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Art as a Tool in Quantum Mechanics

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Throughout history, whenever there has been a new revolution in thought society has been able to understand the new concepts presented and often times assimilate the new information into their understanding of the world – albeit sometimes that assimilation took decades, centuries, or multiple generations and usually was met with considerable initial resistance.[1] For instance, everyone in ancient Greece understood what Empedocles meant when he said the world was composed of four elements (earth, water, fire, and air), and everyone in Europe also understood what Copernicus meant when he said the earth revolved around the sun – despite vehemently disagreeing with the notion for two hundred years.[2] In the past century, however, the largest advances in science have been mostly incomprehensible even to highly-educated members of society, much less the layman. In particular, the concepts of general relativity and quantum mechanics, the cornerstones of modern science, have remained a seemingly obscure mystery to the masses. While these ideas appear to have had, and continue to have, the same revolutionary effect on scientific thought that Empedocles's elements and Copernicus's heliocentrism induced, the ideas still remain obscured, at best, to most people's common knowledge; essentially, society is having the revolution without the necessary assimilation. To combat this, art can be deployed as a tool to bridge the gap in understanding of quantum mechanics in specific, and furthermore, art can serve as a useful complement to a student studying quantum mechanics especially through its interpretation of delocalized electron density – a byproduct of the particle's wavefunction that is an important aspect of quantum mechanics. In fact, the divergence of art and science in education can be traced back to the 17th century for Western society and the 19th century for American education where, perhaps, this arbitrarily-instilled demarcation between disciplines is an unnecessary hindrance toward a broader and more diverse participation in scientific fields.[3]

First and foremost, in order to proceed toward a solution the problem needs to be clearly identified; that is, why do the ideas of quantum mechanics prove so evasive to a general understanding. Niels Bohr, one of the founders of quantum mechanics commented:

"It is one of the basic presuppositions of science that we speak of measurements in a language that has basically the same structure as the one in which we speak of everyday experience. We have learned that this language is an inadequate means of communication and orientation, but it is nevertheless the presupposition of all science… For if we want to say anything at all about nature—and what else does science try to do?—we must somehow pass from mathematical to everyday language." [4]

The ideas that form the foundation of quantum mechanics are certainly not incomprehensible, but the language with which quantum mechanics is written – mathematics – is not a language in which everyone is sufficiently fluent. Hence, it is the translation from mathematical speech to colloquial vernacular that is hindering wide-spread understanding; quantum mechanics provides a new schematic to view the world and the blueprints are written in a largely foreign language. Although, in a similar fashion to traditional languages, there are ways to become more conversant: practice is an obvious means of developing language fluency, but a more subtle method involves the association of new words to pictures in order to connect their meaning. Shlain expounds on an analogous idea:

"Whether for an infant or a society on the verge of change, a new way to think about reality begins with the assimilation of unfamiliar images. This collation leads to abstract ideas that only later give rise to a descriptive language." [4]

Therefore, the addition of art to help understand abstract topics like quantum mechanics seems intuitive. Hopefully, once images are perceived – those images arising from mathematics – our descriptive language of quantum mechanics becomes more literate and universal.

While not specifically focusing on quantum mechanics, other attempts of weaving physics and art together in a related manner have been previously attempted. In 2007, Galili and Zinn[5] investigated the impact of including multiple famous works of art to be thoroughly examined in an undergraduate physics course. The intent was to foster an understanding of some of the concepts in optics through critical discussion and examination of art and how the artists implemented optical-based techniques in order to emphasize their work. The results appeared to indicate a more comprehensive connection to the material by students as well as a stronger confidence in optics by understanding its relation to tangible applications such as artwork. Analogously, van der Veen[6] reported that approaching physics through artwork helped reduce students' fears of learning physics. The researcher applied Greene's Model of Aesthetic Education,[7] founded on what are deemed the first five capacities of aesthetic learning (noticing deeply, embodying, questioning, identifying patterns, and making connections), to an introductory physics course. The curriculum was specifically changed to reflect the use of symmetry as a formative link between art and physics and facilitate an interdisciplinary approach. Admittedly, the study employed a small sample size, nevertheless there was an indication that students' attitudes towards physics were improved which was subsequently translated into a stronger motivation to learn.

With some perspective on the inherent difficulties to the widespread understanding of quantum mechanics and the possible benefits afforded by applying art to physics, it is instructive to examine some examples which establish the importance of art in quantum mechanics. To begin with, it is useful to illustrate a basic example that is so commonplace and familiar to scientists it is regrettably not seen within the context of art, and yet, an artistic rendering clearly affords deeper insight. Figure 1 depicts the collection of orbitals representing the probability density of an electron that possesses an orbital angular momentum of 2, so called d-orbitals. The nature of electrons, as evident from Fig. 1, departs from a classical particle-like picture and assumes a wave-like distribution directly highlighting one of the primary non-intuitive concepts of quantum mechanics.

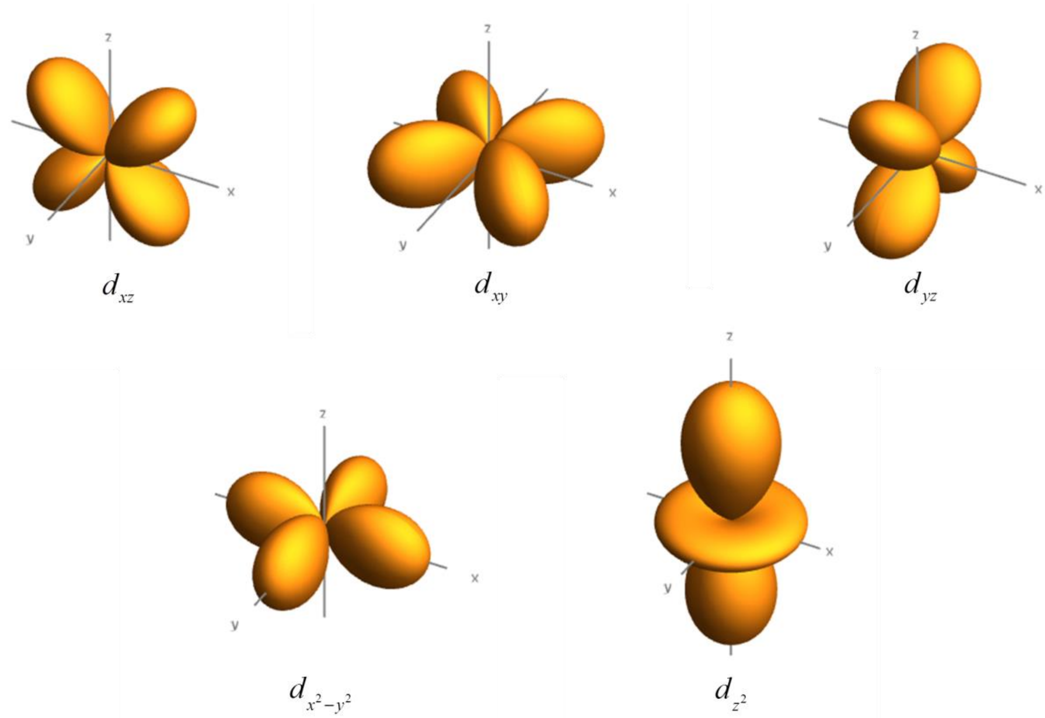

Figure 1: Atomic d-orbitals (l = 2) depicting the electronic probability density are shown as generated using a Mathematica 11.0 software package.[8]

The shapes of these orbitals are determined, in part, by a set of spherical harmonic equations that dictate the angular distribution of the electron density which, for an orbital angular momentum of 2, are:

$$Y_{2,0} = \left(\frac{5}{16\pi}\right)^{\frac{1}{2}} \left(3\cos^2\theta - 1\right)$$

$$Y_{2,\pm 1} = \mp\left(\frac{15}{8\pi}\right)^{\frac{1}{2}} \cos\theta \sin\theta e^{\pm i\phi}$$

$$Y_{2,\pm 2} = \left(\frac{15}{32\pi}\right)^{\frac{1}{2}} \sin^2\theta e^{\pm 2i\phi}$$

These equations form an appropriate set of solutions to characterize how a particle expressed as a wavefunction (a mathematical object governing all observable properties of the electron), behaves while rotating on a sphere – a suitable model for electronic motion around an atom. It seems apparent that, at least in this case, the use of art can be incredibly useful for envisioning and interpreting quantum-mechanical predictions, without such representative diagrams spherical harmonics and consequently electronic orbitals would be abstract entities few would grasp.

Furthermore, the value and applicability of art as presented for electronic d-orbitals easily can be extended to significantly more complex species.

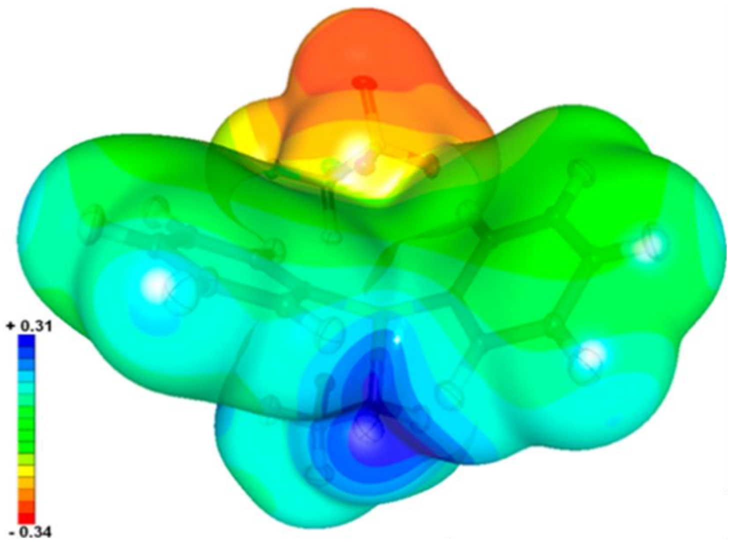

Figure 2: The charge density for a bromoethyl sulfonium salt is shown with an isosurface of static total electron density $\rho = 0.01$ e/Å as reproduced from Ahmed et. al.[9]

Figure 2 depicts a charge density representation of a bromoethyl sulfonium salt where red (blue) shows a region of higher (lower) electron density.[9] While Fig. 1 presented the possible orbitals of an individual electron localized on a single atom, this image demonstrates the electronic density resulting from the electron contributions that arise from a molecule (where many atoms are connected). As a result, the mathematical expressions characterizing the electron density are ostensibly more complicated compared to the relatively simple d-orbitals. Again, the application of art succeeds in better expressing a mathematical outcome which, in turn, makes a quantum-mechanical result more intuitive. Clearly, it is significantly easier to conceptualize the electron density of a molecule through an image rather than an equation where the interplay of such varied and equivalent representations should be appropriately stressed in high-level physics courses.

General scientific literature is permeated with depictions that impart similar conceptual insights as Figs. 1 and 2, but are rarely considered with an artistic perspective. This preliminary unconscious endeavor toward infusing art in science should be further expanded upon to better convey information with the tools afforded by the rich field of art. A successful manifestation of this idea has recently been realized through 3D printing of potential energy surfaces (PESs) and its benefits in classroom environments.[10]

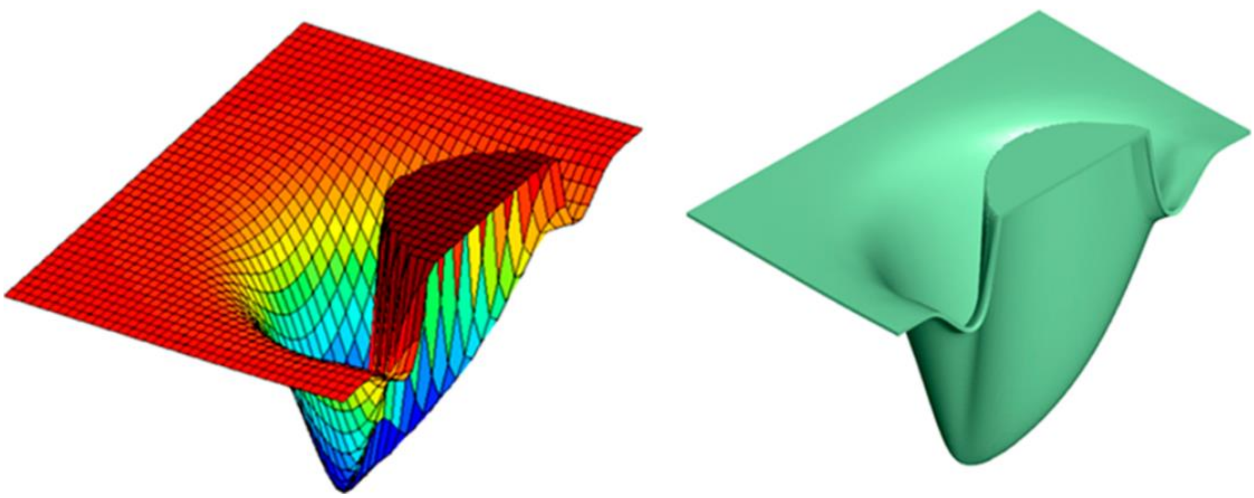

Figure 3: The PES for the ground singlet state of CO_2 is transformed from a mathematical construct to a hand-held model through the use of 3D printing as demonstrated by Lolur and Dawes.[10]

PESs are usually complex hypersurfaces where the encoded electronic-energy topography completely governs molecular structure and reactivity. Additive manufacturing of PESs, as relayed in Fig. 3, provides valuable hands-on learning where students are capable of immediately visualizing and manipulating these surfaces to gain insight into physio-chemical landscapes. The development of such novel applications of art in scientific learning forms the core of how the assimilation of quantum mechanics into easily accessible knowledge can begin to be achieved.

The pursuit to create a broader awareness and understanding of modern physics should begin in the classroom where the need for new generational teaching methods is apparent. The current physics program, which was established in the 1950s, presents a distorted outlook by its over-emphasis on outdate topics and its under-emphasis on burgeoning physics issues that students reportedly relate to. As a result, clinging to this archaic curriculum has had the unfortunate consequence of discouraging diverse participation where an amenable introduction to physics for first-time science students is vitally important for retention in the discipline.[6,11] Furthermore, it has been reported that these survey courses deter further physics study, especially among women, because the current course structure does not allow for valuable self-identification with the material.[12] Hence, the inclusion of art in scientific fields offers a possible solution to the lack thus far of cultural assimilation of recent revolutions in science. While the full understanding of quantum mechanics is a long-term goal that needs to be initiated now, art has already begun to disseminate some physical knowledge into popular culture through entertainment media such as movies and television. For instance, science fiction features such as Star Trek and 2001: A Space Odyssey as well as more grounded portrayals like The Big Bang Theory, while often presenting misguided and/or completely incorrect information, serve to invoke a conscious awareness of some modern scientific developments. So, even though an overhaul of science education is still necessary, perhaps – as for Empedocles and Copernicus – all that is needed for societal assimilation is time.

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