

“DIPOLE MAGNETS” – A COMPUTER-BASED TUTORIAL*

R. R. Silbar, A. A. Browman, W. C. Mead, R. A. Williams
WhistleSoft, Inc., 168 Dos Brazos, Los Alamos, NM 87544

Abstract

Dipole Magnets is one of a set of self-paced interactive training tutorials on particle accelerators that target a broad audience. It covers the bending and focusing properties of dipole magnets. The tutorial contains five sections, four of which are accessible to undergraduate science majors and accelerator technicians.

1 INTRODUCTION

Four years ago WhistleSoft, Inc., began developing a set of computer-based multimedia tutorials on particle accelerators and charged-particle beams. We originally designed the Accelerators and Beams tutorials for the academic market. Our publisher, Physics Academic Software, is in fact marketing four earlier pieces to that audience.

However, we have always had in mind that we might eventually customize these tutorials for particular purposes by National Laboratories running accelerators and by companies producing accelerators for commercial uses. Thus we have taken pains to keep as much material as possible at a level that it is comprehensible to lower undergraduates and accelerator technicians. In fact, most of our work up to the development of *Dipoles* can be understood by end-users who have taken an algebra-based introductory physics course.

Dipole Magnets, like its brothers, integrates interactive On-Screen Laboratories™, hypertext, progressive disclosure (so the student chooses the pace of presentation), line drawings, and photographs. Of particular importance, we feel, is the use of two- and three-dimensional animations to illustrate the sometimes geometrically complex concepts involved in electromagnetism. We also strongly feel that these multimedia techniques enhance the student’s rate of learning and length of retention of the material studied.

Our tutorials are available for both Windows and Macintosh platforms in essentially equivalent versions.

* Work supported by the U.S. Department of Energy under a Phase II SBIR grant. Email: silbar@whistlesoft.com; Web pages: <http://www.whistlesoft.com/~silbar>

2 TUTORIAL CONTENTS

The *Dipoles* module consists of 43 Content pages, 29 Question and Answer pages, and includes Laboratories. The tutorial is presented in five sections:

- **Uniform Bending Magnets**, including discussion of bending angle, magnetic rigidity, radial focusing, and radial betatron oscillation.
- **Non-Uniform Magnets**, including definition of field index and vertical focusing.
- **Fringe Field Effects**, including a demonstration of edge focusing or defocusing.
- **The Kerst-Serber Equation**, in which the restoring force equation (“tune”) is derived. This section is more difficult than the others in that some knowledge of calculus and Maxwell’s Equations is assumed.
- **The Double-Focusing Spectrometer**, which is essentially an example bringing together all of the above material. Students who have worked through the Kerst-Serber section, will understand why field index $n = 1/2$ is optimal for such a device and why the total bend angle is $\pi\sqrt{2}$ radians. Figure 1 shows the concluding page of this section.

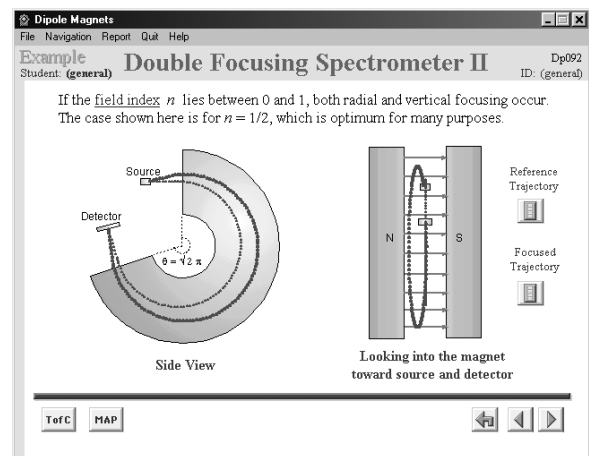


Figure 1: Double focusing spectrometer page.

3 EXAMPLE OF RADIAL FOCUSING

The first section, on uniform bending magnets, also goes into a number of related topics that are simple enough, but not necessarily obvious to the neophyte. Figure 2 shows the page that discusses how such uniform magnets can provide focusing in the radial direction.

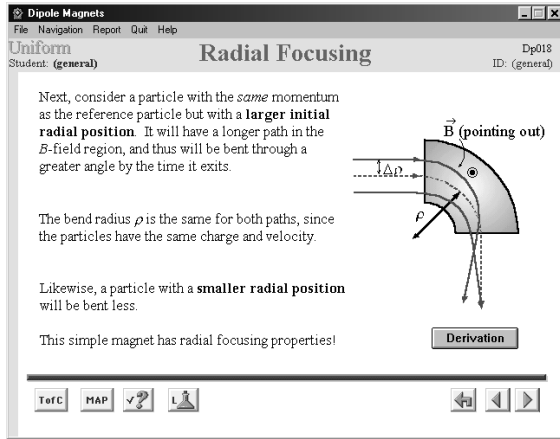


Figure 2: Radial focusing page.

This page is opened in progressive disclosure, one paragraph at a time, with the student in control of when to proceed to the next paragraph. (On subsequent returns to this page, such as through a hyperlink, the page opens without waiting for the student's prompt, but with short pauses between the various sections.) The red particle paths are animated, and the "Derivation" button leads to a page showing *how* the geometry leads to a focusing effect.

Among the buttons at the bottom of the page, the third from the left (with the question mark) leads to a set of multiple choice questions that the student can use to test his or her comprehension of the concept being discussed. The number of correct answers to these questions, as well as a record of how much of the tutorial the student has seen, is available from the "Report" pulldown menu item at the top of the page.

Another button, fourth from the left, leads to a Laboratory, in which the student can vary the displacement, $\Delta\rho$, from the principal axis. In this case, that also shows very graphically the aberrations that arise when this displacement becomes too large. Other buttons here take the student back to the Table of Contents, to a hyperlinked Concept Map, to the last page visited, and to the previous and next pages in this framework for the uniform magnet section.

4 EXAMPLE: BETATRON OSCILLATION

Section 2, on non-uniform magnets, discusses the vertical focusing effect that occurs when the magnet's field index $n > 1/2$. This leads to a betatron oscillation (similar

to that which the student may already have seen in Section 1, but in the radial plane). This page is reproduced in Fig. 3.

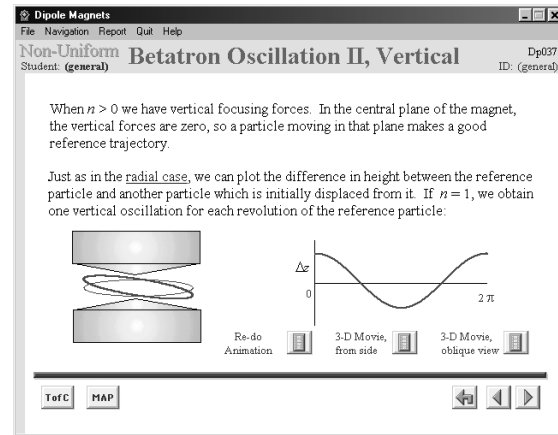


Figure 3: Vertical betatron oscillation page.

This page also opens with progressive disclosure, and when the figures appear, the program traces out the red particle orbit at the same time that it plots the deviation from the principal axis on the right. There is a hyperlink (the blue, underlined "radial case") back to the page in Section 1 discussing radial betatron oscillation. The animation can be replayed, as desired. The other two "movie" buttons show the animation much more realistically in three dimensions, both from the side and from a more oblique point of view.

5 AN INTERMEDIATE-LEVEL PAGE

The previous three figures have blue background borders, indicating they are at an introductory level. In Section 3 there are a few pages at an intermediate level, such as that shown in Fig. 4:

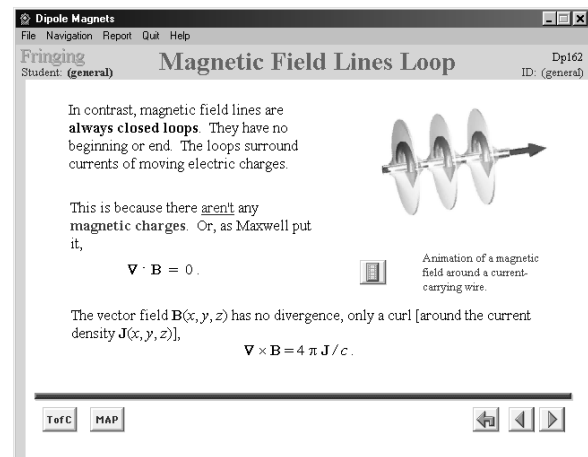


Figure 4: Intermediate-level page from Section 3.

The beige borders indicate this change of level. We called this page “Intermediate” because of the differential form of Maxwell’s equations.

Figure 4 also shows the end-frame of the 3D animation showing the build-up of magnetic field about a current carrying wire as the current turns on.

6 POP-UP WINDOWS

The blue underlined word “aren’t” that you see in Fig 4 looks like a hyperlink to a new page, but in this case it really brings up a temporary pop-up window (mentioning the lack of magnetic monopoles in the universe as we now know it). Figure 5 shows a similar pop-up window that occurs in Section 5, on the double focusing spectrometer.

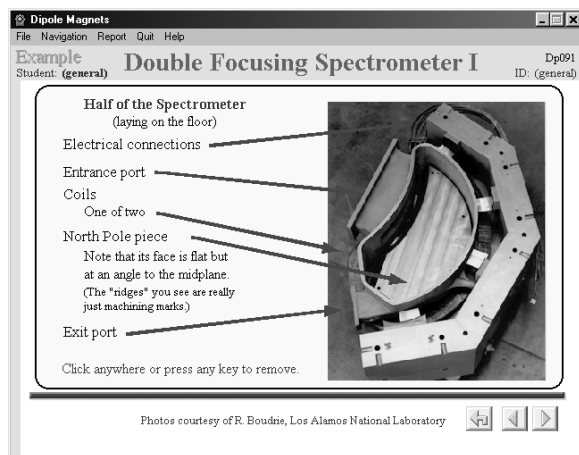


Figure 5: Pop-up window from Section 5.

The photograph shown here (with its callouts) is of the LAMPF Clamshell Spectrometer, which was used for low-energy pion-nucleus scattering experiments in the last decade of LAMPF’s existence as a meson factory.

7 SUMMARY, FUTURE DIRECTIONS

This brief overview of the *Dipole Magnets* tutorial should convince you that it can provide good self-paced training on this subject. It should be particularly useful both to new students, undergraduate and graduate, and to accelerator technicians and operators.

Dipoles will be available from Physics Academic Software later this year.

WhistleSoft expects to complete this project with two other tutorials. The one closest to completion is entitled *Quadrupoles*, and it will consist of six sections:

- **Overview**, indicating why quads are used in charged-particle beam transport.
- **Quadrupole Singlets**, with a discussion of thick-lens quads as well as thin-lens quads.
- **Matrix Transport**, quads and drifts.
- **Systems of Quads**, doublets and triplets.
- **Special Topics**: fringe field effects, higher-order multipoles, and harmonic analyzers.
- **Arrays and Stability of Beams**, using a FODO cell and array as an example.

The first two sections are at an introductory level, the next three are intermediate, and that last is advanced. *Quads* should be submitted to our publisher for review sometime early this summer.

The other tutorial in development, but still in rough form, is *Properties of Charged-Particle Beams*. This piece will cover topics such as the definition of beam size, phase space, beam envelopes, and space charge effects. We hope to have *Beams* ready for review by this fall.

8 ACKNOWLEDGEMENTS

Other persons who have been involved in this project in various ways are Charles Brownrigg, Richard K. Cooper, Matthew Goldman, Kristen T. Kern, Cathy Malloy, and J. Patrick McGee. We have had the benefit of many useful suggestions from a large number of user testers and reviewers of our prototype tutorials. We also thank Prof. John S. Risley, editor of Physics Academic Software, for his advice and criticism.