A haptic approach to spherical vibration modes

Malte UBBEN

Institut für Didaktik der Physik, Wilhelm-Klemm-Str. 10, 48149, Münster, Germany

Abstract. Vibration modes in spherical geometry can be classified based on the number and position of nodal planes. However, the geometry of these planes is non-trivial and cannot be easily be displayed in two dimensions. I present 3D-printed models in combination with computer animations of those vibration modes enabling for a haptic approach which opens the path towards essential features of quantum physics and beyond. In particular, when applied to atomic physics, the s- p-, d-,… electron wave functions are obtained in a natural manner. By also allowing nodal points on the sphere's surface, spin-wave-functions can also be visualized.

1 Introduction

The concept of models itself as part of nature of science is an important aspect of teaching [1]. With the advent of 3d-printung technology, new possibilities for modeling in physics emerge [2].

Along these lines, my main focus will be on a 3d-printed model of vibration modes in spherical geometry beyond any concrete applications in physics in the first part, and concrete applications in physics in the second part.

2 Modeling of spherical vibration modes

2.1 Spherical modes with nodal planes

In modeling spherical vibration modes, the well-known spherical harmonics Y_{lm} were used as a starting point. Each spherical harmonic is classified by its number of nodal lines l on the surface and their orientation with respect to some axis (e.g. the z-axis) is defined by m. This leads to a total of $(2l+1)$ different modes emerging for a given l. Using this knowledge, each harmonic was modeled by mapping it onto a sphere of arbitrary but useful size (see fig. 1). Note, that its maximum and minimum were both visualized in regards to a unit-sphere.

Consider now that the spherical harmonics are scaling-invariant in regards to a radius r. By applying this to the models, the nodal lines of all spheres with a radius less or equal than that of the modeled sphere can be visualized by red nodal planes (see also fig.1, bottom).

As radial nodal planes are also possible when looking at spherical harmonics coupled with radial functions (e.g. electron wave functions in the atomic shell), these were added to the 3d-models as well (see fig 1. top).

2.2 Spherical modes with nodal planes and lines

By also considering not only nodal planes but also nodal planes together with a nodal line, different 3d-models can be created. An example for a spherical wave function with only a nodal line instead of a nodal plane can bee seen in fig. 2, this example providing a visualization of the spin in a 360°-world.

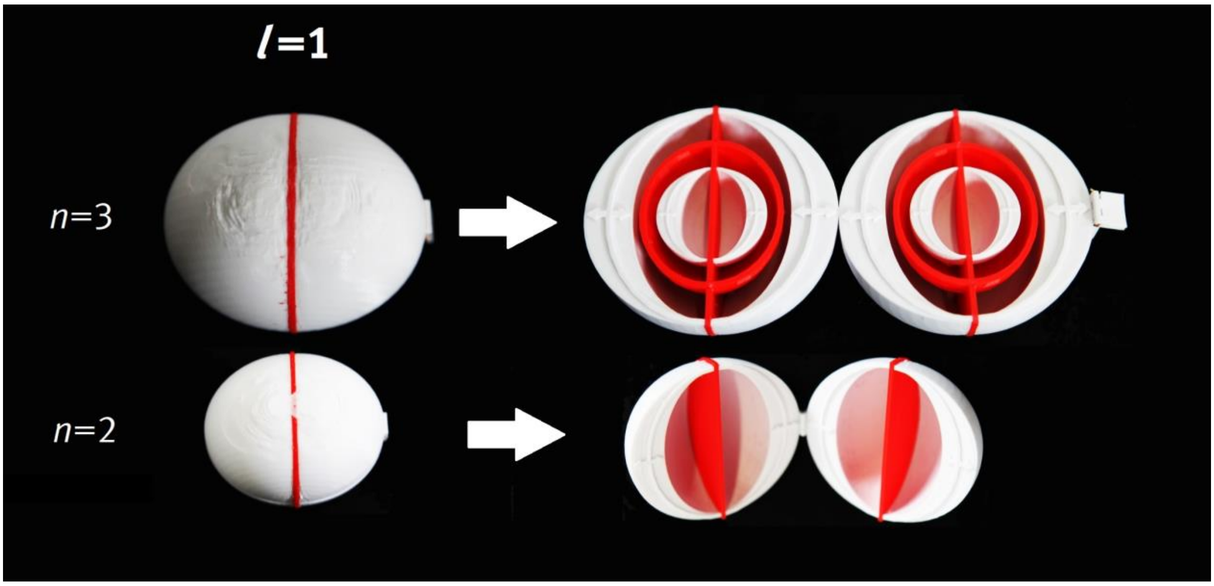

Fig. 1 The 3d-printed versions of spherical harmonics applied to wave functions of bound electrons: 2p-wave function (bottom) and 3p-wave function (top) with respective nodal planes in red.

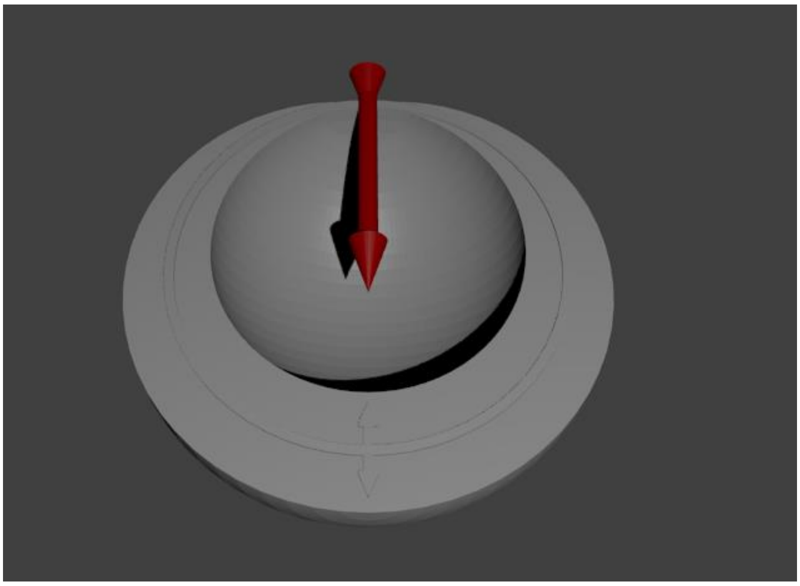

Fig. 2 Spherical wave function with only a nodal line (red) instead of a nodal plane. This function can be used to e.g. describe the spin function of a particle, in this example the direction of the spin is indicated by the arrow.

3 Applications of spherical vibration modes

The spherical vibration modes can be applied in a range of areas in physics education. They give a haptic approach to all areas where spherical vibration modes are used for modeling, such as electron wave functions in the atomic shell, the nuclear shell structure and spins.

References

[1] Clement, J., Model based learning as a key research area for science education, International Journal of Science Education, **22** (2000) 1041-1053

[2] M. Ubben & S. Heusler, A haptic approach to spherical vibration modes (submitted).