establish a link between the present formulation and recently published results for linear-response and electron-phonon interactions, obtained by other techniques.

The paper is organized as follows. We examine in Sec. II the range of experimental parameters in which we expect our theoretical formulation to be valid. In Sec. III we briefly review the physics behind the nonequilibrium-Green-function technique of Keldysh, and Baym and Kadanoff, which is our main theoretical tool, and then introduce the specific model Hamiltonians used in this work. We derive the central formal results for the time-dependent current in Sec. IV. We also derive, under special restrictions, a Landauer-like formula for the average current. In Sec. V, we apply the general formulas to an explicitly solvable resonant-tunneling model. Both analytical and numerical results are presented. We also show that the linear ac-response results of Fu and Dudley[21] are contained as a special case of the exact results of this section. In Sec. VI, we illustrate the utility of our formulation by presenting a much simplified derivation of Wingreen *et al.*[22] results on resonant tunneling in the presence of electron-phonon interactions. Appendix A summarizes some of the central technical properties of the Keldysh technique: we state the definitions, give the basic equations, and provide the analytic continuation rules employed below. In Appendices B and C, we present proofs for certain statements made in the main text, and, finally, in Appendix D we describe some transformations which facilitate numerical evaluation of the time-dependent current.

II. APPLICABILITY TO EXPERIMENTS

A central question one must address is: under which conditions are the nonequilibrium techniques, applied successfully to the steady-state problem, transferrable to time-dependent situations, such as the experiments mentioned above?

The time-dependent problem has to be formulated carefully, particularly with respect to the leads. It is essential to a Landauer type of approach, that the electrons in the leads be noninteracting. In practice, however, the electrons in the leads near the mesoscopic region contribute to the self-consistent potential. We approach this problem by dividing the transport physics in two steps:[23] (i) the self-consistent determination of charge pileup and depletion in the contacts, the resulting barrier heights, and single-particle energies in the interacting region, and (ii) transport in a system defined by these self-consistent parameters. Step (i) requires a capacitance calculation for each specific geometry,[23] and we do not address it in this paper. Instead, we assume the results of (i) as time-dependent input parameters and give a full treatment of the transport through the mesoscopic region (ii). In practice, the interactions in the leads are absorbed into a time-dependent potential and from then on the electrons in the leads are treated as noninteracting. This means that when relating our results to actual experiments some care must be exercised. Specifically, we calculate only the current flowing into the mesoscopic region, while the total time-dependent current measured in the contacts includes contributions from charge flowing in and out of accumulation and depletion regions in the leads. In the *time-averaged* (dc) current, however, these capacitive contributions vanish and the corresponding time-averaged theoretical formulas, such as Eq. (27), are directly relevant to experiment. It should be noted, though, that these capacitive currents may influence the effective time-dependent parameters in step (i) above.

Let us next estimate the frequency limits that restrict the validity of our approach. Two criteria must be satisfied. First, the driving frequency must be sufficiently slow that the applied bias is dropped entirely across the tunneling structure. When a bias is applied to a sample, the electric field in the leads can only be screened if the driving frequency is smaller than the plasma frequency, which is tens of THz in typical doped semiconductor samples. For signals slower than this, the bias is established entirely across the tunneling structure by accumulation and depletion of charge near the barriers. The unscreened Coulomb interaction between net excess